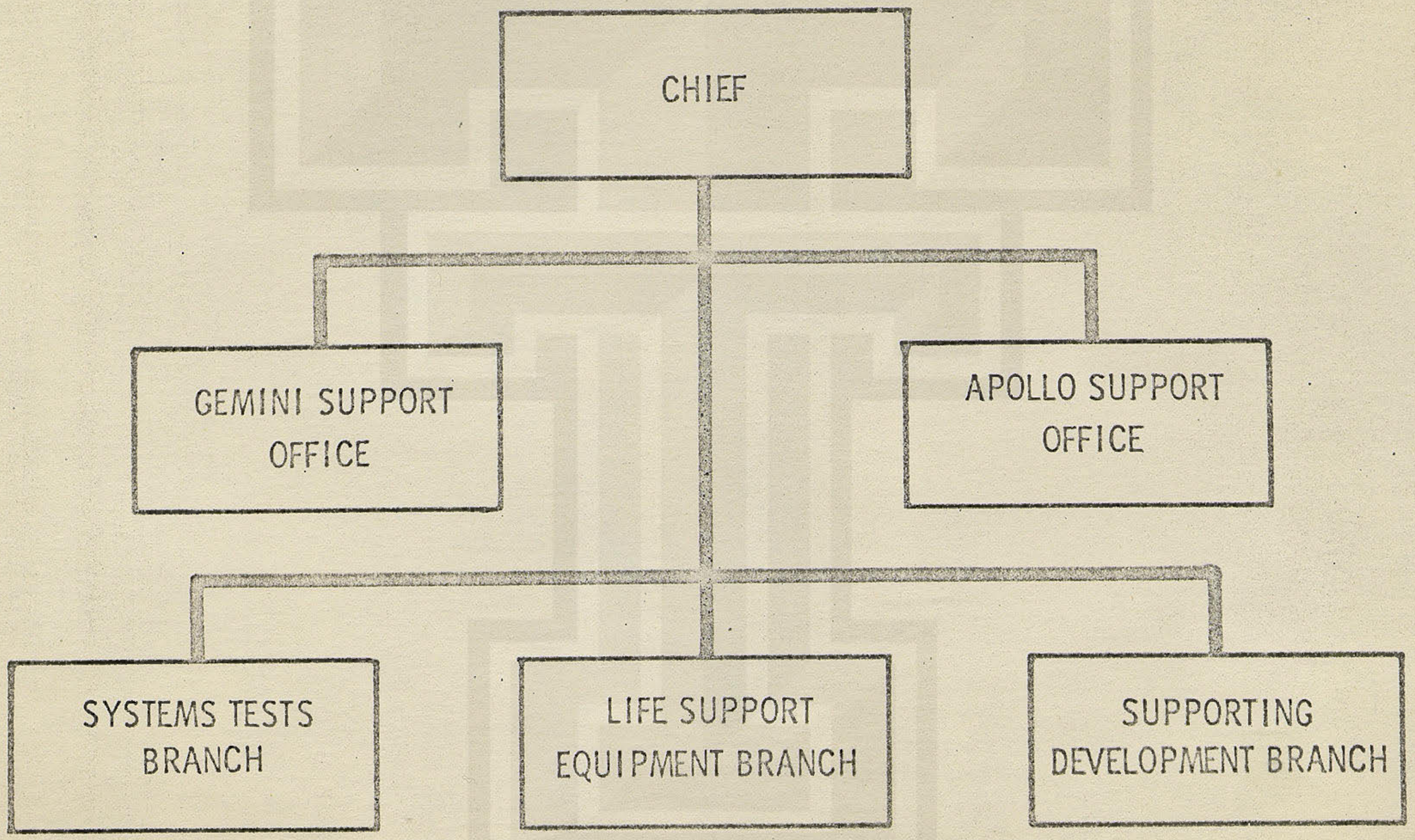
CREW SYSTEMS DIVISION



MM 66-7382

NASA LIFE SCIENCES ORGANIZATION

Jack Bollerud, Col, USAF, MC
Acting Director, Space Medicine
MANNED SPACE FLIGHT
Headquarters, NASA
Washington, D.C.

I Concept of Organization

II Program Coordination

III Headquarters Organization of the Life Sciences

a. Bioscience Programs

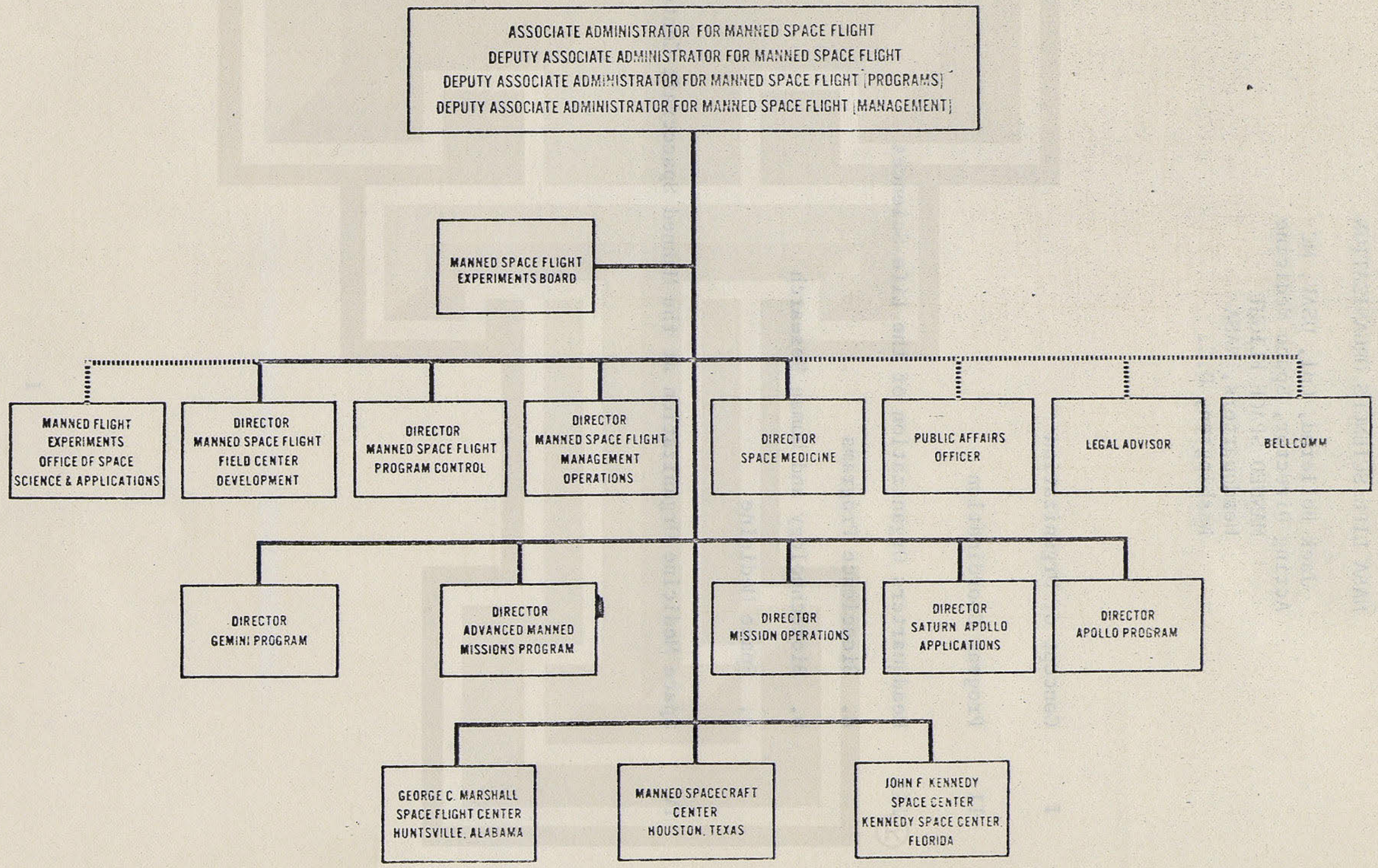
b. Biotechnology and Human Research

c. Space Medicine

IV Space Medicine Organization at the Manned Spacecraft Center

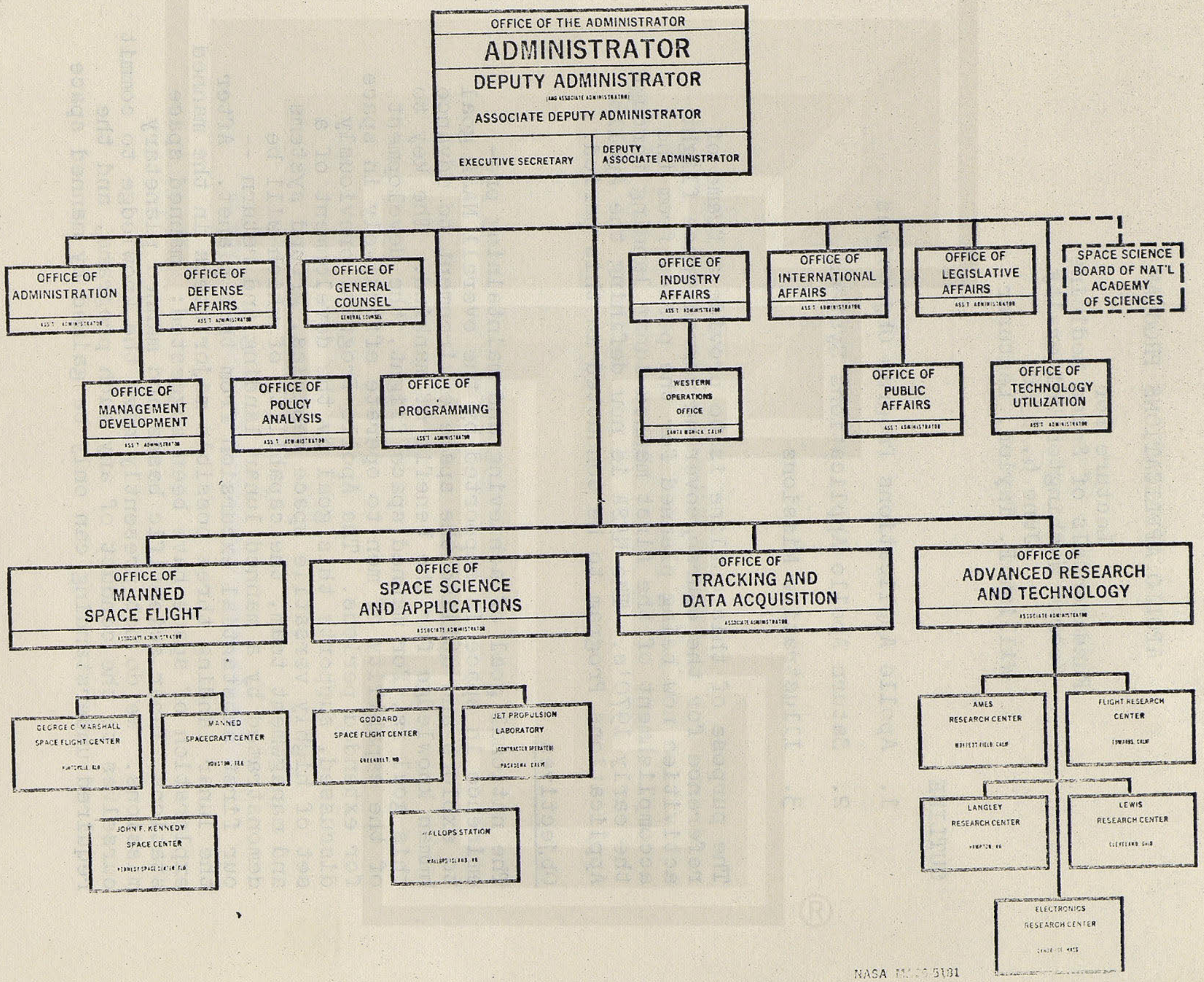
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OFFICE OF MANNED SPACE FLIGHT



NASA MSR65-10.836

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



NASA MC 66-5101

APOLLO APPLICATIONS PROGRAM

Lecture for
Fundamentals of Space Medicine
George Washington University
June 6, 1966
William B. Taylor, Lecturer

OUTLINE

1. Apollo Applications Program Objectives
2. Saturn Apollo Applications Systems
3. Illustrative Missions

The purpose of this outline is to provide a frame of reference for the course, covering manned space flight activities now being planned for the period from the accomplishment of the first manned lunar landing through the early 1970's. The NASA is now defining the Apollo Applications Program to be conducted in this period.

Objectives

The national goal of achieving and maintaining pre-eminence in space is supported by the overall NASA goal to explore and utilize the space environment to advance human knowledge for the benefit of mankind. The key to this goal is, for manned space flight, the development of the capability of men to operate effectively in space for extended periods. The Apollo Program, previously discussed, supports this goal by the development of a set of highly versatile space vehicles, ground systems and management team, the capability of which will be demonstrated by a manned lunar landing and return -- our first substantial excursion from this planet. After the lunar landing three possible major steps in the manned exploration of space have been suggested: manned space stations, lunar scientific bases and manned planetary missions. We do not presently have the knowledge to commit ourselves to the conduct of any such programs, and the required understanding can only be gained by manned space experience. The Apollo Applications Program is being planned to provide the bridge of knowledge which will enable the nation to make decisions on the next major U.S. space goals. The Apollo Applications will, as the name implies, use developed and tested Apollo spacecraft and Saturn launch vehicles, thus providing continuity to our efforts without requiring the commitment of major new resources for development. Specific Apollo Applications Program objectives are:

(1) extended manned lunar exploration, up to two weeks on the lunar surface, and four weeks in lunar orbit

(2) manned operations in any earth orbit of up to one year duration

(3) conduct of scientific, technological and applications experiments in the near-earth and lunar environments

Long duration missions are of especial importance since they minimize the cost per man space flight hour, and astronaut time is the limiting resource in most missions.

Systems

Saturn Apollo Systems available to the Apollo Applications Program include two launch vehicles, the Saturn IB and the Saturn V, and the Apollo spacecraft consisting of the Command/ Service Module and the Lunar Excursion Module. Apollo missions using these flight elements are supported by the world wide NASA Tracking Network, mission control facilities and launch complexes. This is supported by a nation wide complex of government-industry facilities and skilled manpower. By 1970 the capability will exist to produce and launch more than six Apollo-Saturn space vehicles per year.

Studies have confirmed the feasibility of using this inventory for a variety of proposed Apollo Applications missions without interfering with the Apollo lunar landing goal.

Missions under consideration include:

(1) Low altitude earth orbit missions using both the basic Apollo spacecraft and the spent upper stage of the Saturn IB as laboratories for long duration flight.

(2) Synchronous earth orbit missions for astronomy and communications experiments.

(3) Lunar orbit missions for survey of the entire surface of the moon.

(4) Extended-duration lunar surface missions using two Saturn V rockets and two spacecraft to permit two week excursions on the moon.

Payload performance capabilities are presented, and system modifications currently under study are discussed.

Illustrative Missions

Four missions are outlined as examples of Apollo Applications activity in the early 1970's:

(1) A low altitude long duration earth orbit mission using a Saturn spent stage and Apollo spacecraft. Extended duration is achieved by resupply of the space vehicle by additional Saturn IB-launched Apollo spacecraft.

(2) A 3-man synchronous earth orbit astronomy mission for 45 days at 19,350 n.mi. altitude using a modified Apollo spacecraft launched by a Saturn V.

(3) A 3-man,28-day lunar polar orbit survey using cameras, radar and surface probes.

(4) A 2-man, 2-week lunar surface mission using two Saturn V launches, the first to deliver a modified Apollo LEM to the surface to serve as a shelter, the second to transport the men to and from the surface. Exploration is conducted using a surface vehicle delivered with the shelter.

SOME EFFECTS OF EXPOSURE TO WEIGHTLESSNESS AND A ROTATING ENVIRONMENT WHICH HAVE THEIR GENESIS IN THE VESTIBULAR ORGANS

Ashton Graybiel

Traditionally, the semicircular canals and otolith organs have usually been considered together and referred to as the vestibular organs. This designation, although appropriate at times, underemphasizes their individuality, an individuality exaggerated under conditions of weightlessness and a rotating spacecraft. Under ordinary conditions, the "canals" are stimulated by the accelerations generated with rotary motions of the head. The six canals, bilaterally paired and oriented approximately in orthogonal planes, are uniquely structured to respond to angular or gyroscopic accelerations. At the ampulla the fluid-filled canal is blocked by a sensory structure, the upper portion of which is free to swing in response to movements of the fluid. The sensory elements, acting as transducers, convert mechanical to electrical energy, and the impulses are conducted to the central nervous system. The canals subserve such useful functions as sensing rotation and aiding in visual tracking and the maintenance of postural equilibrium. When man is exposed to unusual patterns of angular or gyroscopic accelerations, severe disorders may result involving not only disturbances in normal function but also, seemingly, absurd effects some of which are best known under the term motion sickness.

The four otolith organs, bilaterally paired, consist essentially of curved macular plates with calcium carbonate concretions embedded among the hairlike projections of the sensory cells. When the position of the head is changed with respect of gravity, the greater specific weight of the otoliths causes the hairs to bend and mechanical energy is converted to electrical energy and the resulting impulse is conducted to the central nervous system. This input senses position and change in position of the head with respect to gravity and thus subserves such useful functions as the perception of linear motions, orientation to the upright, and postural equilibrium. Two additional points must be emphasized. First, the otoliths function accurately within a limited range or arc with reference to the upright and second, many so-called gravireceptors in addition to those in the otolith organs aid in orientation to gravity.

When a person is subjected to linear accelerations he now senses the vector sum of gravitational and inertial forces as the gravitoinertial upright which may or may not correspond to the visual upright. Moreover, exposure to certain unusual patterns of linear accelerations may cause motion sickness in some persons even in the absence of stimulation to the canals.

WEIGHTLESSNESS

In weightlessness there is deafferentation (suppression) of the otolith organs. Not only the otolith apparatus but all receptors directly or indirectly stimulated by gravity are affected. The otolith and nonotolith gravireceptors, however, are affected quite differently by man's activities in a weightless spacecraft. Stimulation of the otoliths could occur only in consequence of bodily movements involving the head. On the other hand, touch, superficial and deep pressure, kinesthetic and other somesthetic gravireceptors could be stimulated by deformations or movements of parts of the body even while the head was held motionless. Moreover, some of the somesthetic inputs would provide cues which would accord with the visual upright, whereas even if the otoliths were stimulated by head movements the force vector rarely would point in the direction of the visual upright. The semicircular canals are not directly affected in weightlessness inasmuch as they are stimulated by the <u>inertial</u> forces associated with rotatory motions of the head.

Theoretically, it was predicted that in orbital flight astronauts might experience disorientation and a type of motion sickness. The former would be explicable on the basis of absence of cues or false cues. Motion sickness was predicted on the basis that it is caused by unusual patterns of afferent impulses from the otoliths and that suppression of impulses constituted an abnormal pattern. Experiences in parabolic flight suggest that if weightlessness is a factor in precipitating motion sickness it is not a strong one and in orbital flight only Titov complained of such symptoms. If weightlessness was the cause of Titov's symptoms,it suggests that he was more susceptible than the other astronauts and that a problem exists. If weightlessness was not the significant etiologic factor, other possibilities would include injury to the labyrinth on liftoff, labyrinthitis from other cause, or rotations of the spacecraft.

ROTATING ENVIRONMENT

In a rotating environment movement of the head in any direction or about any axis not parallel to the axis of rotation will generate, respectively, Coriolis and gyroscopic accelerations. The latter produces a gyroscopic torque which, through cross-coupling, is an unusual but effective stimulus to the semicircular canals. The bizarre nature of this stimulus may cause visual illusions and postural difficulties, and, if the stimulus is sufficiently strong or the person sufficiently susceptible, severe functional disturbances. The term canal sickness has been proposed as a convenient means of distinguishing this type of motion sickness. The otolith organs, and nonotolith gravireceptors as well, are stimulated by the vector sum of gravitational, centripetal, and Coriolis forces. Near the axis of rotation the last two forces are small, but at increasing radii for the same angular velocity, they become increasingly great. The changing values with bodily movements and at different positions with reference to the force environment in the spacecraft will have a small but significant influence independently of the effects on the semicircular canals.

There are important differences between the force environment in a rotating spacecraft in orbital flight and a rotating room on earth, but the simulation is sufficiently good to extrapolate, with caution, the results to conditions in a rotating spacecraft. A number of investigations have been conducted in a room rotating at velocities from 1.0 to 20.0 RPM. Other things being equal, the higher the angular velocity the greater the stress. There is great individual variance in susceptibility to the characteristic symptomatology. The time-course usually follows a typical pattern of summation and adaptation. After adaptation has occurred, cessation of rotation causes a return of symptoms. A rotating environment poses problems and offers opportunities to investigate psychophysiological mechanisms which will be discussed in more detail.

Dr. Herbert Pollack
IDA

Synopses

Problems to be encountered that effect metabolic requirements.

a) Atmospheric environment
b) Temperature
c) Immobility
d) Weightlessness
e) Radiation
f) Nutrition

One must prove that man can survive the environmental conditions found in outer space without impairment of function or what is equally important to resist the effects of sudden re-imposition of de-orbiting and entry acceleration and earth's gravitational forces.

Short-term flights up to 5 days now well documented. Indications have been found of certain changes.

Crew selection is of major importance followed by training and acclimatization.

Medical problems are not a major factor in short term flights. Development of concepts of space stations of 30 days and longer open a whole new category of problems.

A. The pathophysiology of the effects of zero-G on the Human.
B. The pathophysiology of reduced atmospheric pressure and low O_2 tension.
C. The day to day clinical medical problems and the impact of zero-G on their frequency, deviation, intensity and response to therapy.

D. Response to thermal stress.

Dehydration is a major problem. All astronauts to-date have lost weight even in short flights. This is a dehydration problem.

Secondary effects -

Hypovolcanic shock?

Concentrated urine and gravel

Action of pharmacologic agents under these conditions are unknown.

Life Support Systems must be selected based upon several conflicting criteria.

1. Single gas system
2. 2-Gas system - choice of 2nd gas
3. Multiple gas system
4. CO_2 control
5. Humidity control
6. Cabin Pressure - vs suit pressure -- problem of bends.
7. Toxic gas accumulation from metabolic end products - Flatus. Choice of food and impact on flatus.

Energy, Fluid-Electrolyte and Mineral Metabolism; Anticipated or Predictable Changes in Space Flight

(Abstract for Lecture in Course on Space Medicine)

G. D. Whedon

I. Energy Metabolism

Calorie requirements: Until specific studies of energy expenditure during space flight are carried out, it must be assumed that in a craft with limited space, reduction in physical acivity will result in a 10-30% decrease in calorie needs for effective function and weight maintenance. In crafts allowing considerable movement under shirt-sleeve conditions, energy expenditure will be similar to or possibly slightly increased in comparison to ground depending upon physical efficiency in weightless movement. Space suit activity will increase calorie requirements by as much as 50%.

Composition and type of diet: Relatively normal ratios of protein, fat and carbohydrate will provide CO_2 and O_2 exchange volumes which will not tax a CO_2 scrubbing system. Although freeze-dehydrated, then reconstituted natural foods of low fiber, low laxative nature have been recommended for best acceptability, liquid diets have proven acceptable in lengthy ground studies and may be considered for use, particularly in metabolic studies, because of consistency of composition in addition to ease of storage and quantitative measurement. A variety of considerations have led to specific recommendations on mineral, electrolyte and vitamin compositions of the diet.

Waste: Handling and storage of urine and stool wastes present particular problems in the confined environment of a space vehicle. These problems are accentuated when accurate, continuing collections must be made for metabolic studies.

Suggested Studies: Despite the considerable amount of pertinent data available from ground studies of the effects of immobilization and confinement, weightlessness and other stresses are expected to exert either different influences or similar influences in greater degree so that extensive studies are planned of the effects of space flight on energy expenditure, nitrogen and carbohydrate metabolism, hepatic function and body composition.

II. Fluid and Electrolytes

Water Balance: From fundamental considerations of fluid requirements, the water intake should be 2.5 liters daily, sufficient to cover ordinary fluid losses via the kidneys, skin and lungs and to maintain urine specific gravity at 1.015 to minimize the possibility of gravel formation in the urine. Preliminary observations, however, suggest that special attention will need to be given to water balance in space flight because of 1) possible excessive losses of water by sweating which may or may not be related solely to high environmental temperatures in the cabin of the space craft, and 2) increased urine volumes due to an effect of weightlessness related a) to orthostatic influences on renal function or b) to suppression of antidiuretic hormone.

Electrolyte metabolism: A daily requirement for sodium and other electrolytes can be readily stated for ordinary circumstances, but the requirement in space flight may be increased by excessive losses in sweat and urine related either to thermal stress, to effects of orthostasis on renal function or to effects of altered adrenal function.

Acid-base balance: The possible development of hypercapnia due to decreased ventilatory chest movement associated with confinement may lead to respiratory alkalosis (acidemia).

Renal function: The known changes in renal function related to orthostasis may occur in the weightless state, either temporarily following which adjustments are made, or some relatively permanent alteration may take place.

Urinary tract stone formation: While certain factors related to urinary tract stone formation in long immobilization are well known (urinary calcium and phosphorous levels, urinary citric acid and pH, urinary volume) and have tended to be accorded possibly undue emphasis, additional important factors in the urine are now recognized, such as pyrophosphate, trace metals and mucoproteins.

Suggested Studies: Space flight studies are being planned to determine the effects of weightlessness and other stresses on water and acid-base balance, electrolyte metabolism, renal function and on factors related to urinary tract stone and gravel formation.

III. Mineral Metabolism

Maximal attention has been focused on the possible striking and serious effects of weightlessness in space flight on the skeletal system. Predictions of rapid demineralization are based on past studies of the effects of immobilization (in bed rest) in normal subjects in which calcium excretion gradually increased over a five weeks period, urinary calcium more than doubled and calcium balance became negative on a moderate level of calcium intake. Studies are planned for measurement in flight of rates of mineral loss both by metabolic balance and by radioisotopic techniques. Under development are a number of methods for measuring bone density more accurately than in the past to determine the degree of demineralization expected to result in peripheral bones and in the spine.

BIOCHEMISTRY IN SPACE ENVIRONMENT - Colonel Edward C. Knoblock

I. Problem Areas for Consideration in Weightlessness

1. Cardiovascular System
2. Liver & Kidney Function
3. Muscle Activity
4. Endocrine Function
5. Electrolyte Balance
6. Calcium Balance
7. Radiation Injury
8. Acid Base Balance

II. Metabolic Variables Relating to Problem Areas

1. Electrolyte variations
2. Protein changes
3. Enzyme activity
4. Red and white blood cell integrity
5. Steroid variations
6. Calcium mobilization and increased excretion
7. Carbohydrate utilization
8. Lipid utilization
9. Trace metal requirements
10. Vitamin requirements

III. Monitoring of Metabolic Variables

1. Liver and kidney function tests
2. Electrophoretic determinations for protein variations
3. Determination of electrolytes for electrolyte balance
4. Determination of carbohydrate and lipids
5. Determination of hormone activities
6. Measurement of enzyme and isoenzyme activities
7. Trace metal measurements
8. Hematological parameters
9. Determination of vitamin levels

IV. Instrumentation involved - present in terrestrial laboratory

1. Conventional instruments and apparatus
   a. Spectrophotometric equipment
   b. Electroanalytical equipment
   c. Volume measurement equipment
   d. Paper strip procedures
2. Reagent Preparations and Standards

V. Instrumentation for Weightless Laboratory

1. Requirements for weightless laboratory
2. Problems of conventional equipment
3. Development requirements

J. F. Kubis

HABITABILITY
(With special reference to extended space missions.)

I. Meaning

A. A dyadic interaction (tenant vs. habitat)
B. Habitability as a relative term
C. Constraints (particularly applicable to space missions)
   1. Environmental restrictions
   2. Human tolerances
   3. Technological capability

(Note: Habitability is not a fixed concept. Motivation and cultural expectations influence one's attitudes towards what is livable and what is not. It is commonplace for communities to legislate what is habitable, condemning what but a few decades ago were generally acceptable living standards.)

II. Fundamental Questions: Habitable for ...?

A. What purpose?
B. Whom?
C. How long?

(Note: Motivation is critical to the concept of habitability. The overall purpose of a space mission may supply the necessary motivation for an astronaut to accept the many serious inconveniences that may be encountered on a prolonged space flight. Very few men would find a space capsule habitable. Consequently, at present such men have to be carefully selected and trained. Finally, the space capsule of today would not be habitable on an extended space flight.)

III. Components of Habitability

A. Physical
B. Physiological
C. Psychological
D. Social

(Note: These components cannot be considered apart from capabilities, limitations, needs, and hazards. Early treatments of habitability have emphasized the physical aspects of the environment and the physiological resources available to man to withstand various stresses and hazards, with particular emphasis on the tolerances under which his physiological functions can operate. The psychological or behavioral aspects, though not neglected, were given sparse attention. This is an inevitable developmental trend, for first things should come first and mere survival is surely a prerequisite for refined behavior. Social needs and interactions will soon have to be considered as extended space missions or orbiting space laboratories are developed with their necessary requirements of multi-man crews.

These components are not independent. For example, extreme confinement undoubtedly affects physiological reactions negatively, may produce profound psychological changes, and could tend to maximize social irritations. None of these outcomes is conducive to a successful space mission.

Special emphasis will be given to the behavioral--psychological and social--components of habitability.)

IV. Unique Aspect of Habitability of Space Stations

Of all the experiences and stresses involved in space flight, by far the most unique will be that of weightlessness. Much has been conjectured as to the effects this condition will have on the physiological and psychological integrity of the astronaut but no definitive results will be available until the space flights are extended in time. At that time more compelling data may be available to decide on the need for "artificial gravity."

(Note: The interaction of weightlessness with the many other stresses involved in space flight will undoubtedly pose numerous challenges to the adaptive capabilities of the astronaut and to the creative ingenuity of the engineer.)

V. Levels of Habitability

A. Minimally life sustaining--behavioral performance restricted and practically non-functioning.
B. Bearable,--but with relatively restricted behavioral capability.
C. "Workable"--with moderately efficient behavioral performance.
D. Comfortable--and with capability for efficient behavioral performance.
E. Enjoyable.

(Note: Condition A is intolerable while E is improbable in present day conceptions of space exploration.)

VI. Modification and Maintenance of Habitability

A. The Environment
  1. External or outer space environment
     a. Little probability of controlling or modifying outer space.
     b. With continued developments in science we can expect better accuracy in predicting variations in outer-space hazards. Ex. estimating temporal and spatial characteristics of changes in radiation.
  2. Capsule or space-station environment
     a. No theoretical limitation on improvements possible in the space station environment.
     b. The limiting factors: engineering and cost restrictions.
     c. Critical modifications possible by means of rendezvous techniques.
        (i) For maintaining habitability: supplies, repairs.
        (ii) For improving habitability.

B. The Tenant (Astronaut, Scientist)
   1. Selection -- implies finding the proper man to fit into the habitability requirement profile.
   2. Training
      a. Pre-flight
         (i) To withstand severe physiological stresses and inconveniences.
         (ii) To maintain and control the space station environment.
   3. Crew Rotation -- to prevent degradation due to inability to maintain performance under the confining and restricting habitability requirements of a space station.

(Note: It is quite apparent that control and modification of habitability is least possible for the external environment. Although man is adaptable and modifiable, the range of his behavior is restricted so that training produces limited changes in his capability to adjust to unusual and biologically constricted environments. By far the greatest flexibility for modifying the astronaut's immediate environment lies in the ingenuity of engineers to design and construct viable space stations.)

VII. Determining Habitability

A. A priori considerations based on accumulated data from
   1. Accidental events Ex. ship-wreck
   2. Analogous situations Ex. polar expeditions, submarine experiences
B. Basic physiological and medical data
C. Experimentation on various specific aspects of habitability
D. Simulation experiments in other than space vehicles
E. Experiences from previous space flights
F. As for large space stations, in-flight habitability would first be established aloft with a maintenance crew, changes being made until the required level of habitability has been attained. When this condition has been met, the remainder of the crew, maintenance and scientific, would be sent aloft to take over their duties in the space station.

VIII. Basic Principle Underlying Human Habitability

Simply stated, a system is considered habitable if man can function as man within its environmental confines. Consequently the use of man and mission to obtain information that could have been obtained equally well by an animal or by a machine is not only wasteful but degrading.

Dr. Jesse Orlansky

OUTLINE

1. Location of Man in the System

2. Integrating the Environment

3. Value of Man

4. Finding a Place for Man

    a. Systems Analysis

    b. Allocation of Functions

    c. Developing a Design Convenient for Man

5. Specifications and Handbooks

    a. Anthropemetric Data

    b. Visual Data

    c. Rotation

    d. Sound Perception

    e. The Average Man

6. Dynamic Interactions Between Man and Machine

    a. Training

    b. Scheduling of Work and Rest in Space

    c. Evaluation and Simulation

Maitland Baldwin, M.D.

NEUROLOGICAL PROBLEMS IN SPACE FLIGHT ENGINEERING

For the purposes of this seminar, the nervous systems of the space-flight crews may be considered as integral components of the vehicular design which provide specialized capabilities in guidance, communications, recording of experiential data and control of internal environment. From this point of view, these specialized capabilities may also be considered as constraints in the design for flight whenever it is desirable to optimize their vital effectiveness through modification of inanimate systems.

Optimal performance of the nervous system in provision of these specialized capabilities depends on a relatively consistent physical environment with specific provisions for maintenance of a normal metabolic exchange, an adequate sleep-rest cycle, a relatively uninterrupted work cycle, as well as avoidance of sensory deprivation. Similarly, the normal activities of vision and hearing, as well as the sensitivities of balance should be protected and promoted by the physical surroundings. Finally, general measures for safety and comfort must play a role in the adjustment of the nervous systems under these unique conditions just as they do in more ordinary working situations.

Obviously the impact of these general requirements on total design is greatest in the life support systems, but it may be realized in internal configuration as well. Moreover, in-flight evaluation of physiological performance may impose an additional set of design criteria in situations where an objective assessment of biological condition is desirable. Then physiological monitoring equipment will be required within the vehicle.

Since the problems of metabolic exchange, vision, hearing, balance and sensory deprivation receive detailed consideration elsewhere in the seminar, this dissertation is largely concerned with the problem of the sleep-rest cycle and physiological monitoring, although some discussion of sensory deprivation is also included.

James V Warren, M.D.

The Normal Circulation

The heart and blood vessels are organized into a complex functional unit that provides blood to the various parts of the body. Each functional aspect of this system is controlled by feedback type mechanisms and the entire system organized to meet the varying demands for blood in different parts of the body. By and large, the body is able to meet these demands, although at times there may be transient inadequacies. The organizational pattern could be expressed as follows:

1) Control of blood flow to the capillaries depending upon local needs, determined primarily by chemical factors but supplemented by nervous impulses. This part of the system is dependent upon an adequate perfusion pressure (blood pressure).

2) A mechanism for maintaining an adequate arterial blood pressure. The carotid sinus and other reflex arcs are involved in maintenance of a reasonable level of control although there is considerable minute-to-minute variation.

3) The cardiac output or in other words the amount the amount of blood pumped by the heart is adjusted to meet the total needs of the body for that particular moment. Predominantly this is adjusted to meet metabolic requirements. For instance, it is increased under the stress of exercise, but other factors such as heat loss and emotions may play a strong influencing role. The characteristic of the normal circulation is a flexibility in the level of blood circulation dependent upon body needs.

Faulty Integration of the Normal Circulation

Under a variety of circumstances the normal circulation will fail to operate in a properly integrated fashion. Examples of this are as follows:

1) Syncope (fainting) is a failure of integration of the circulation. There are many causes of fainting; some associated with cardiovascular disease, but the common variety of fainting is of the type described here. It occurs in normal individuals under stressful, usually emotionally charged circumstances. The loss of consciousness is related to inadequate arterial pressure to push blood upward to the brain, and hence the faint is more apt to occur in the upright position. There are various other symptoms that may occur at the time related to an extensive discharge of nervous reflexes in a disorganized fashion.

2) The circulation may become somewhat disturbed by emotional influences, the rapid heart beat and power occuring with emotional charged situations is a good example. The cardiac output under these circumstances may be markedly increased and there may also be changes in arterial pressure. The person may become aware of his heart beat (palpitation) and he may feel anxious or some other change in feeling state.

3) Under special stressful circumstances, other abnormalities of the circulation may occur. For instance, under the stress of human centrifuge fainting of a different sort than that described above may occur. It too is characterized by sudden loss of consciousness. Under conditions of increased atmospheric pressure and then release, air embolus (bends) may also occur. In summary, circulatory integration may become faulty in the normal individual under stressful circumstances of various sorts extending from relatively minor emotional impacts to serious and profond stresses such as gravitational force and increased ambient pressure of the atmosphere.

Failure of the Circulation Due to Disease

Causes

Many types of factors may cause cardiovascular disease. The principle ones are arteriosclerosis , rheumatic fever, high blood pressure and a variety of diseases that influence the myocardium. Despite the variation in causes, the impact of these diseases may be classified in a few general categories.

Types of Disturbances

Heart Failure

When heart disease involves the heart and interferes with its function as a pump the situation described as heart failure occurs. This represents a relatively moderate but important and usually prolonged limitation of the function of the heart as a pump. The manifestations experienced by the patient are not directly attributable to the diminished blood flow but result from secondary phenomena that occur and are described under the general heading of congestive heart failure. They are mainly respiratory symptoms with shortness of breath, as a predominant one and those due to increased extracellular fluid content of the body (edema).

Shock

Shock occurs with more serious and acute disturbances of the functions of the heart but may have other causes such as trauma. Shock due to heart disease is predominantly due to acute inadequacy of the heart as a pump and occurs in such situations as myocardial infarction.

Vascular disease with diminished blood flow may occur in various diseases affecting specific parts of the body. Most prominent is coronary artery disease with diminished blood flow to the heart muscle itself. This results in either transient attacks of pain (angina pectoris) or in death of the heart muscle in the area involved (coronary occlusion, myocardial infarction, heart attack). If the cerebral vessels are involved it may lead to cerebral dysfunction or to gross neurologic defect with paralysis of one half of the body, (stroke). Involvement of the blood vessels serving the extremeties may also lead to pain on motion and in the more severe situations to necrosis and death of the peripheral tissues, requiring amputation.

Other forms of vascular disease such as bacterial infections exist, but the categories indicated above are the most prominent ones.

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Outline
Cardiovascular Physiology
Engineering aspects of Space Medicine
The George Washington University

Loren D. Carlson

1.0 General characteristics of the cardiovascular system, Figures 1-1, 1-2, 1-3
- 1.1 Closed two circuit system
  - 1.11 Systemic
  - 1.12 Pulmonary
- 1.2 Subdivisions in the circuit
  - 1.21 Pump
  - 1.22 Arteries - Arterioles
  - 1.23 Capillaries
  - 1.24 Venules and Veins
- 1.3 Parameters
  - 1.31 Pressure
  - 1.32 Resistance
  - 1.33 Flow
  - 1.34 Compliance
  - 1.35 Capacity

2.0 The control system - cybernetic analysis
- 2.1 Sensors - general characteristics
  - 2.11 Pressure
  - 2.12 Volume
- 2.2 Effectors -
  - 2.21 At the pump
  - 2.22 At the periphery
  - 2.23 Central control "center" concept

3.0 Specific examples of function
- 3.1 Posture - supine to erect Fig. 3-1, 3-2
- 3.2 Exercise Fig. 3-3
- 3.3 Acceleration Fig. 3-4
- 3.4 Weightlessness Fig. 3-5, 3-6

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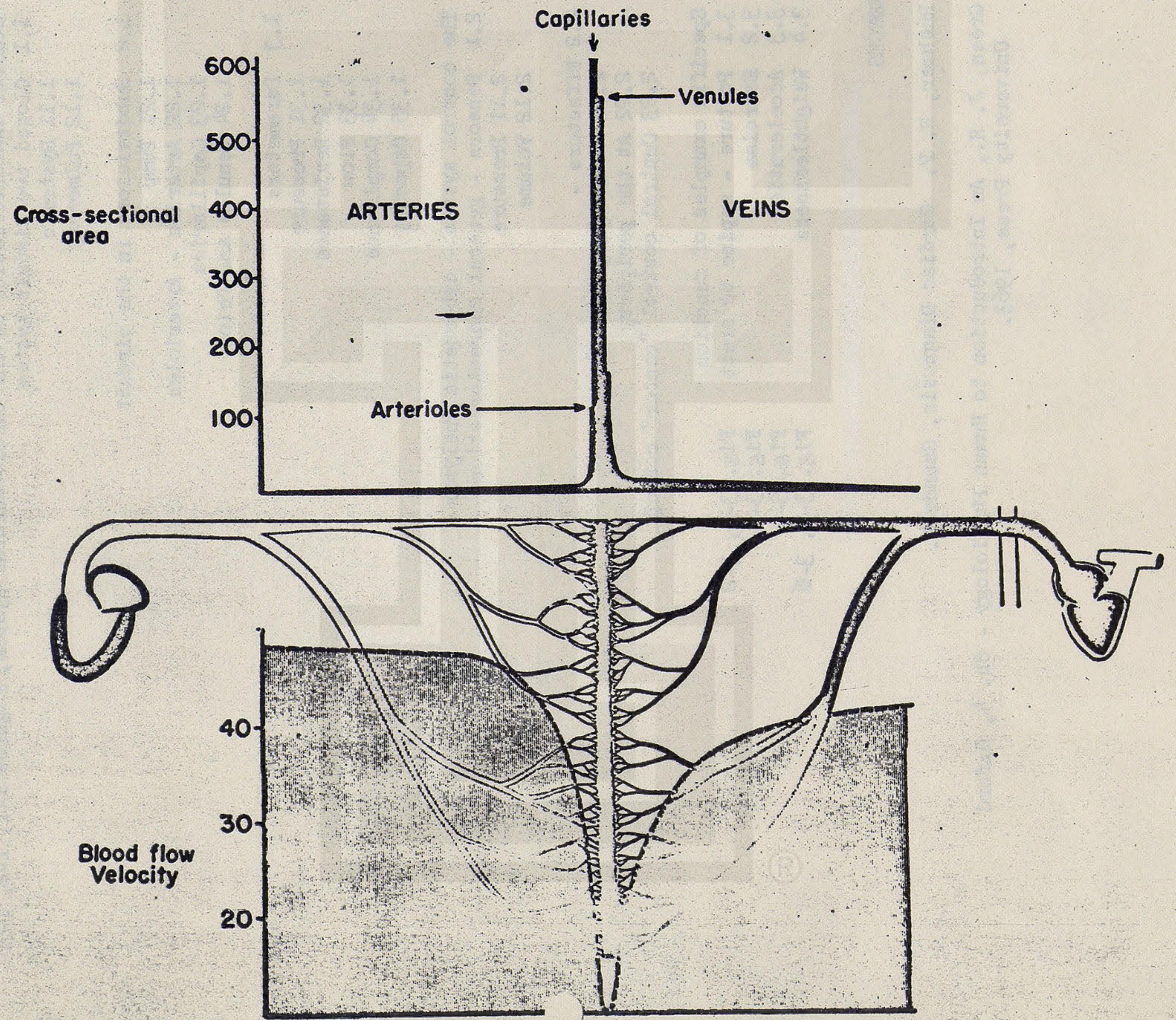
THE RELATION OF CROSS-SECTIONAL AREA TO VELOCITY OF BLOOD FLOW



Diagrams 1-5 Characteristics of the circulatory system (From Rushmer)

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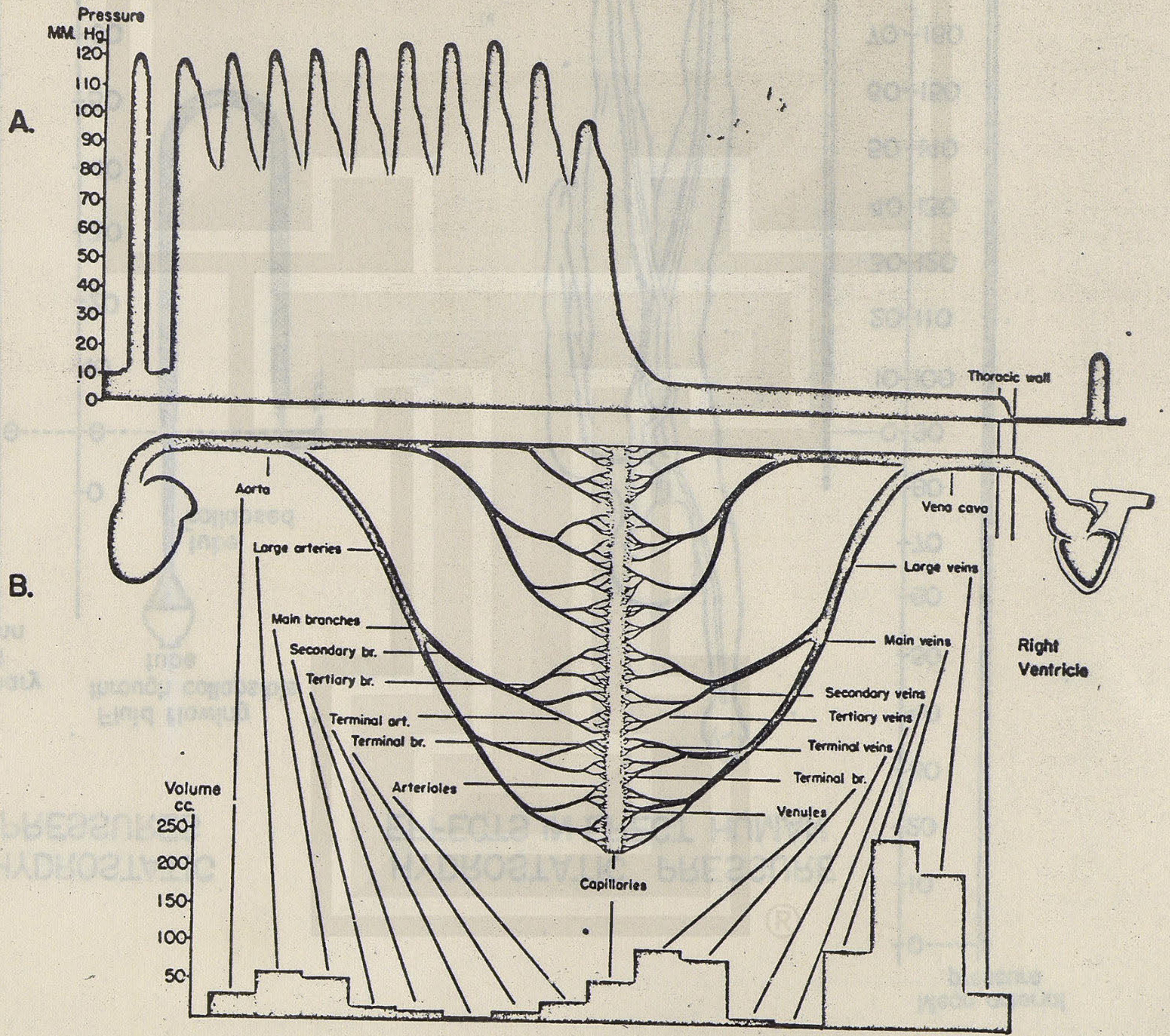
PRESSURES (A) AND VOLUMES (B) IN THE SYSTEMIC CIRCULATION



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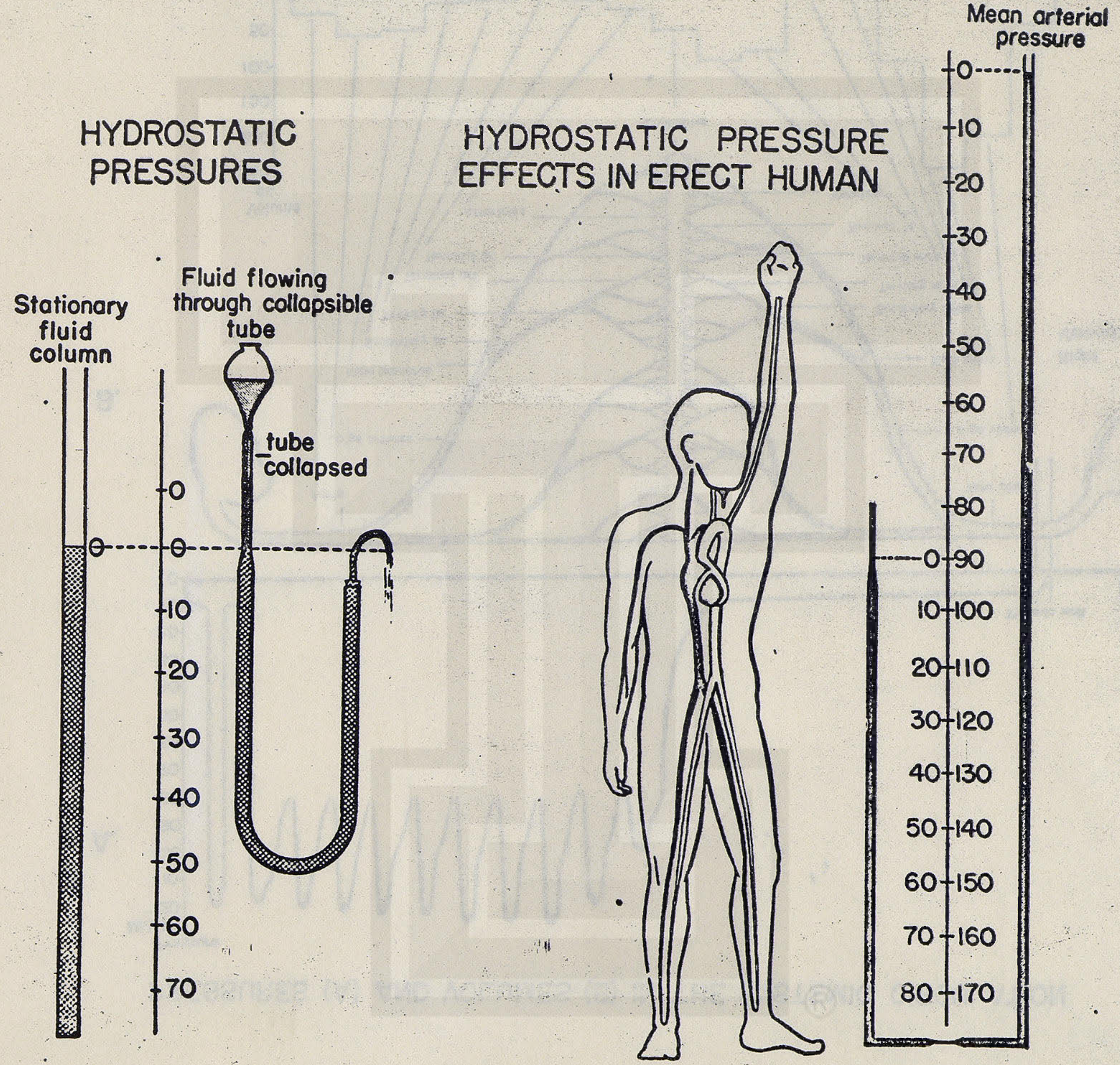
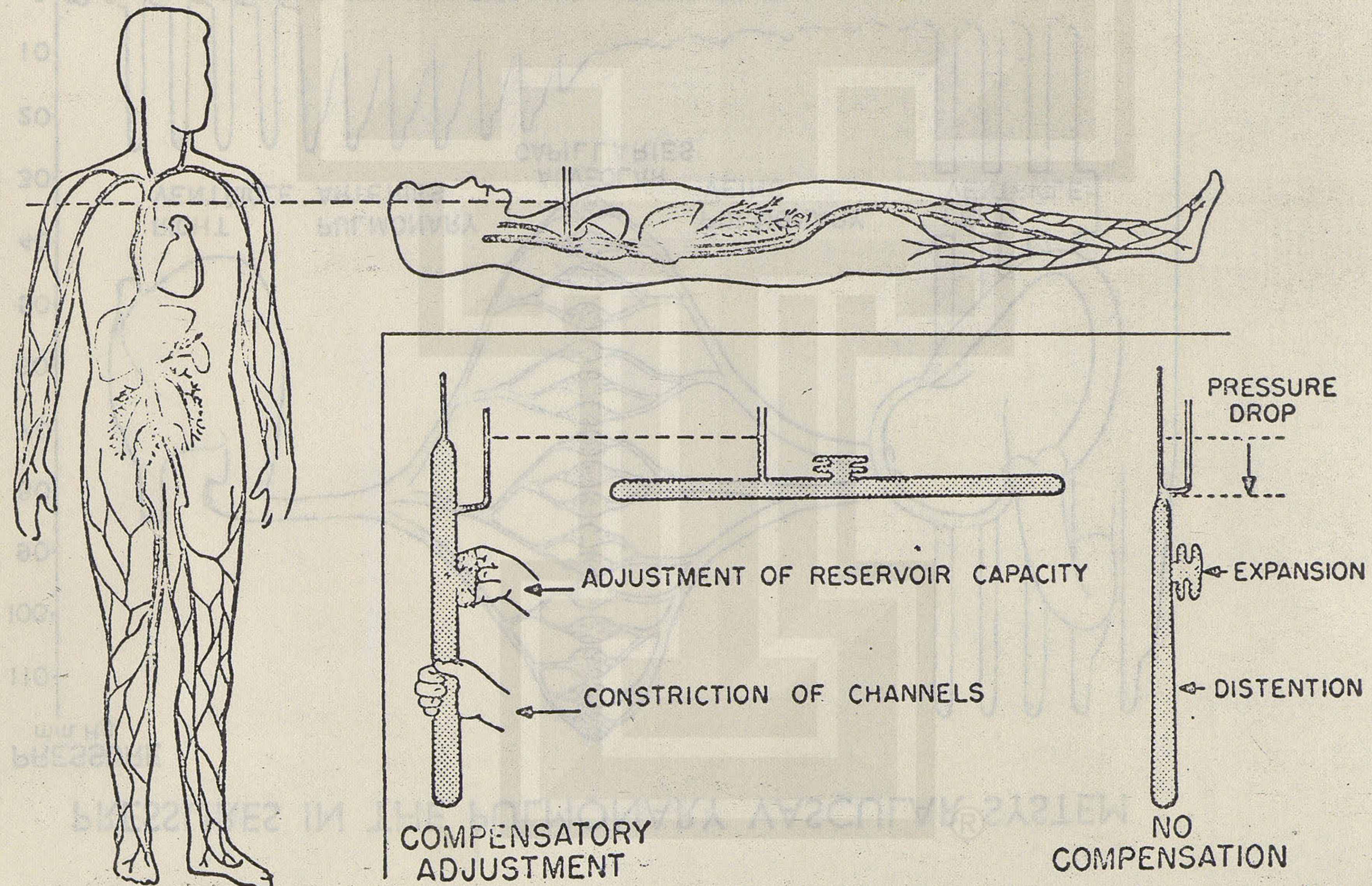


HYDROSTATIC PRESSURES
HYDROSTATIC PRESSURE EFFECTS IN ERECT HUMAN
Stationary fluid column
Fluid flowing through collapsible tube
tube collapsed
0
0
10
20
30
40
50
60
70
Mean arterial pressure
0
10
20
30
40
50
60
70
80
0 90
10 100
20 110
30 120
40 130
50 140
60 150
70 160
80 170

30

MAINTENANCE OF CENTRAL VENOUS PRESSURE



PRESSURES IN THE PULMONARY VASCULAR SYSTEM

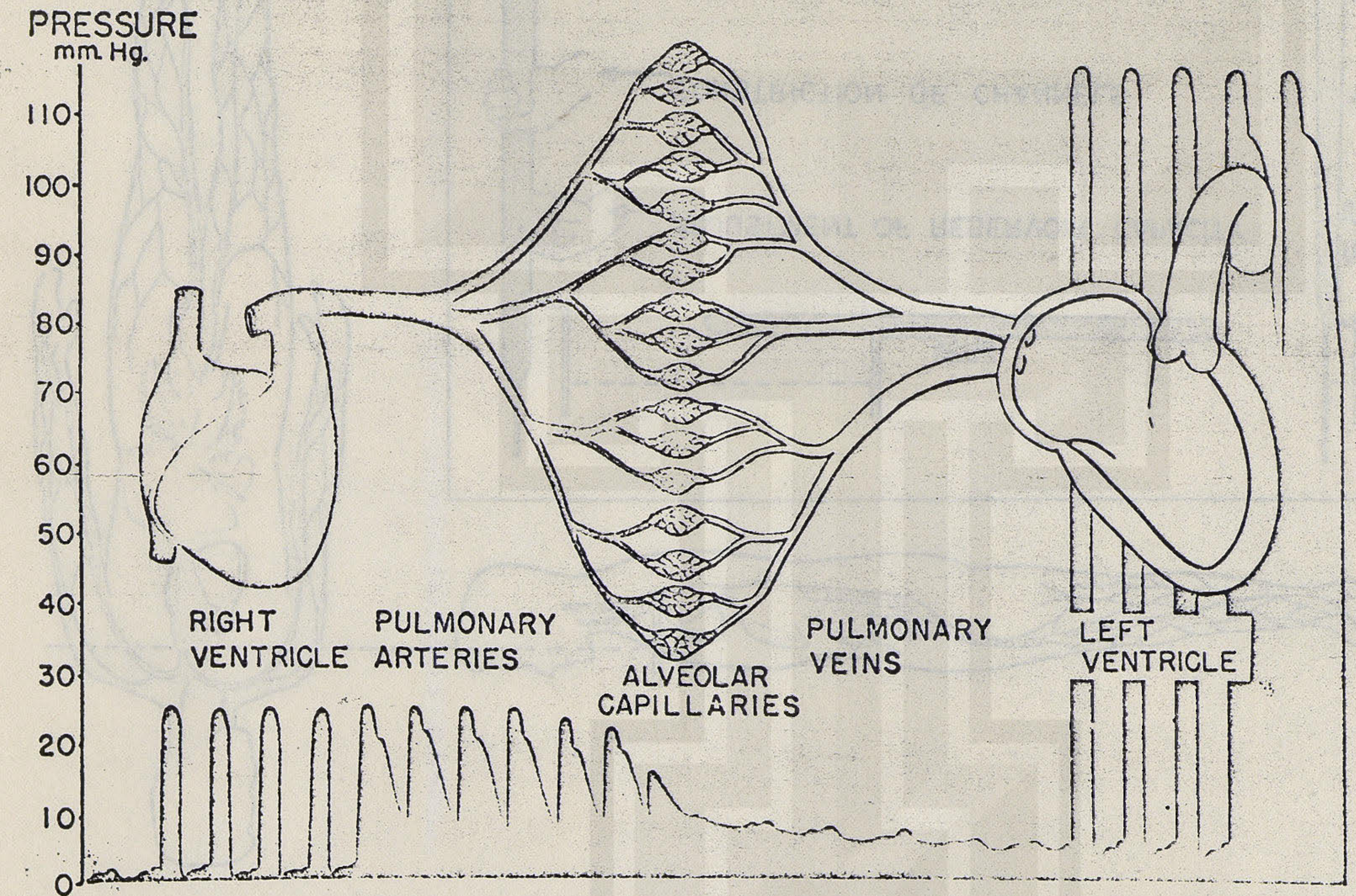
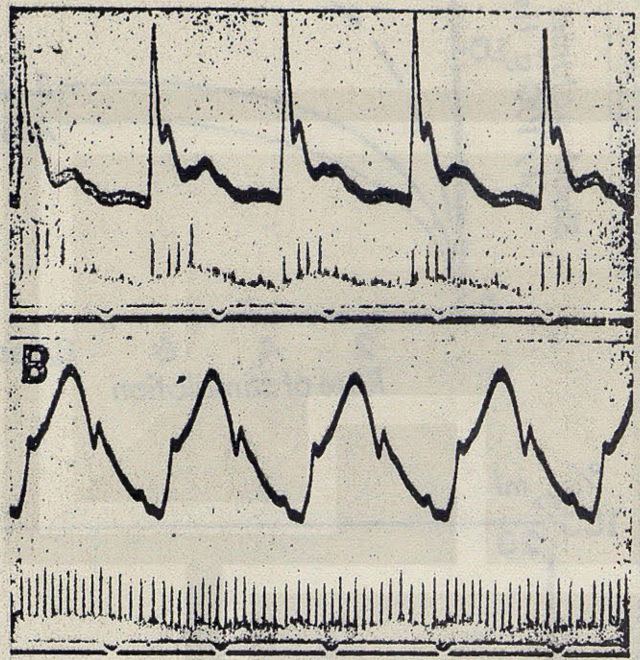
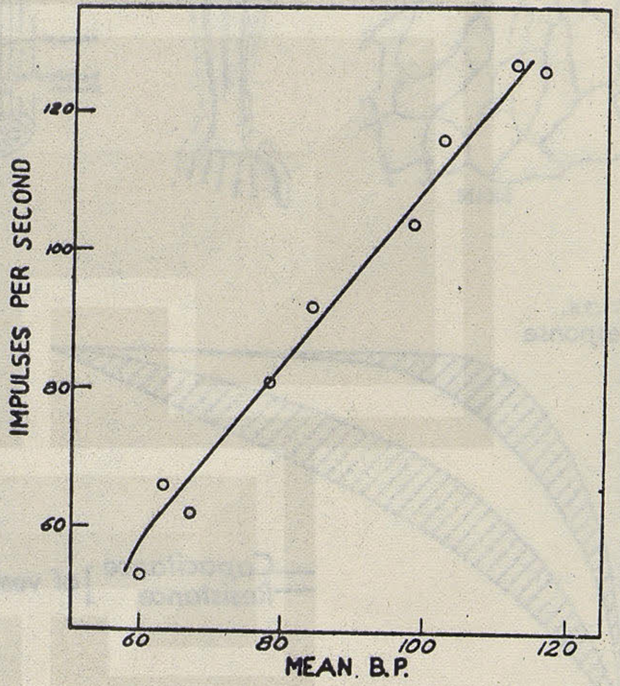


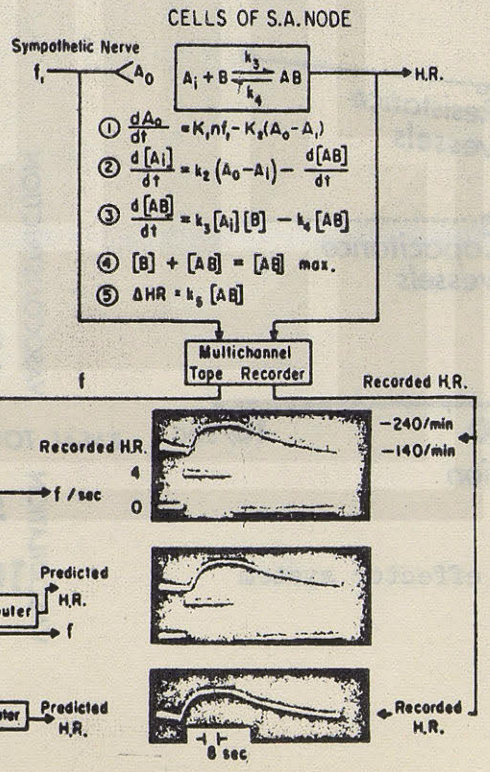
FIGURE 2. Since the pulmonary arterial system offers slight resistance to blood flow, the pressure difference between pulmonary artery and left atrium amounts to only 4 to 6 mm. Hg. This low pressure head drives the same volume of blood through the pulmonary circuit as flows through the systemic circulation with a gradient of some 90 mm. Hg.

Diagram 6. Properties of pressoreceptors (the sensor system)

6







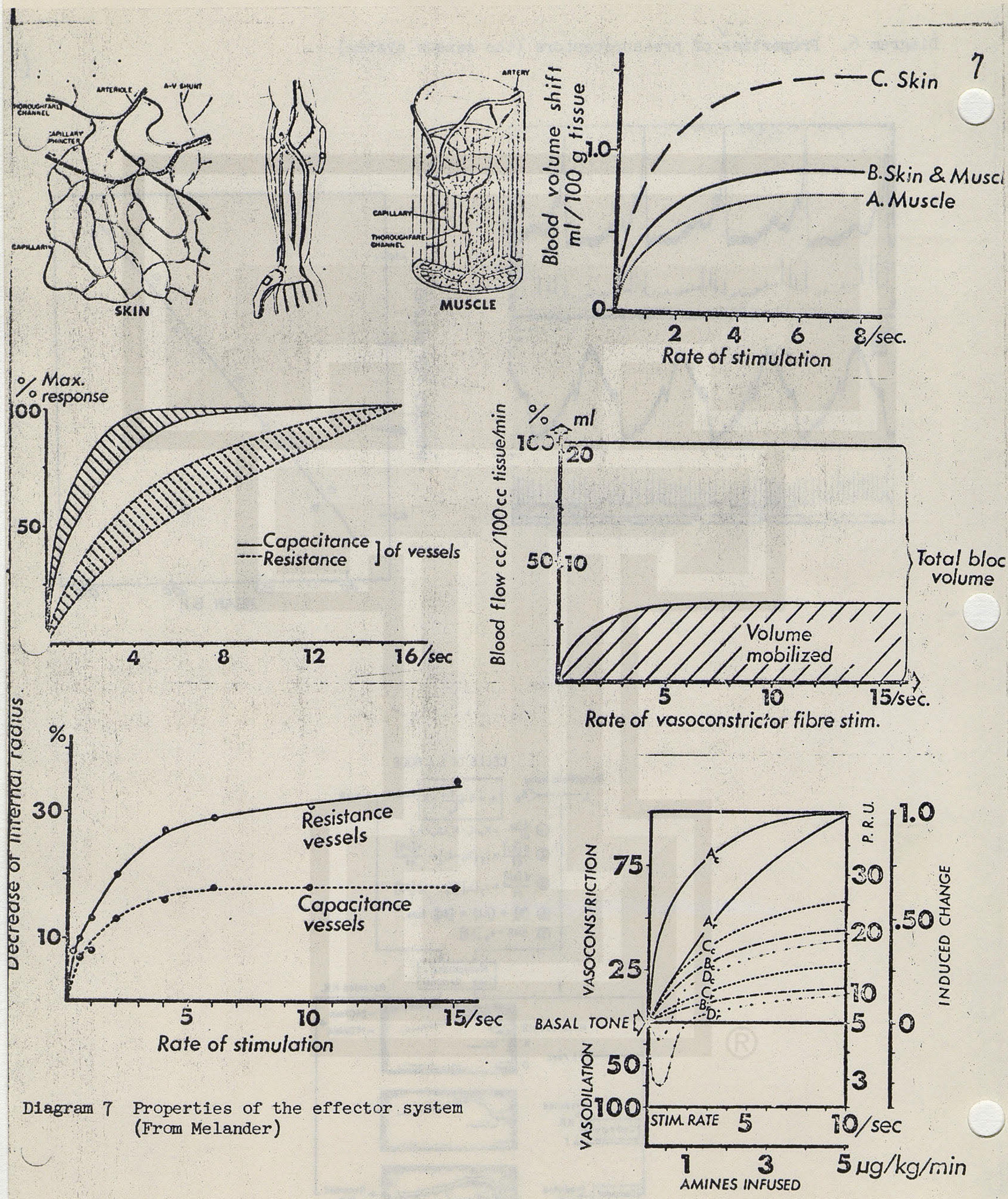
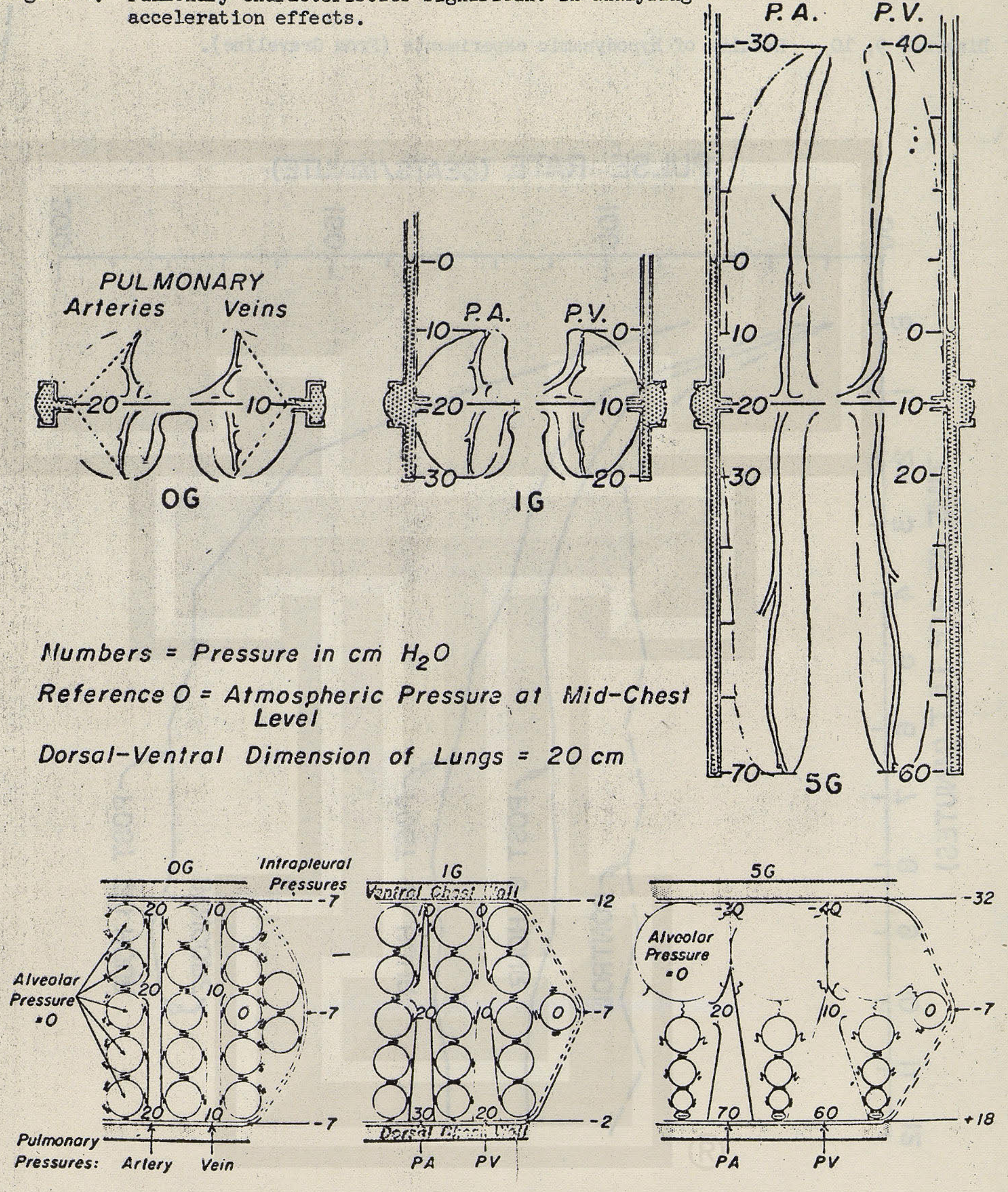
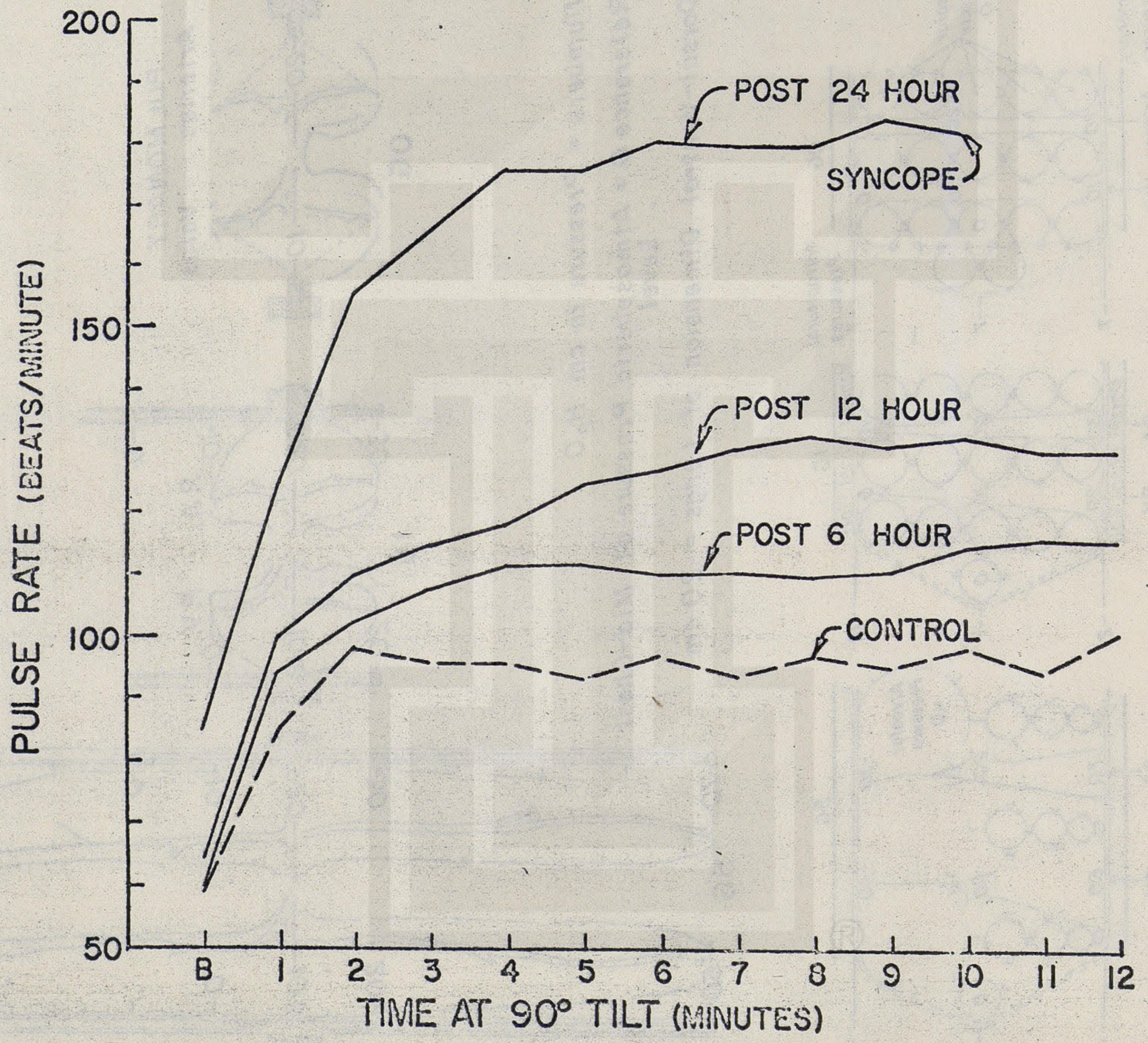


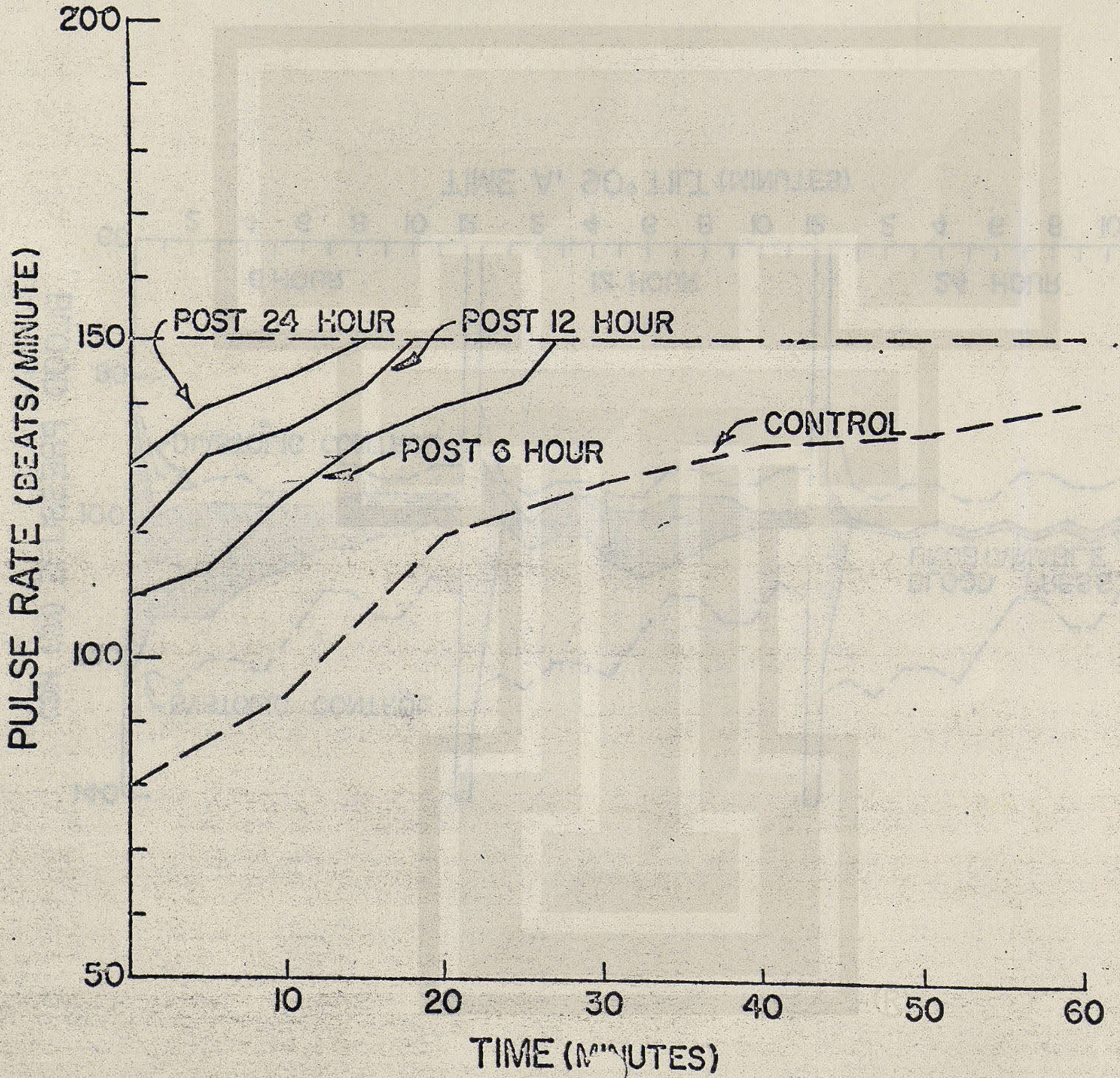
Diagram 7 Properties of the effector system (From Melander)

Diagram 8. Pulmonary characteristics significant in analyzing acceleration effects.





Diagrams 9, 10 Results of hypodynamic experiments (From Graveline).


200
150
100
50
PULSE RATE (BEATS/MINUTE)
POST 24 HOUR
POST 12 HOUR
POST 6 HOUR
CONTROL
10
20
30
40
50
60
TIME (MINUTES)

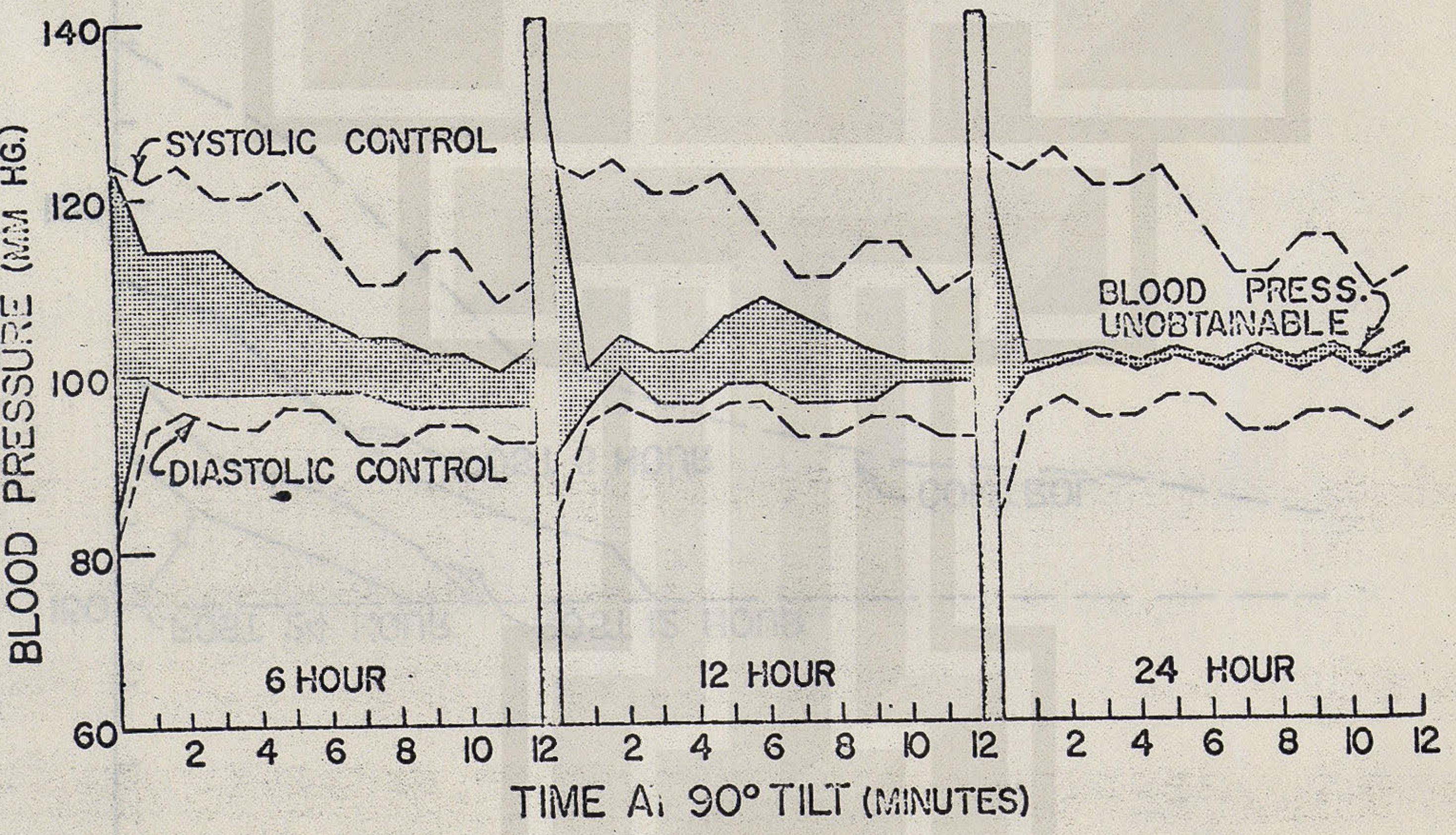


Diagram 11 A post flight experiment.

Newton W. Allebach
Capt., MC, USN

I. Introduction

A. Electrophysiology of the myocardial cell.

B. Volume conductions and dipole concepts.

C. Anatomical determinants of ventricular depolarization.

II. The Normal Electrocardiogram

A. Technique of obtoining

B. Nomenclature

C. Criteria of normalcy

1. QRS, ST, and T contour and heading

2. Rhythm

III. The ECG as a Medical Monitor

A. Value

B. Inherent problems

C. Importance of a validated system

1. Conventional 12-lead

2. Frank-triaxial

IV. Factors Which Alter the Normal ECG

A. Posture

B. Exercise

C. Heat and cold

D. Emotion, e.g., startle

E. Gravitational forces

F. Drugs

G. Electromagnetic forces

V. The Arrhythmias

A. Benign or functional

B. Secondary to organic heart disease

VI. Conduction Defects, Intraventricular

A. LBBB

1. Mechanism

2. Recognition

3. Significance

B. RBBB

1. Mechanism

2. Recognition

3. Significance

a. Congenital

b. Acquired

VII. Coronary Artery Disease

A. Incidence

B. Life history

C. Coronary artery disease vs coronary heart disease

1. Limitations of the ECG

D. The acute coronary incident

1. Electrophysiology

2. ECG manifestations

3. Sequelae

VIII. Coronary Heart Disease Without Recognized Infarction

A. Small unidentified infarcts

B. Ischemic heart disease; infarct

1. Angina Pectoris

2. Exercise ECG

3. Conduction disturbances

4. Differential ECG diagnosis

IX. Other Acute Cardiac Myopathies

A. Pericarditis

B. Trauma

C. Acute corpulmonal

X. Summary

A. Evident value of ECG as a monitor

B. Impartance of triaxial system

OUTLINE OF PRESENTATION FOR SYMPOSIUM ON ENGINEERING ASPECTS OF SPACE MEDICINE

R.E. FORSTER

ASPECTS OF HUMAN RESPIRATORY PHYSIOLOGY PERTINENT TO SPACE ENGINEERING

I. Introduction: Respiratory and circulatory systems compensate for the long diffusion paths in larger animals. Effects of variation in gravity are not all predictable and may be extremely subtle. Chemical activity [proportional to partial pressure] of respiratory gases in the cells is the important property.

II. Composition of inspired gas.

General difficulties of determing detrimental effects.

A. O_2: Body adapts remarkably, but there are definite upper limits, and growing evidence of more strict lower limits.

B. CO_2: Again body can adapt, but there are definite upper limits.

C. Inert gases: Toxic effects are produced at higher pressures. Presence of an inert gas in alveoli needed to prevent atalectasis.

III. Respiratory function on lungs divided for discussion into four steps.

A. Mechanics: considering lung as bellows; normal values.

B. Distribution of exchanging blood in relation to gas flow:

C. Diffusion exchange of gas between alveolar air and capillary blood:

D. Circulation of blood through capillary bed of lungs and thence to tissue capillary beds: normal values.

A. Mechanics of respiration

1. Normal physiology: diaphragmatic action: pleura and intrapleural pressure: Spirometry and lung volumes: Airway resistance: Compliance

2. Possible effects of changes in gravity

a. change in lung volumes

b. change in airway resistance

B. Distribution of blood and gas flow

1. An important problem: A major dysfunction in disease: Extreme case with all blood flow to one lung and all gas flow to the other. Ratio of alveolar ventilation to capillary blood flow is the important factor.
2. Concept of respiratory dead space as wasted ventilation experimentally hard to measure. May have same effect on gas exchange as non uniform ventilation blood flow.
3. Several known regulatory mechanisms to maintain a balance between capillary blood flow and alveolar gas ventilation at the microscopic level.
4. Effect of space flight on distribution problems: Increased gravity produces extreme distortions: Decreased gravity will alter mechanical balance in lungs.

C. Circulation: discussed mainly elsewhere.

1. Pulmonary circulation is low pressure and more susceptible to changes in surrounding pressures, particularly intrapleural and atmospheric.
2. O_2 carried in blood bound reversibly to haemoglobin: CO_2 as bicarbonate.
3. Hydrostatic pressure differences in/lung limits gravitational force man can tolerate.

living

IV. Control of respiration.

A. Effect of arterial P_{CO_2} and pH on medullary respiratory centers.

B. Effect of arterial Po_2 on the chemoreceptors in the aortic arch and bifurcation of the carotid.

C. Cerebrospinal fluid pH and Pco_2.

D. Reflexes and sensation from elsewhere in the body.

E. Temperature

F. Higher centers in the central nervous system.

G. Possible derangements with changes in gravity. In zero G, reduction in sensation may lower respiratory minute volume to dangerous level, particularly during sleep.

V. Self cleansing actions of the lung

A. Cough: expells larger bodies from upper airway. Ineffective in lower airways.

B. Mucus sheet: propelled by the rythmic beat of cilia from the respiratory bronchiole to the pharynx. Effects of changes in gravity on this system are unknown. Extremely important in removing finer particulate matter from the lung.

Earl H. Wood, M.D., Ph.D.

Outline of Presentation for Symposium on <u>Engineering Aspects of Space Medicine</u>,

~~October 19, 1964~~

Research aspects of cardiorespiratory physiology as applied to space

Introduction:

A. Definition of research

A disciplined effort to increase knowledge of any aspect of human understanding

1. Methods of approach applicable to biomedical research

a. A productive approach is to study reactions of a system to a reproducible degree of stress, transient or maintained.

B. Research aspects of space flight in relation to cardiovascular physiology

1. Relation to aerospace medicine and physiology

Space physiology and space medicine are concerned chiefly with man's reactions to the stresses associated with flight. Hence these fields present multiple opportunities for research concerning physiology of the organ systems susceptible to these stresses.

2. Conduct of such research

a. In actual flights

1. Controlled experimentation difficult

2. Recording problems - gradually being overcome

b. In simulators designed to reproduce the various stresses of space flight

1. Controlled experimentation more easily attained

2. Recording problems less difficult

c. Non-simulatable stresses

1. Major one, sustained zero gravity, cannot be simulated on earth. Consequently its effects can only be studied during space flight. The opportunity to study the cardiovascular and respiratory

effects of prolonged exposure to a zero gravity environment is unique to space flight.

3. Examples of stresses associated with space flight which can be simulated on earth

   a. Zero atmospheric pressure

   b. Accelerations associated with launch and re-entry phases of flight or flight maneuvers

   c. Others

4. Specific research aspects in relation to cardiorespiratory physiology

   a. Cardiorespiratory reactions to acceleration will be discussed in particular since it is in my field of interest and knowledge.

C. The human centrifuge as a tool for research in cardiorespiratory physiology

1. Description of human centrifuge

2. Applications in cardiorespiratory research

   a. Control of blood pressure

   Positive acceleration can be used to produce sudden decreases in arterial pressure at head level of any desired degree. Study of the reactions of the cardiovascular system induced in this manner to elucidate circulatory physiology has been only partially exploited.

   b. Alterations in cerebral and retinal blood flow

   Positive acceleration can be used to produce temporary reproducible degrees of stagnant anoxia of the retina and brain of conscious normal human beings and hence offer a potentially fruitful field for study of the interrelationships of the level of consciousness, electrical activity of the brain and retina, arterial pressure at head level and blood flow to these areas.

   c. Alterations in pressure relationships and ventilation-perfusion ratios in the lungs

The low pressure pulmonary circulation is particularly susceptible to hydrostatic effects produced by acceleration.

The pulmonary system requires large air-alveolar membrane-fluid interphases for proper function.

Because of the great difference in specific gravity of air and blood, unavoidable regions of severe hydrostatic pressure imbalances result at the air-alveolar membrane interphases due to the multiplication in weight of the thoracic contents during exposures to increased levels of acceleration. Consequently the functions of the pulmonary system are very susceptible (perhaps more so than any other of the vital bodily processes) to malfunction due to acceleration.

Temporary obliteration of air containing alveoli (atelectasis) in the dependent portions of the lungs can be produced during and following exposures to acceleration such as encountered in the launch and re-entry phases of space flight. Large arterio-venous shunts occur in these regions of the pulmonary circulation and cause a reduction in the amount oxygen carried by arterial blood.

D. Feasibility and safety of such research

1. Studies of tolerance levels of man to various levels and types of acceleration carried out in multiple laboratories in this and other countries have demonstrated that under properly controlled conditions, the afore-mentioned alterations can be produced with safety and without demonstrable permanent sequelae.

   It is believed that this means of producing temporary severe alterations in the function of various organ systems of intact conscious individuals offers a valuable means for the further elucidation of their physiology.

E. Need for electronic data-processing and computation

1. Because of the multiple inter-related variables involved in such studies, use of electronic data-processing methods seem practically mandatory for full exploitation of the possibilities.

2. Description of system developed for this purpose

   a. Applications to other biomedical problems

PHYSIOLOGICAL ASPECTS OF WEIGHTLESSNESS

James P. Henry, Ph.D.

I. General

A. Background

B. Description of sensations in weightlessness

II. Sleep

III. Vision

IV. Position sense, equilibrium, and coordination

V. Alertness

VI. Cardiovascular Deconditioning

A. Mechanisms

B. Effects (Tilt table studies and general observations)

C. Prevention

VII. Summary

Engineering Aspects of Space Medicine
Special Senses
John Lott Brown, Ph.D.

I. INTRODUCTION

If man is to play more than a passing role in space, his sensory capabilities and the demands which may be imposed upon them must be understood and evaluated. All of the information which he will receive on a space mission will be provided by his senses. It is the purpose of this presentation to review current knowledge of how the more important sensory modalities function and how they contribute to our perception of the environment.

II. VISION

The sense of vision will probably be the most important of all the senses to an astronaut. A major part of this presentation will therefore be devoted to a detailed consideration of the visual sense.

A. The Appropriate Physical Stimulus for Vision.
   1. The visible spectrum: Electromagnetic energy in the range of 370 to 760 millimicrons.
   2. Sensitivity of the visual detector: 2 to 7 quanta delivered within 0.1 second.

B. Range of Response.
   1. Adaptation. Variable sensitivity of the retina permits adaptation to luminances over a range of greater than 1,000,000:1.
      a. The mechanism of adaptation. Primarily a neurological rather than a photochemical process.
   2. Problems associated with extremes of illumination.
      a. Threshold stimulation.
      b. Excessive illumination and flash blindness.

C. Spatial Resolution and the Detection of Form.

1. Anatomy of the retina and visual pathway.
   a. The number of retinal receptors.
      (1) Rods: 120,000,000
      (2) Cones: 5,000,000 to 7,000,000
   b. Nerve fibers in the optic nerve pathways. Currently accepted number of fibers is approximately 1,000,000 although recent evidence suggests that there may be more. In any case, there are insufficient fibers to provide for direct connection of more than a very few of the retinal receptors to the brain.
2. Retinal interaction.
   a. Concentric arrangement of receptive fields with inhibitory and excitatory regions.
   b. A neurological mechanism for the enhancement of contour.
   c. Demonstration of perceptual phenomena which may be mediated by mechanisms of retinal interaction.
3. Cortical information processing.
   a. Specialized cells for perception of line elements
   b. A mechanism for the recognition and recall of complex forms
   c. Demonstration of perceptual phenomena which may depend upon cortical information processing.
4. Limitations of visual acuity related to experiences of astronauts.

D. Temporal Response Characteristics of the Eye.

1. Critical duration of stimulation: 0.01 to 0.1 second.
2. The visual system as a differentiator.
3. Repetitive stimulation and applications of harmonic analysis.

E. Color Vision

1. Trichromatic theory
   a. The existence of three specialized color receptors.
2. Opponents processes
   a. Evidence from human vision for opponents processes.
   b. Neurophysiological support for opponents processes.
3. Demonstrations of phenomena which support current theories of color vision.

F. Depth Perception

G. Applications of the visual sense on space missions.

III. HEARING

A. The Appropriate Physical Stimulus.

1. Compression wave in an elastic medium.
2. Need for artificial communication links in outer space.

B. Range of Response of the Human Ear.

1. Frequency: 10 to 20,000 cycles
2. Power requirements: 10^{-16} watts/cm^2 to 10^{-3} watts/cm^2
3. Problems associated with extremes of sound power.

C. Temporal Response Characteristics.
 1. Adaptation. High speed adaptation of the auditory system.
 2. Temporal analysis of complex signals comprised of several frequencies.

D. Review of Anatomy of the Auditory Mechanism.
 1. The basis for mechanical transmission of sound to the inner ear.
 2. The cochlea and how it receives the energy of auditory stimulation.

E. Neurophysiology of Hearing.
 1. Neural interaction dependent upon frequency of stimulation
  a. Frequency sharpening.
 2. Binaural effects and sound localization.
 3. Corticofugal fibers and their possible relation to attention.

F. Pattern Recognition in the Realm of Sound.
 1. Analogies with the recognition of complex form in the realm of vision.
 2. Maximum utilization of band width.

IV. VESTIBULAR FUNCTION
 A. The Anatomy of the Vestibular Mechanisms
  1. The semi-circular canals
  2. The utricles
  3. The saccules

 B. The Appropriate Stimulus for Vestibular Mechanisms
  1. Linear acceleration
  2. Angular acceleration

 C. Ranges of Stimulation and Threshold Values

D. Illusions and Problems Which May be Associated with Space Flight.

V. THE INTEGRATION OF SENSORY INFORMATION

A. The Concept of Sensory Inputs in Various Modalities as Consciously Distinguishable

1. Basis for the concept
2. Validity of the concept
3. Inter-sensory illusions of orientation.

B. The Reticular Formation of the Brain Stem.

1. Its role in sensory integration

VI. OTHER SENSES

Their relevance in space flight.

A. Tactual
B. Gustatory
C. Olfactory

B. F. Burgess, Jr.
Cdr. (MSC) USN

ACCELERATION

The first systematic investigations of the physiological effects of acceleration were conducted less than fifty years ago. Within this span of half a century, man has made such aeronautical progress that he has not only learned to fly, but has expanded his parameters of flight from altitudes of a few hundred feet to altitudes in excess of a hundred miles and velocities of forty miles per hour to velocities exceeding 17,000 miles per hour.

Although animals were used in the first true research oriented endeavors, man was first to experience the debilitating effects of acceleration. Nearly a hundred years before the birth of the airplane man was being exposed to radial accelerations for "therapeutic" reasons. In 1814 patients in the psychiatric wards of LaCharite hospital in Berlin were "cured" of their hysteria after being rotated several times on what was probably the first human rated centrifuge. Doctor Horn of this hospital reported that suffers from various types of mental disorder derived great benefit from being subjected to radial acceleration. He stated that "those suffering from violent madness emerged in a much quieter frame of mind." This does not appear surprising when we consider the fact that the patients were apparently subjected to high negative ($-G_z$) accelerations for extended periods of time.

After the outbreak of World War II the effects of acceleration on man assumed a more important role. The rapid increase in the strength of aircraft and in the propulsive force of aircraft engines enabled man to rapidly push back the limits of his flight envelope. Now for the first time the airplane challenged the physical and physiological capabilities of man by exposing him to the hostile environments of a rarefied atmosphere and high levels of acceleration. It immediately became apparent that there was a common denominator present for both of these stressors, namely - an inadequate oxygen supply to the brain. Although the end results are similar, the mechanism for producing them have no such similarity. In the former case, hypoxia is usually due to a deficient partial pressure of oxygen in the breathing gas, while the hypoxia caused by acceleration is due to the body's inability to maintain an adequate cerebral circulation.

The physiological problems of space vehicle launch and reentry are primarily those of acceleration. Similar problems are encountered in convential flying. When a pilot changes the direction of flight or the speed of his aircraft, acceleration forces are developed by the aircraft which react upon the pilot. By convention, the magnitude of these forces is described in terms of multiples of the force of gravity; 1 G equals the acceleration due to gravity. The direction in which the force acts upon the pilot is currently being described by several sets of acceleration nomenclature. Unfortunately, a standard terminology for describing acceleration and its various components has not been adopted by the medical and engineering groups. Since the background experience of those interested in the engineering aspects of space medicine are so varied, and there is such wide variations in acceleration nomenclature, the various systems of describing G vectors are equated in the following chart.

INSERT ENCLOSED CHART HERE

POSITIVE G OR ($+G_z$)

The take-off speed of the 1930 vintage airplane is approximately 40 miles per hour and the cruising speed is in the order of 100 miles per hour. In flight however, such aircraft are capable of maneuvers which develop forces of acceleration which far exceed the physiological limits of normal function of the pilot. In performing a 360 degree turn, the pilot could be subjected to a force equal to 3 G acting for 30 seconds; a loop would expose the pilot to a 5-6 G for periods up to 15 seconds. Both maneuvers produce forces which act to drain blood from the brain, the latter being sufficient to produce blackout and unconsciousness if no anti G protective mechanism is used.

NEGATIVE G OR ($-G_z$)

If the aircraft described above were flown inverted, the accelerative forces would act to displace blood from the heart into the head. Tolerance to this type of acceleration is generally conceded to be relatively low, somewhere in the order of 3-5 G for a few seconds. Although human subjects have been exposed to ($-10G_z$) for 0.1 of a second during downward ejections, tolerance to this type of acceleration for any extended period is very limited by eye and head pain.

TRANSVERSE G OR ($+G_x$) AND ($-G_x$)

Accelerations perpendicular to the long axis of the body were of academic interest to the physiologists long before the era of space travel. A supinating seat for airplanes resembling a modified barber's chair was proposed near the end of World War II. These early studies culminated in the development of the "contour" couch which has been adopted for use by pilots of space vehicles.

The take-off phase of flight in aircraft which rely upon aerodynamic lift produce a transverse acceleration load of less than 1/2 G upon the pilot. Launch of an aircraft from a catapult of an aircraft carrier exerts 3-4 ($+G_x$) on the pilot for a few seconds. The vertical take-off of a rocket is more forceful. In order to achieve orbital or escape velocities of 18,000 or 25,000 miles per hour, respectively, the space vehicle must be accelerated at magnitudes of G acting long enough to give a G-time history of from 1000-1500 G-seconds. For example, a mean acceleration of 12 G acting for 90 seconds would be required to give the vehicle escape velocity and altitude.

Investigations on the human centrifuge demonstrated the effectiveness of the prone and supine positions in decreasing the detrimental effects of acceleration on the human organism. From the very inception of the idea of space travel, it was apparent that it would be necessary for the occupants of the space vehicle to be oriented in such a manner that the accelerative forces would act transverse to the long axis of the body.

Not only would it be impossible for the space traveler to perform during the high G forces of boost accelerations while sitting in the conventional upright position (receiving ($+G_z$) acceleration), but an equally important problem would occur during reentry into the earth's atmosphere. In either case, the total decelerative load of reentry in G-seconds will approximate the acceleration load of boost into orbit.

In general human tolerance to ($+G_x$) and ($-G_x$) accelerations is essentially the same if an adequately comfortable, full body restraint system is employed. There are certain factors however, such as visual problems caused by tearing and the difficulty of perfecting a restraint system for the prone position, which makes the supine position ($+G_x$ acceleration) easier to withstand. While physiological alterations which limit man's ability to withstand ($+G_z$) accelerations are primarily cardiovascular in nature, chest pain and respiratory difficulties are the limiting factors in transverse acceleration.

LATERAL OR ($+G_y$ AND ($-G_y$)

There has been little requirement for investigations into the physiological effects of lateral accelerations. It is generally assumed, however, that tolerance to this type of acceleration is of the same order of magnitude as that to transverse acceleration. In the limited centrifuge investigations that have been conducted, exposures were terminated due to chest pain and vascular engorgement with pain in the dependent forearm and elbow. Much of the discomfort was attributed to the lack of an adequate full-body restraint system.

ANTI G DEVICES AND METHODS OF PROTECTION AGAINST THE EFFECTS OF ACCELERATION

The device or method selected for protection against the effects of acceleration is determined by the acceleration vector. The pneumatic anti-G suit, which has not been significantly improved since World War II, is of primary value in protecting pilots against ($+G_z$) acceleration. This suit consists of a series of 5 interconnected bladders which are positioned over the abdomen, thigh, and calf. When inflated they act as a torniquet to impede the flow (and pooling) of blood in the lower extremities. In this manner a large central blood volume is maintained, the cardiac output is greater, and consequently cerebral circulation is improved.

Self-protective straining maneuvers used by pilots increase arterial pressure and decrease perepheral pooling of blood thereby increasing the tolerance to ($+G_z$) accelerations.

Protective devices for ($-G_z$) acceleration are of little importance due to the rare chance of the pilot being operationally subjected to this type of acceleration. Since retinal and subconjunctival hemorrhages are frequently produced by ($-G_z$) acceleration, protective pressure helmets and goggles have been used but with questionalbe success.

Protective devices for transverse and lateral accelerations depend almost entirely on comfortable body support - restraint systems. Some relief from respiratory difficulties and chest pain has been obtained by positive pressure breathing.

In general, it can be stated that man's ability to survive and perform useful tasks while being subjected to high levels of acceleration is dependent upon many factors: the rate and direction in which the acceleration is applied, the physical condition, and to some extent the motivation of the subject.

There is a pressing need for additional research in the field of biodynamics, not only to define methods for distributing the G loads in order to maintain the human organism intact, but also to preserve man's ability to perform useful tasks while being subjected to un-natural gravitational environments. Not until the aerospace scientists, both medical and engineering, more completely evaluate the inherent dangers posed by such problems as acceleration, particularly after prolonged periods of weightlessness, will man achieve mastery in his conquest of space.

ACCELERATION NOMENCLATURE IN CURRENT USE

Actual heart displacement	Terminology used to describe acceleration			
Towards feet	Positive G or head to foot	Headward	Eye-balls down	$+G_z$
Towards head	Negative G or foot to head	Footward	Eye-balls up	$-G_z$
Towards spine	Transverse (chest-to-back)	Forward facing	Eye-balls in	$+G_x$
Towards sternum	Transverse (back-to-chest)	Backward facing	Eye-balls out	$-G_x$
Towards left	Lateral (right-to-left)	Rightward	Eye-balls left	$+G_y$
Towards right	Lateral (left-to-right	Leftward	Eye-balls right	$-G_y$

NOISE AND VIBRATION

Dr. Henning E. von Gierke
Chief, Biodynamics and Bionics Division
Aerospace Medical Research Laboratories
Wright-Patterson Air Force Base, Ohio

Airborne noise and structure-borne vibration are the more or less periodic higher frequency components of the total mechanical force and pressure environments encountered in space vehicle operations while sustained acceleration, static pressure changes, impact and blast make up the static and transient components. There are three sources of airborne noise: (1) noise from the propulsion system, increasing in intensity with the thrust of the engine and containing increasing amounts of low frequency energy as the diameter of the rocket exhaust is larger; (2) boundary layer noise, increasing with dynamic pressure (q); and (3) noise from equipment carried inside the vehicle. This latter noise is the only source to be considered while the spacecraft is outside the atmosphere. Structure transmitted vibrations are caused by unstable forces from the engines or irregular aerodynamic forces acting on the vehicle (buffeting).

The estimated or measured noise and vibration environments are compared to human safety and performance criteria to determine if the required crew performance can be assured. If the environmental stresses appear too high, one or a combination of the following measures is taken to provide the degree of crew protection required: reduction of the noise or vibration energy at the source, isolation of the subject from the environment and additional personal protective equipment.

NOISE AND VIBRATION cont'd.

Laboratory simulators are available to produce the operational noise spectra (electrodynamic speaker systems, sirens) and vibration spectra (one- or several-degree-of-freedom shake tables) required for realistic human factors testing and biological research work.

Noise (20 to 20,000 cps) affects man primarily through the organ of hearing. At extremely high noise intensities instantaneous injury to the middle and inner ear can occur. At lower intensitities long-time noise exposure can result in temporary, or finally in permanent hearing loss. This reduction in hearing acuity is caused by damage to some of the receptor nerve cells in the inner ear. Even at relatively low intensities noise can interfere with the speech communication vital to performance. It also can be the source of annoyance. Quantitative criteria for these various effects are available and being used in system design. Protective equipment is available when necessary. Non-auditory effects of noise involve other organs than the auditory system but are important usually only at extremely high intensities. All effects of noise depend not only on the intensity but also on the frequency spectrum of the noise; noise control measures also are strongly frequency dependent.

Vibrations in the frequency range below 100 cps are those most troublesome for man. Unfortunately, this is also the range where vibration control by isolation is most space- and weight-consuming. The effects on man of vibrations in this region are strongly frequency dependent; mechanical resonances of various body parts and organs can occur at certain frequencies and amplify the effectiveness of the input energy with respect to the particular body region.

NOISE AND VIBRATION cont'd.

There is, for example, a resonance of the thorax and abdominal viscera in the 3 - 6 cps range and a resonance of the head compared to the shoulders around 30 cps (for the sitting subject). The first resonance can lead to pain symptoms at relatively low vibration acceleration levels, thus limiting physiological tolerance of the subject. The head resonance can result in blurred vision and decreased performance capability on exposure to relatively low levels in this frequency range. These are simplified examples to demonstrate how the body's dynamic response influences critically the physiological and performance tolerance limits. Human tolerance and performance limits depend in detail on the direction of application of the vibration, the body position and support, the exposure time, and many other factors. Only approximate criteria are available in this area and additional research to clarify the various mechanisms of biological action is required.

In actual flight, noise and vibrations are experienced in combination with other environmental stress factors, a fact requiring conservative application of the available criteria which have to date been derived from results of only one stressor at a time.

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Dr. Wilmot N. Hess

SPACE RADIATION AND MAGNETIC FIELD ENVIRONMENT

I. The Solar Atmosphere

A. The solar corona is unstable and blows a wind of protons and electrons at the earth at a velocity of about 400 km/sec.

B. The magnetic field of the earth which is roughly dipolar is pushed in by the solar wind and limited to existing inside a cavity called the magnetosphere. The shape of this cavity and of the distorted field lines inside it have been calculated.

C. Changes in the solar wind characteristics produced by eruptions on the sun cause effects at the earth. Changing the solar wind pressure on the magnetosphere causes it to change shape and size and as a result changes the magnetic field at the surface of the earth.

II. Cosmic Rays

A. Cosmic protons with very high energies with up to 10^9 ev continually arrive at the earth from deep space. We know their fluxes and energies relatively well but rather little about their origin.

B. When a magnetic storm occurs at the earth produced by an enhanced solar wind, this frequently decreases the flux of calculated cosmic rays arriving at the earth. This effect called the Forbush decrease can be roughly understood in terms of our understanding of the interplanetary medium.

C. We know that energetic protons are occasionally made near the surface of the sun. These particles are occasionally observed on sea-level detectors but more frequently on satellites and balloons. The energetic rays extend above 10^9 ev.

1. Solar cosmic rays, as far as we know, are always made in the region of large solar flares. Various schemes for the acceleration of the particles have been suggested but their mode of origin must be considered an open question.

2. The solar protons arrive at the earth some time after the flare. Flares near the west limb of the sun produce faster arriving protons due to the geometry of the magnetic field. The propagation process resembles fairly closely the diffusion of the particles.

3. When solar protons arrive at the earth, they produce several effects. At the polar cap regions they produce an increased ionization in the ionosphere and because of this a reduced influx of

cosmic radio noise to the earth. These polar cap absorption events are measured by a device called a riometer and can be used quantitatively now to study solar proton events.

4. There have been about one half dozen very large solar proton events observed in the past ten years. They frequently occur as multiple events from one sunspot group.

III. The Radiation Belt

A. Satellite measurements have lead to general knowledge of the spatial distribution of high and low energy protons and electrons in the radiation belt.

B. We understand quantitatively the source and losses of the energetic protons near the earth. The protons are made by decay of neutrons coming out from the atmosphere of the earth and are lost by interaction with the thin atmosphere present at very high altitudes.

C. A recent model explains several of the features of the low energy protons in the outer belt by assuming the protons are diffused into the magnetic field from the outside by a magnetic pumping process.

D. Significant radiation belts have been made in the past by explosions of high altitude nuclear bombs. These have enabled up to measure the lifetime of trapped electrons which was not previcusly possible. We understand reasonably well the decay of the starfish belt in terms of atmosphere scattering and whistler interaction.

E. From a knowledge of the electrons' lifetimes from studying artificial belts, we can understand qualitatively the natural electrons in the radiation belt.

F. From studying synchrotron radiation we are quite sure that Jupiter has an electron radiation belt substantially more intense than the earth's. Saturn shows no synchrotron radiation evidence of a radiation belt. The Mariner probe did not find a belt on Venus.

IV. Total Encountered Particle Fluxes

A. Solar proton events - We have a reasonably good idea of the total particle flux that would have been encountered in the several large solar proton events in the past 10 years. By various schemes of solar flare prediction, we can try to minimize the chance that an astronaut would encounter solar protons in a trip to the moon.

B. Radiation belt flux - the flux of particles that a satellite would encounter in traversing the starfish radiation belt and the inner radiation belt protons have been calculated for various circular orbits.

ENGINEERING ASPECTS OF SPACE MEDICINE

George Washington University

Radiation Biology - Lecture Outline

Douglas Grahn

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I. The Interaction of Radiation with Matter

A. Initial physical and chemical events

1. Electromagnetic radiation - photoelectron and recoil electron production; relatively sparce production of ion pairs.

2. Particulate radiation - recoil protons, mesons, neutrons, etc.; secondary γ and x-radiation; dense ion pair production along particle track.

3. Formation of radicals in water: H, OH, H_2O_2, HO_2; breakage of chemical bonds; events occurring in 10^{-12} to 10^{-6} seconds.

B. Molecular and cellular effects of radiation

1. Modification of DNA molecule, enzymes, and other proteins; disruption of biochemical processes.

2. Induction of genetic change - gene mutation and chromosome aberration.

3. Cell death; modification of cell function.

C. Tissue and systemic effects of radiation

1. Proliferating tissues (blood forming, intestinal wall) - reduction or inhibition of cell division; depression in cell number and tissue function.

2. Non-proliferating tissues (liver, kidney, CNS) - persistence of damaged cells; absence of immediate evidence of injury.
3. Systemic manifestations of cell and tissue damage.

D. Miscellaneous factors

1. Time-intensity variables - reduced biological effectiveness by dose protraction and fractionation.
2. Relative biological effectiveness (RBE) - recognition of differences in biological effect due to pattern of energy transfer and ionization density.
3. Partial body exposure.
4. Chemical and bone marrow therapy.

II Human Radiation Biology

A. Acute radiation injury

1. Central nervous system injury - dose range 1000r and up - survival time less than one week; death from shock, fluid loss, hemorrhage, widespread tissue destruction.
2. Hematopoietic injury - dose range: 50r - 650r - sublethal to lethal; death in one week to two months; minimum lethal dose ca. 150r. Death from hemorrhage, infection, anemia.
3. Prodromal responses - nausea, vomiting for several hours to one day; fever, loss of appetite, diarrhea; minimum dose probably 50r for most sensitive - 250r probably will produce prodromal reactions in all persons.
4. Subacute injury - protracted recovery in survivors or sublethally exposed; temporary sterility.

B. Chronic or long term radiation injury

1. Reduced life expectancy - extrapolation from animal data suggests a non-linear response to single doses and an estimate of 15 - 20% (~ 6 - 8 years) reduction by 400r - 500r; more linear response expected from continuous low intensity exposure and an estimated loss of 1 - 2 days per r accumulated.

2. Leukemia induction - probability of leukemia occurrence: $1\text{-}2 \times 10^{-6}$/r/year for 15 - 20 years post-exposure for doses of 50r or greater.

3. Other malignancies - present evidence indicates increased death rate from gastric, pulmonary and skin cancer.

4. Cataract formation - linearly increasing probability above 200r - may approach 100% above 1000r.

5. Genetic damage - mutation rate for recessive visible genes: $5\text{-}25 \times 10^{-8}$/r/gene; recessive lethal mutations per gamete: $1\text{-}20 \times 10^{-4}$/r.

III Determination of Radiation Safety Standards in Manned Flight Operations

A. Present ICRP and NCRP maximum permissible dose (MPD) values generally unacceptable

1. MPD's set for potentially large populations at risk - not small flight crews.

2. MPD's set to hold biological hazard to occupationally exposed group as "negligibly small".

3. MPD's set for assumed career of about 50 years.

4. Philosophy of standards inconsistent with problem of multiple risk situation of manned flight.

Engineering Aspects of Space Medicine

B. Radiation protection primarily a matter of "acceptable degree of risk" vs "mission failure"

1. Risk primarily a function of acute radiation injury endpoints - gastrointestinal, hematopoietic, skin damage.
2. Risk secondarily a function of long term effects and career limitation.
3. Acceptable radiation risk may vary with each mission profile.

J. Warren Keller

RADIATION SHIELDING IN SPACE

I. Introduction

II. Passage of Radiation Through Matter

A. Protons

1. Ionization Loss - loss of energy through inelastic collisions with bound electrons

2. Stopping Power - rate of energy loss in material - function of particle energy and medium being penetrated

3. Range - distance traveled in material before being stopped - function of particle energy and medium being penetrated

4. Nuclear Collisions - inelastic collisions with nuclei of the material being penetrated - cascade and evaporation processes - production of secondary radiations; neutrons, protons, gamma rays

B. Electrons

1. Ionization Loss - loss of energy through inelastic collisions with bound electrons

2. Scattering - elastic coulomb scattering from atoms of the material being penetrated - decreases range - affects angular distribution

3. Radiation Loss - gamma rays (or bremsstrahlung) produced in deceleration process - fraction of energy loss through radiation, energy of bremsstrahlung, angular distribution dependent on material

4. Range - distance traveled in material before being stopped - function of particle energy and medium being penetrated

III. Methods of Calculation

A. General Approach

1. Idealized Geometry - slab geometry used to approximate spherical shield for isotropic incidence

2. Complex Geometry - realistic vehicle geometry is complex - sectoring technique used - many possible errors

III. Methods of Calculation (Cont'd)

B. Protons

1. Primary Protons - simple calculation to determine energy and angular distributions and dose behind shield

2. Secondary Radiations - complex problem - good data on production lacking but being generated by both experiment and theory

C. Electrons

1. Primary Electrons - complex problem - many assumptions used - Monte Carlo techniques useful for generating data

2. Electron Bremsstrahlung - assumptions necessary for practical calculations - gamma ray shielding involves both exponential attenuation and build-up factors

IV. Shield Effectiveness

A. Protons

1. Geomagnetically Trapped Protons - dose decreases very slowly with increase in shield thickness - secondaries not important for thin shields - low Z materials most effective

2. Solar Protons - dose decrease more pronounced with increase in shield thickness because of soft spectrum - secondaries not important for thin shields

B. Electrons

1. Natural Electrons - rapid decrease in dose with increasing shield thickness for penetrating electrons - bremsstrahlung sets limit on practical shield effectiveness - heavy materials most effective for stopping electrons but also produce greatest amount of bremsstrahlung

2. Artificial Electrons - greater shielding problem than natural electrons

V. Summary

Dr. D. E. Beischer

Physiological Effects of Magnetic Fields

An outline

Why are magnetic fields of interest to manned space travel?

Strong magnetic fields are considered as protection against ionizing radiation similar to the shielding action of the geomagnetic field. Application of such fields is considered also in ion propulsion, magnetic docking, energy storage, and other applications. These applications would depend on light weight superconductive magnet systems.

Magnetic fields of low intensity (about 1/1000 of the geomagnetic field) are expected on the moon and their possible physiological effects are of interest in connection with manned lunar landings.

How do extreme magnetic fields affect man?

The only effect of a very weak magnetic field (1/1000 of the earth's field) was observed in the visual sector (strong decrease of the flicker fusion threshold).

No systematic physiological studies with humans have been made on the effects of strong fields. Occasional observations showed that magnetic fields up to 20,000 gauss can be tolerated by man without sensation in part or total body exposure for short periods of time. There seems to be no cumulative effect of exposure to fields of 5,000 gauss for three days per year per man. Occasional spells of dizziness were noticed.

However, animal experiments in strong magnetic fields advise to caution. Recently, an effect on the electrical processes of the heart, demonstrated in the ECG, was noticed in monkeys and effects on all electrical processes in living tissue are expected. A number of experiments with animals indicate a general effect of unspecified etiology on all growing tissue. Inhibition and stunting of growth has been observed in a number of biological systems including tissue cultures. A delay of wound healing belongs in the same category of observations.

Influences of magnetic fields on function and behavior have also been described. A directional effect of the geomagnetic field on migrating and homing birds has often been discussed and a directional influence on the movement of snails has been fairly well established.

Alternating fields have visual effects (magnetophosphorescence) and fast changing very strong magnetic field, used in metal forming, stimulates motoneuron action. Some biomagnetic oddities such as the amelioration of tissue damage by radiation observed recently in the flour beetle and the existence of a magnetocardiogram will also be discussed.

Magnetobiology is a typical field which found impetus by possible space applications to the benefit of a new physiological insight.

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(Lecture Outline for George Washington University College of General Studies series entitled "Fundamentals of Space Medicine")

Space Related Medical Aspects of
Ultraviolet, Visible, and Infrared Radiation

by

John A. Buesseler, M. D.

I <u>Introduction</u>:

Although the beneficial effects of natural sunlight have been appreciated by man since early recorded time, fruitful efforts at studying the biological effects of radiation began with the description in the late 18th Century of a series of disorders demonstrably due to abnormal cutaneous responses to light. However, in the absence of adequate theoretical and technical tools, real progress in the field of photobiology had to await the 20th Century. It is the brief exploration of this recently acquired knowledge, as it relates to space flight, with which this presentation is concerned.

II <u>The Electro-Magnetic Spectrum</u>:

Electro-magnetic disturbances which propagate themselves through space exhibit an unusually wide range. The center of the spectrum is usually taken to be the small band of radiations recognizable to the human eye as visible light. From this as the center, the spectrum extends in both directions, on the one hand, electro-magnetic oscillations several miles in length and, on the other, to cosmic rays with a wave length of approximately one-trillionth of a millimeter. Because the series of radiations involved are continuous, division into groups is somewhat arbitrary. Therefore, for the purposes of this discussion, the ultraviolet radiation band is considered to include wave length of 10 to 400 millimicrons, the visible band to consist of wave lengths of 400 to 780 millimicrons and the infrared radiation band includes wave lengths of 0.78 to 6 microns.

III Biological Effects of Electro-Magnetic Energy:

Radiant energy exerts a biological effect upon animal tissues only in so far as it is absorbed by them. The process of absorption may be considered to consist of two forms: a) the energy of the radiation may be dissipated in the resistance offered by the tissue to its passage, or b) the radiation is absorbed into an appropriate part of the molecular system of the organism. In the second mechanism, radiation is directly absorbed in an inverse relationship to its wave length. Thus the proportion of energy absorbed from ultraviolet light is greater than that from infrared radiations. Radiant energy absorbed in this manner results in an increased rate of molecular movement and, if sufficient in quantity, can alter the nature of the tissue by producing an abiotic (photo-chemical or photo-electric) lesion or a thermal lesion.

IV Abiotic Lesions:

The ultraviolet band of the energy spectrum produces a photo-chemical reaction in animal tissues. The substances particularly involved are the proteins and the effect is essentially a photo-chemical denaturation. The typical reaction appears only after a latent period of generally six to eight hours. The cellular manifestations are most often an inhibition of mitosis, a nuclear fragmentation, and an eosinophilic reaction in the nucleus and cytoplasm of the cell.

Because the reaction is dependent on the absorption of energy, a critical threshold of wave length and of intensity of radiation is necessary to excite it. In practice the degree of reaction varies directly with the time of exposure, inversely as the square of the distance of the source of light and directly as the cosine of the angle of incidence.

Most biological research and clinical data related to ultraviolet radiation has been concerned with the wave length band extending from the lower border of visibility (approximately 400 millimicrons) to the earth-bound limitations of transparency of air (approximately 180 millimicrons). It has been found that the erythemal effect is produced by the wave band from 180 to 315 millimicrons with peak action in the region of 240 and 297 millimicrons. Tanning effect is produced by the wave band from 315 to 400 millimicrons.

Although the body of the astronaut is protected by clothing or shielding, the areas of potentially greatest relative exposure to ultraviolet radiation in space are the eyes and the skin of the face.

V <u>Visible Light Disturbances and Lesions</u>:

Because of a lack of dispersion medium above the earth's atmosphere, reflection of light on the haze and cloud cover of the earth results in a so-called "reversed light distribution." Bright light from below the subject is not shielded by the eyelids and thus produces a veiling glare whereas attempts to read instruments against such a bright background results in a dazzling glare effect. Both types of glare reduce effective visual acuity.

Except for clinical cases of photo-allergy, the pathological effects of visible light radiation on the human skin has been essentially unexplored. However, in relation to a damaging effect upon the structures of the eye, it is generally accepted that such effect is largely unrelated either quantitatively or qualitatively to any particular portion of the visible light wave lengths band but depends more simply on the concentration of energy incident in this region of the eye. There is presently no firm evidence that visible light causes pathological lesions in the eye except where it is absorbed by the pigmented structures and is of sufficient intensity so that its conversion to heat is great enough to produce a thermal lesion. Outside of the earth's atmospheric cover, visible light emanating from the sun is sufficiently intense to constitute a source of potentially damaging radiation to the eye.

VI <u>Infrared Thermal Lesions</u>:

Although radiation of any wave length on being absorbed suffers degradation into heat to some extent, particularly when it encounters pigmented tissue, pathological thermal effects are most readily produced by the infrared band of the spectrum. Such radiational burns may be classified as: a) flash burns which result from the absorption of a large amount of radiant energy in a short period of time and b) a burn which involves a smaller concentration of energy acting over a considerable time period.

In regard to the skin, the wave length band from 0.8 to 1.5 micron can penetrate to a depth of 3 cm if sufficient energy is envolved; whereas, penetration of radiation with a wave length above 6 micron is virtually nil.

For the eye, infrared radiation of 0.8 micron wave length results in 78% of the incident energy reaching the retina. At 1.5 micron, 20% of incident energy reaches the lens and only 3% reaches the retina. At 3 micron and above, essentially all of the incident energy is absorbed by the cornea.. The band of greatest biological damage is from 0.8 to 1.2 microns.

Outside of the protective cover of the earth's atmosphere, the potentially damaging effect of the solar infrared radiation, particularly to the face and the eyes, is a matter of concern which is yet to be resolved.

Edward J. McLaughlin, Ph.D.

Code MMD - Space Medicine

SIMULATION

I. WORKING DEFINITION - THREE APPROACHES:

A. Convenience

B. Performance

C. Control

II. BACKGROUND

A. Early Simulators

B. Integrated Simulators

III. SIMULATION THEORY

A. Approach

B. Model

C. Program

IV. CLASSES OF SIMULATORS

A. Flight

B. Ground

1. Fixed Base

2. Moving Base

V. UTILIZATION OF SIMULATION DATA

A. Design Studies

1. Vehicle

2. Human

B. Systems Evaluation

C. Operational Procedures

D. Human Capacities

E. Training

F. Prediction

VI. SIMULATION METHODOLOGY - DEVELOPMENT SEQUENCE

A. Purpose

B. Task Analysis

C. Method

D. Equipment

E. Training

F. Subjects

G. Duration

H. Data

I. Results

VII. SUMMARY AND CONCLUSIONS

THE ROLE OF THE VESTIBULAR ORGANS IN THE EXPLORATION OF SPACE

I. Vestibular Mechanisms

A. Peripheral Organs

B. Central Nervous System Connections

C. Normal Functions

D. Functional Disturbances

1. The gravitoinertial force environment.

2. Illusions.

3. Neuromuscular disturbances.

4. Motion sickness.

II. Weightlessness and Subgravity States

III. Rotating Environments

IV. Summary

Under natural living conditions the most important cues for the perceived direction of space are furnished by the visual and gravitoinertial force environments. The best concordance between the two is manifested with man upright and its achievement represents one of the most dramatic manifestations of man's adaptation to his outer environment. Thus, in the course of his primitive sense experiences, the visual world underwent a reversal to conform with the gravitational upright and the central nervous system integrative mechanisms, continuously ensuring spatial orientation, constitute an elegant example of homeostasis.

It is necessary to keep in mind the evolutionary manner in which orientational homeostasis was acquired properly to appreciate how and why it is disturbed when man extends his natural abilities by artificial means. In adapting to these new force environments man at once reflects his habituation to specific natural terrestrial conditions, and the plasticity which characterizes his central nervous system. The conditions of aerospace flight have presented the greatest orientational problems for the following reasons; 1) man is operating in three dimensional space; 2) he may be exposed to a variety of force environments differing in magnitude and patterning of forces; 3) the transitions are usually abrupt, leaving little time for adaptation; 4) the forces may have injurious effects, and 5) the awareness of a possible abort poses a hazard ~~(1-3).~~.

Functional disorders may be a consequence of exposure to unusual force environment, including mental confusion, disorientation, illusory phenomena, motion sickness, and neuromuscular disturbances, including ataxia. Man's ability to cope with these disorders is determined by many factors which fall into different categories including 1) inherited characteristics, 2) the acquired functional central nervous system integrative patterning, 3) the ability to intellectualize the orientation task and deal with symbolic information, 4) the mental and physical demands of the operational task, other than orientation, and 5) the specific characteristics of the unusual force environment.

In approaching this problem from the operational standpoint the objectives are accuracy in predicting man's responses in gravitoinertial force environments to be encountered, definition of tolerance limits in terms of comfort, functional disorder and pathological change and validation of countermeasures. This represents an enormous undertaking due in no small part to the difficulty or impossibility of stimulating different force environments in the laboratory and, even when possible, the difficulty in providing small controlled incremental changes in strength of stimulus. Some of the investigations will have to be conducted under flight conditions despite the constraints due to cost and the many other disadvantages recognized as belonging to field laboratories.

In delimiting the subject matter for purposes of this report, attention will be focussed on some of the problems involved in spatial orientation which have occupied many investigations in our laboratory over a long period. The first part will be in the nature of a review, followed by a discussion centering mainly on disturbances which may be experiences in weightlessness and in rotating orbiting spacecraft.

POTENTIAL TOXIC HAZARDS IN SPACE FLIGHT

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The toxic effects of radiant energy, including the effects of ionizing radiation, microwave, ultraviolet, visible and infra-red light are being discussed by others. For this reason, this discussion will limit itself to the toxic effects of material substances, expecred to be encountered, in space travel. The subjects to be discussed are outlined below. It is assumed that we are dealing with space flights of six months or longer duration.

I. The Atmosphere of the Space Ships:

A. Particulate Matter (Solid)

1. Mechanical Effects:

These effects include skin and eye irritation, irritation to the intestinal and pulmonary tracts. They include irritation from material such as cotton, wool, animal hair, certain synthetic fibers and particles of proteinase nature including bacterial debris. They also include particles from food and excreta. In a weightless environment any of these particles may become atmosphere born. If particular importance are particles produced by wear due to friction. Chronic irritation, by the clothes worn by the astronaut is also a potential hazard. Decomposition of plastics and fragmentation must also be considered.

2. Allergic Response: In long range flight, allergy can develop to any of a host of substances included in (1) mentioned above. Chemical allergy is common in the chemical industry and the constant handling of certain materials can also result in allergy. Mercury is a particular offender and allergy to mercury is common.

B. Gaseous Composition:

1. Oxygen: The range of oxygen partial pressures tolerated by man, for extended periods of time, is rather narrow. Long-range experiments indicate toxic symptoms even at PO_2 levels as low as 174 mm of mercury as compared to 150 mm, at sea level, normally. Toxic symptoms appear at levels 110 mm of mercury typical to chronic hypoxia, for short periods of time, less than a few days, levels of the order of 400 mm of mercury have been tolerated. Symptoms of high oxygen pressures include substernal distress, syncope, pulmonary irritation, convulsions,

general malaire and fatigue. Enzyme inhibition results in deterioration of the overall metabolic process.

2. Ozone: Ozone is produced whenever oxygen is irradiated by ionizing radiation including ultraviolet light and low potential discharge. Thus, ozone produced in space travel becomes a potential significant hazard. Ozone in air, at levels higher than 0.1 ppm, becomes significant in long range flight. The toxic effects of ozone simulate that of high oxygen concentration levels. Some of the toxic effects of ionizing radiation are due to ozone formation.

3. Carbon Dioxide: High concentrations of carbon dioxide result in acidosis and the attendant sequellae. Early symptoms of carbon dioxide intoxication are headache, drowsiness and decreased efficiency.

4. The Inert Gases: The presence or absence of the inert gases particularly, nitrogen and their effect on the well being of the individual in long range experiments is controversial. One obvious effect of the absence of any inert gas is the fact that if the individual holds his breath for a period of time (e.g., 2-3 minutes), there is danger of lung collapse since a certain volume of gas is needed to keep the alveoli distended. Nitrogen, helium, neon and mixtures of these components have been suggested and tested.

5. Carbon Monoxide: The major danger of carbon monoxide intoxication is decreased efficiency of the individual, since high levels are not anticipated. Above 20% of hemoglobin saturation with carbon monoxide there is danger of death. At levels below 4%, hemoglobin saturation the levels can be tolerated. Such levels are often reached by heavy smokers. Carbon monoxide occurs in small amounts in normal exhaled air. It can also be produced in the space capsule by ionizing radiation or high temperatures acting on any organic materials such as plastics, oils, foods, etc.

6. Other Gases to be Considered:

a. Hydrogen sulfide and oxides of sulfur are a distinct probability of atmosphere contamination during space travel. Materials on the spacecraft such as rubber contain a relatively high percentage of sulfur. Degradation of food and from flatus ones obtain the sulfur containing gases. For H_2's the upper limit of tolerance is 20 pp.m. Toxicity at low concentrations is mainly due to combination with hemoglobin and the cytochromes.

b. Fluorine and Compounds of Fluorine: Because of the use of Teflon and related plastics, in numerous components of the space capsule, one must consider the results of their degradation. Teflon softens at 250°C and above that temperature degradation products appear. Ionizing radiation also degrades teflon at low temperatures. Thus, the danger of fluorine contamination of the atmosphere is a real one. Freous are also fluorine compounds and must be considered as potential toxic agents.

Fluorine in the atmosphere is toxic above the 0.1 ppm level.

c. Gases from Flatus: The volume of flatus varies from 500 (± 50%) milliliters per 24 hours in the normal adult. The lower volume is associated with a milk diet and the higher volume with a legume diet. The composition varies and generally consists of: - CO_2 - 8 - 34%; methane - 0-56%; hydrogen 1-4%; and nitrogen 10-64%. Other components such as H_2's, skatole and metabolism intermediates exist in small and variable concentrations. The higher percentage of combustible gases which may accumulate in a confined space represents a fine hazard, but not necessarily a toxic hazard. The precummulation of even small amounts of such intermediates as cadoverine or putrescine from bacterial decay in the intestine does represent a potential toxic hazard.

d. Other Gases: Chlorine is a toxic above the 1 ppm level. Generation by electrolysis from sodium chloride can possibly occur and must be considered. Decomposition of chlorine containing organic compounds such as in certain plastics (e.g., tygon, Kelef, etc.) are a distinct possibility.

Cyanide formed from nitrogen and carbon by ionizing radiation needs to be considered. Human tolerance is up to approximately 10 ppm in air. However, these observations are made for short periods and long range effects will probably simulate carbon monoxide poisoning. Cyanide inhibits the cytochrome oxidase system.

Metalic compounds such as of zinc (15 ppm toxic level), and copper (15 ppm toxic level) must also be taken into account. Beryllium, used in numerous components of the aircraft is of such high toxicity that the minimum acceptable concentration of this material should be below the level of detectability. Mercury and other heavy elements should not be present above the 1 ppm. level in the atmosphere. Although these heavy elements can be tolerated at higher levels for short periods of time, their effect is cumulative and this must be considered in long range flight.

e. Aerosols: Aerosols comprise fine suspensions of liquids, such as water or oils, which serve to act as solvents for chemicals, such as N_3, acids, alkalis, alcohols and other substances. Since particles readily suspend in the weightless state it becomes apparent that aerosols are formed more readily in space flight than under the influence of gravity.

Much of the "smog" in contaminated areas on earth may be classified as aerosols of irritating chemicals derived from factory or automobile exhausts. Any regent or liquid medicinal carried on board is capable of forming an aerosol when the container is opened. The fine suspension of water serves as a solvent, in addition, for the decomposition products of organic materials, such as plastics, on board. It can serve also to increase the hazard of toxic substance in the atmosphere by dissolving and thus concentrating them. Toxic effects from single eye irritation to systemic intoxication must be considered. Allergic manifestations are also distinct probabilities.

II. Drinking Water:

1. Particulate Matter; Mechanical effects are the major probelm which may develop. Spicules of fiber glass from degradation of the water tanks, if used, or plastic or metal particles would all serve as mechanical irritants to the intestine tract.

2. Soluble Contaminants: Any of the elements, considered toxic may contaminate the water supply. Those include mercury, thalluim, bismuth, cadmium, beryllium, arsenic, antemony, silver, copper, lead, fluorine, zinc, and others depending upon the metals carried on the spacecraft the composition of the water tanks, filters and purification equipment. Bacterial contaminants must also be considered. If a recycling process includes ion exchange, then one must consider the efficiency of the ion exchange system in removing these and other contaminants. Generally, a level of 0.1 ppm. of these elements should not be exceeded. For elements like sodium, chlorine, calcium and magnesuim, these should be kept to a minimum although concentrations as high as 100 ppm, can be tolerated even for magnesium for long periods of time. Concentrations of other soluble contaminants such as sulfur compounds (H_2s, SO_2) can serve as a hazard if present in excess of 10 ppm.

III. Food:

1. Organic Substances: Since the food intake will be largely of dehydrated natural foods, the hazard exists of the intake of toxic amounts of insecticides from fruits, and vegetables. Certain foods such as chicken and meat products are produced under the stimulating effect of certain hormone preparations. In dehydrated form, it is possible to consume larger amounts of a particular chemical than would be consumed of the hydrated product. Thus, such a hazard exists in long range flights.

2. Inorganic Susbstances: Ingestition of the elements listed would produce toxic symptoms in excess of the levels indicated. In mg/24 hrs. the maximum acceptable limit for certain elements is as follows: antemony 0.5, arsenic 0.6, lead, 2.5, mercury 1.0, cadmium, 0.5, beryllium 0.1, cyanide 1.0, fluorine 3.0, thallium 0.5. Any of these elements will produce acute symptoms at relatively low dosage. For example, if 10 mg of cadmium is ingested at any one time toxic symptoms are observed. Some of these elements like thallium or lead will affect the central nervous system. Mercury is particularly injurious to the kidneys. Atemony and arsenic will interfere with normal metabolism by inhibiting normal oxidative phosphorylation, in addition to the gastritus observed when a large dose is taken. Fluorine inhibits glycolysis and lipose activity. In general, these elements inhibit metabolism and even in small amounts will result in a decrease in the number of erythrocytes resulting from an aplastic anemid.

3. Radioactive Elements: If experiments are carried onboard. using radioactive substances the hazard exists in ingesting them contamination

with the hands or surfaces of the capsule. The toxic effect of most of these elements, depending upon their half life, is essentially the same as receiving a continuous dose of irradiation externally. The toxicity will vary with the type of emission, activity and half life of the isotope.

IN-FLIGHT MEDICAL EXPERIMENTS

S. P. Vinograd, M.D.

I. GENERAL PRINCIPLES

A. Incremental approach is method of NASA Manned Space Flight to Determine feasibility of prolonged manned flight.

B. Two purposes of in-flight medical information:

1. Medical safety in-flight (mission at hand)
2. Determine effects of space flight (future missions). Primary purpose of in-flight medical experiments.

C. Experiments must be:

1. Valid
2. Reliable
3. Technically and Operationally feasible:

(a) Technical (engineering) constraints

Examples:

(1) Volume

(2) Weight

(3) Power

(4) TM Requirements

(5) On-Board recording requirements

(6) Long Lead Time

(b) Operational Constraints:

Examples:

(1) Time

(2) Non-Interference with Astro freedom of motion

(3) Non-Interference with other Mission Objectives

(4) Ease of Performance

(5) Ground Support Requirements

D. Medical Problems Requiring Experiments:

1. Stress Factors

(a) Prolonged Weightlessness and Combinations of others with it are only ones that cannot duplicate terrestrially.

(b) List of Stress Factors of Prolonged Flight (Barring Launch)

(1) Weightlessness

(2) Ionizing Radiation

(3) Confinement

(4) Social Restriction

(5) Monotony

(6) Threat of Danger

(7) Artificial Atmosphere

(8) Toxic Substances

(9) Particulate Contamination of Atmosphere ("Floating" Particles)

(10) Micro-organisms

(11) Change in Circadian Rhythms

(12) Magnetic Fields

(13) UV Light

(14) IR Exposure

(15) Noise

(c) All except weightlessness and combined effects can be investigated on ground - once measured.

2. Stress Effects on Man:

(a) Most important (present status)

(1) Cardiovascular Deterioration
(2) Bone Demineralization
(3) Muscle Atrophy
(4) Dehydration

Phenomena of Disuse

(b) Other important effects possible:

(1) Hematologic
(2) Respiratory
(3) Vestibular
(4) Metabolic
(5) Peristaltic
(6) Ciliary
(7) Alertness
(8) Performance

(c) Disuse phenomena a potential problem on return to G environment primarily

E. In-flight medical experiments objectives:

1. Operational purposes:

(a) Determine human effects of prolonged space flight
(b) Mechanisms of Effects
(c) Means of predicting on-set and severity
(d) Means of prevention and/or remedy

2. Scientific purposes:

F. Method - Comparison of In-Flight with Baseline Data

1. Sources of Baseline Data

(a) Astronaut Selection, Medical Surveillance, and Training Procedures

(b) Ground Based Studies (Non-Astronaut Subjects)

(1) Bed Rest Studies

(2) Studies Validating Methods and Hardware

(3) Stress Studies (Subjects Instrumented During Stressful Activity)

2. Purposes of Baseline Data

(a) Control for Comparison of In-Flight Data

(1) To determine validity of observed changes

(2) To distinguis space flight factor as cause of observed change

(b) Validity of Measurements and Methods Planned for used in flight

(c) Establish normal range of responses to stress

II. MERCURY PROGRAM

A. Medical Measurements - Project Mercury

1. Safety Medical Monitoring

(a) Temperature

(b) Respiration

(c) ECG

(d) Blood Pressure

2. Medical Experiments

   (a) Xylose Absorption

   (b) Calibrated Exercise

   (c) Tilt Table - Flack Test

   (d) Urinary Calcium Output

   (e) Hormone Assays, Steroids, Adrenalin, Catechol Amines

   (f) Radiation Dosimetry

B. Medical Findings - Project Mercury

1. Cardiac Arrhythmias (Physiological)(Critical Periods)

   (a) Ectopic Beats

   (b) Tachycardia

2. Transitory Circulatory Change (weightlessness not proven cause)

   (a) MA-8, mottling of skin and venous distension of ankles

   (b) MA-9, near syncope, reduced tilt table tolerance

3. Dehydration

4. Norepinephrine Reduction (needs confirmation)

5. Reversal of Neutrophile-Lymphocyte Ratio Post-Flight MA-9, cause unknown, probably not significant

6. Negative Findings: Calcium Excretion, Xylose Absorption, Calibrated Exercise.

III. GEMINI PROGRAM

A. Safety Medical Monitoring same as Mercury; Equipment Improved

B. In-Flight Medical Experiments

1. M-1 Venous Cuffs; Preventive Measure

2. M-2 Tilt Table and Fluid Compartments (now operational procedure)

3. M-3 Calibrated Exercise

4. M-4 Phono-Electrocardiography

5. M-5 Hormone Assays

6. M-6 X-ray Densitometry

7. M-7 Calcium and other Electrolyte Balance

8. M-8 In-flight Sleep Analysis (EEG)

9. M-9 Otolith Function

C. Processing of Proposed In-Flight Medical Experiments in Manned Space Flight

1. Space Medicine Division
   (a). NIH Study Sections
   (b). Medical Advisory Council (Scientific Evaluation)

2. ECB

3. MSC, Houston (compatability evaluation)

4. MSFEB

IV. ORL STUDIES - SPAMAG

A. Method - Format

1. Three Phases

   a. Support of Crew

   b. Medical Experiments

   c. ORL Design and Operations Recommendations

2. Final Product Including Recommendations for:

a. Prerequisite Space Flight Experiments

b. Prerequisite Ground Based Experiments

c. Prerequisite R&D

B. Importance of SPAMAG Study

1. Assist Design of ORL

2. Assist Formulation of Over-All Medical Experiments Program.

V. APOLLO PROGRAM

A. Three categories of Medical Experiments:

1. Define Environment, Intra- and Extravehicular, and Lunar (i.e., Man Made and Natural)

2. Determine Human Response

3. Test Evaluative Techniques Considered for Future Programs

B. Presently Planned Apollo In-Flight Medical Experiments

1. SA 204 - First Manned Apollo

2. SA 205 - Second Manned Apollo

C. Lunar Surface Medical Experiments - Present View

VI. APOLLO APPLICATIONS PROGRAM

A. General

B. Medical-Behavioral experiments; dual approach

1. R&D Program

2. Proposed experiments - Scientific community

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GROUND BASED STUDIES

The ground based studies are part of the space medicine program. Within this frame they have their own specific function and this is indicated in Table I.

TABLE I

GROUND BASED STUDIES

PURPOSE:

1. To study the effect of the space environment (earth simulation) on the astronaut.

2. To determine monitoring requirements and needs of protecting the astronaut.

3. To develop monitoring methods and protective devices.

4. To evaluate monitoring methods and protective devices.

5. To provide baseline data for evaluation of in-flight observations in the fields of anthropometry, physiology, and psychology.

6. To prepare the astronaut for spaceflight by exposing him to simulated space stress and familiarizing him with the mission's tasks and problems.

7. To supplement, extend, and verify in-flight observations.

8. To check out complete systems or subsystems (space suits, life support system).

If it is one of the major goals of the ground based experiments to supplement and extend in-flight information, we need criteria for selection of experiments and of suitable experimental approaches, and for interpretation and evaluation of results. This is the purpose of Table II.

TABLE II
COMPARISON OF GROUND BASED STUDIES WITH IN-FLIGHT EXPERIMENTS

ADVANTAGES:

No limitation of weight volume and power.

Chance of using large number of subjects, animals or plants (statistical significance).

Use of bulky equipment may increase sensitivity and reliability of measurements.

Possibility of increasing the variety of measurements and the frequency of data collection.

Availability of experts in many fields.

Possibility of using delicate procedures like intra-arterial measurements in man and surgery in animals.

Ease of scheduling.

Low cost.

No hazard to subject.

DISADVANTAGES:

Simulated instead of true space environment.

Lack of motivation.

Absence of hazard factor.

Difficulty of getting adequate data on astronauts or equivalent.

These two tables indicate what can be done and what cannot be done by means of ground based experiments. In addition we have to identify the problems that have to be solved. For this we use a matrix system plotting 58 environmental factors against 142 physiological and psychological functions. The 8236 intersections are then rated as to:

1. Critical for Apollo Mission.

2. Not critical for Apollo but possibly for future manned space flight.

3. Notcritical.

4. Unknown.

The utilization of this matrix approach is indicated in Table III.

TABLE III

IDENTIFICATION OF PROBLEM AREAS   STORAGE AND RETRIEVAL OF INFORMATION

Use of matrix approach by plotting the space-environmental parameters against the physiological and psychological functions.

a. Systematic approach assures that all possible problems will be considered.

b. Matrix provides a framework for collection and integration of existing information.

c. Storage of information for easy retrieval of information on individual effects or large fields.[1]

d. Identification of loopholes of information requiring further research.

e. Identification of problem areas.

f. Utilization of rating of intersections as a means of scheduling ground based studies according to mission requirements.[2]

g. Establishing a framework suitable for integrated presentation of many types of medical problems (normal ranges, sports physiology, industrial hygiene).

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1. (U.V. radiation and visual acuity)(environmental temperature and work performance)
2. (1 = Apollo 2 = Apollo Applications 3 = Lunar Shelter 4 = Mars Mission)

In manned space flight we are not only interested to find the tolerance limits under various environmental stresses, but we would like to know also when the performance of the astronaut will be significantly affected. Therefore, we are trying now to use a three dimensional matrix with mission phases and mission tasks as the third dimension. Dr. McFarland will discuss this work in greater detail.

A MODEL FOR THE SOCIAL SYSTEM FOR THE MULTIMAN EXTENDED DURATION SPACE SHIP *

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ABSTRACT

The conditions of isolation, confinement, and other stresses to which extended duration space crews will be exposed are unprecedented and many of the problems are not yet understood. Hypotheses directed toward principles to optimize crew organization and adaptation must be generated from present knowledge. Extrapolations might be attempted from various literature sources of human experience in extreme situations. However, the appropriateness of such generalization depends on the system similarity of the various situational contexts to that of the spaceship. A model social system for such microsocieties was constructed and system profiles of [illegible] well known system patterns were compared with that postulated for the extended duration spaceship. Greatest similarity was found for submarines, exploration parties, naval ships and bomber crews, and least for shipwrecks and disasters, industrial work groups, and prison groups.

INTRODUCTION

This report is part of a research program undertaken in anticipation of a need for behavioral science principles related to crew adaptability in the microsociety of extended duration space missions. Current analyses by space scientists at Boeing (1965), Douglas (1965) and General Dynamics (1965) of the timetable for manned flights to Venus and Mars estimate the earliest flyby of Mars between 19[illegible] and 1977 and landing between 1982 and 1986. It is apparent that the conditions of confinement, isolation, and stress to which these crews will be exposed, during flights of one to three years duration, are unprecedented and that the problems involved are as yet not clearly understood. The lead time is not great and these problems must receive immediate attention to provide adequate opportunity for the research and development that will be required.

The present study is an attempt to understand and formulate the group behavior problems applicable to the extended duration space mission. It is concerned with group organization, structure, and interpersonal interaction of crew members in the environmental circumstances of a typical mission. The approach is to attempt to formulate a set of principles of social structure and group behavior as hypotheses for further research, using present knowledge as a point of departure. To maximize the application of present knowledge, it has been planned to supplement reviews of relevant literature with consultation with selected social scientists and experienced personnel in related situations.

Preliminary Exploration

One of the first steps in this study involved correspondence with a carefully selected panel of over 200 distinguished social scientists chosen on the basis of expertise in some aspect of the overall problem. They were sent a summary of the project objectives, approach, and procedures, and were asked to suggest significant problem areas, relevant literature, and ideas that might, in their judgment, pay off. This correspondence elicited overwhelming approval of the undertaking, without exception, from the entire panel, and a wide range of suggestions in response to the questions raised.

After reviewing and summarizing the suggestions, however, it became apparent that some definite criteria were needed to judge the relevance of data based on various situations, ranging from laboratory experiments to hazardous field observations, to the problems of the extended duration space ship. Such criteria in effect imply a conceptual model of the social system of the space ship microsociety.

Model definition was implicit in the discussion of constraints expected in the space ship situation that was presented in the summary memorandum referred to above. Among the probable features of this situation, the following were mentioned:

1. A formal organization with prescribed responsibility patterns for the entire crew;
2. Crew composition characterized by an elite corps of highly selected, trained, and educated volunteer specialists, all extremely ego-involved in the program and the mission;
3. Low organizational autonomy as a result of the NASA organizational and operational system and the affiliation of crew members with military and civilian career services;
4. Low formally prescribed status distance among crew members; and
5. High task demand and mutual dependence, under high levels of isolation, confinement, limitation of mobility and privacy, and environmental threat.

These constraints are believed to be correct, but

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although they point out several important characteristics of the space ship social system, they fall short of specifying the model. Further speci[illegible]ion is attempted in this paper.

The Literatures on Isolation and Stress

An obligation of scientists approaching the present problem is to review critically available records and literatures on human experience in stressful, isolated, and confined situations in order to extrapolate significant observations, at least as hypotheses, to the situation of the extended-duration space ship. However, the literature in this broad category is vast and varies widely in relevance. Among the potential sources of information that have been suggested by consultants or staff members are field studies, participant accounts, and historical documents of incidents concerning naval ships, submarines, aircrews, prison populations, mental hospital populations, personnel at remote-duty radar sites and work parties, industrial work groups, athletic teams, exploration parties, personnel in air-raid shelters, shipwrecks, disaster situations, POW camps, and a variety of related situations that have received attention because they emphasized some unusual aspect of crisis, hazard, confinement, isolation, small-group process under stress, or the like. The problem of generalization of observations from such diverse situations is a major one which has received little systematic consideration by social scientists, who have apparently been more interested in particular aspects of behavior selected for study than in the contextual and systems aspects of the situations in which the behavior occurred.

The importance of this issue may be illustrated by an example. Consider for instance the difference between the effects of prison confinement of convicted criminals, of hospital confinement of mental patients, of confinement during depth bombing of a trapped submarine crew, and of confinement of a space crew in a capsule on a 500-day mission. The obvious differences, in intellectual and social level of the different groups, their motivation and identification with the situation, the conditions of confinement, the nature and acuteness of the stresses endured, the group solidarity, their training and preparation for the experience, and the payoff to individuals and group for successful endurance of the confinement, require little comment. In our opinion, variations among other relevant variables, such as those enumerated, may be of greater magnitude than that of the common, but by no means identical, variable, confinement.

Unfortunately, such is the nature of the literature available as background for the study of this new social situation in which isolation and confinement appear to be prominent conditions. However, these must be considered not only as particular aspects of a complex, multidimensional social system, but also in relation to other significant dimensions of the system. Despite the attention they have received, it appears that recognition of these variables as primary foci of the problem would be oversimplification.

DIMENSIONS OF THE MODEL

A distinction must be made between the broad dimensions of different types of social situations in which men have faced extreme environmental hazard and the modes of interaction exemplified in their behavior. In the former category, which is the focus of the present analysis, are such factors as group size, membership composition, organization, types of goals, sites of activity, equipment, skills, authority, and the like. The latter includes interpersonal behavior, leadership style, factors promoting or interfering with member motivation, and other principally behavioral aspects of group functioning. For purposes of clarity in communication we shall designate the first category by the term system structure of the microsociety, and the second, behavior patterns. In some cases, group behavior patterns may be highly standardized and appear as dimensions of structure.

In a perceptive report on the American Mount Everest Expedition, Emerson (1964) identified a number of aspects of the system structure of the Expedition as a means of facilitating the generalization of his results to a related class of group undertakings. Particular attention was directed in this report to three structural factors: (a) group size, (b) pursuit of group goals for which success or failure can be empirically defined, and (c) probability of success uncertain. Other factors, such as membership preselection and composition, sites of activity, equipment, skills, and authority involved were implicit in the identification of the Expedition. Such description of the setting in which certain behavior patterns were observed places these behaviors in a context of social structure in which the relevance of important constraints imposed by the system or particular system requirements can be evaluated. Generalization across contexts would be greatest when system characteristics are most similar. As similarity decreases, it is necessary to evaluate the effects of the variations observed.

The aim of this discussion is to propose a standard set of system structure characteristics that could be applied generally as a means of ordering various microsocieties according to their similarity to each other. This preliminary effort does not consider the weight or relative importance of particular characteristics to various systems or the variations among these over time or in different system states (confrontation with different problems). Some inferences on these issues are logically apparent and some information is available in the literature. However, the studies are scattered and do not fit into a uniform taxonomy. It is possible that the present attempt may have heuristic effects on needed studies of this type.

The system description involves seven categories that have general relevance. These are:

I. Objectives and goals
II. Philosophy and value systems
III. Personnel composition
IV. Organization
V. Technology
VI. Physical environment
VII. Temporal characteristics

Each of these categories involves important factors which can be ordered to some extent on continua conducive to comparative analysis.

Objectives and Goals

Several aspects of the objectives and goals of social organizations are more properly treated under category 4, organization. These relate to the degree of formal structure and involve consideration of whether they are officially specified and published or implied, whether they are mandatory or voluntary, and the nature of the authority under which they exist. In this section, the aspects of concern are the following:

Polarization. This reflects the extent to which an organization is goal oriented with respect to one or more major goals of importance to its sponsors and members. The space organization is highly polarized in both programs and projects, with clearly defined, announced goals.

Remoteness. This aspect refers to the time required between initiation of an activity and goal attainment. As the space program progresses, remoteness of overall goals is decreased, but duration of individual missions tends to increase, making their particular goals more remote.

Success Criteria. The criteria of success in goal attainment may vary from confusion and ambiguity, in the case of certain types of organizational goals, to clearly defined, measurable events or dimensions. Space mission goals have generally involved specific, measurable criteria, but some ambiguity may be pointed out in the assignment of credit. It has appeared, at least in the public press, that a greater share of credit is due to the planners and directors whose training and guidance was followed so skillfully by the astronauts in flight.

Success Uncertainty. An important consideration in any group enterprise involves the amount of uncertainty of mission success, both objectively and as perceived by the participants, and the objective and perceived consequences of failure. Despite the phenomenally successful record of American manned space missions to date, they may all be objectively characterized as involving high risk. The superb planning, provision of "backup" systems, testing, training, and overall preparation for successive missions has undoubtedly reduced subjective risk and increased confidence in the Mercury and Gemini programs. Nevertheless, new programs, such as Apollo, MOL, and Mars, bring new problems of unknown and known hazards to be faced and both objective and subjective uncertainty may be expected to fluctuate as new programs and missions within programs are activated.

Philosophy and Value Systems

The aspect of organizational philosophy of most general interest in the present context involves the values accepted with respect to the relative importance attributed to alternative goals and alternative means, costs, and risks related to the attainment of the preferred goals. With the exception of formal religious organizations, the governing value systems are rarely available in documentary form, but must be inferred from a variety of sources, such as the record of critical decisions made, key appointments, speeches and directives (as well as selected correspondence) by key officials, and the like. Such a study of NASA and related official values with respect to the space program would be valuable in the context of the present study. In its absence, the following speculations are tentatively proposed:

First, the operations of the American space program appear to continue the tradition of American military aviation with respect to command structure, mission emphasis, respect for individual lives, and cost-risk decisions.

Second, the American government has until now given the space program a very high priority and has placed virtually all of its facilities at the disposal of the space agencies for effective support.

Third, the astronaut value systems appear to reflect those of American military airmen, in character, motivation toward mission, family, and personal goals, professional attitudes and identifications, and of the traditions of American culture with respect to religious, moral, political, and social philosophy.

Personnel Composition

To the extend that the intellectual, motivational, personality, educational, professional, and moral characteristics of its members affect the functioning of an organization, both by the constraints implied by interaction of these with other factors, the limitations or specifications of the organization with respect to such characteristics constitute an important dimension.

More specifically, this category may be examined with respect to the upper and lower limits of intellect, education, training, experience, specified personality and moral characteristics, motivation of members to participate, dedication to mission, physical requirements, required skills, age range, sex, marital and parental status, religious background, and the like. This inventory might properly include the entire range of individual differences and demographic characteristics. However, in the present context, it is believed that most of the relevant factors have been enumerated. The well-known bases of astronaut selection have, at least thus far, proved successful, although it is not possible to examine many of the criticria critically. To date, the astronaut group has been drawn, first from a select group of military test pilots with extensive jet experience, and more recently from a more heterogeneous group of men with this or other relevant scientific training. In all cases, intellectual, motivational, emotional maturity, moral, educational, and physical standards have been exceptionally high.

Organization

It is necessary to examine organizational structure in terms of the degree of formal structure involved, organizational complexity and formal provision for authority, decision-making and direction (command). These considerations involve centralization of authority, sanctions permitted, provision for succession, chain of command, and the power and role structure. Other factors include autonomy, control of member behavior by the organizational authorities, degree of participation of members in organizational activities, and degree of stratification of ranks or echelons.

The question of authority brings in formal documents, such as constitution, laws, directives, and the like, which may specify objectives and goals, as well as the limits of authority assigned to various offices and roles.

Although the organizational characteristics of the Mercuty and Gemini programs and space crews can be fairly well described, certain changes may be expected in extended-duration missions as a result of their duration and isolation, concerning which decisions must be made, to which it is hoped the present study may contribute. The organizational patterns of the Mercury and Gemini programs, with respect to overall structure as well as crew organization resemble closely those of military aviation, with much of the command responsibility held by ground command. However, in the Mars mission and other extended-duration efforts, there are grounds for expecting the transfer of much authority to the spaceship commander, and with this, problems of assuring integrity of command in the isolated space ship become acute. Another factor, which probably belongs in this category, is the size of the organization, in terms of the number of participants required to perform the central tasks.

Technology

It is almost meaningless to discuss organizational behavior without taking account of the nature, complexity, characteristic operations, and traditions implied by the technology involved. The technology not only makes distinctions, such as between jet aviation and the earlier piston-propeller era, which involve differences in speeds, altitudes, schedules, and pay-load, but also between personnel types, traditions, training, and other significant factors associated with the respective technological fields. The technology of the space programs is new, although it follows the aerospace tradition. Among the peculiar aspects are the overwhelming significance of intensive training in anticipated emergencies as a means of insuring reliability of performance, the high level of training, experience, and skill required of crew members, the glamor associated with astronaut status (at least until the present), and the high risk associated with the very masculine (in the United States) astronaut role. The space technology has created new jobs, new vocabulary and technical jargon, and is currently regarded as one of the frontiers of human advancement. The type and extent of training and preconditioning provided participants are related to this section.

Physical Environment

Among the significant characteristics of various social systems are the distinctive features of their task environments, which have implications for the level of risk involved and the nature and magnitude of stresses encountered. The space environments are principally two, the space medium, which is unfriendly and hazardous to man, and the space ship and equipment which protect him and provide a supportive environment that enables him to endure in space. In extended duration missions, with the enforced isolation and confinement of groups of men from 8 to 12 in number for periods up to 500 days or longer, the protective capsule itself may be a major source of social stress, compounded by the period of time during which crew members must share the unnaturally confined quarters as work, living, recreational, and quasi-personal space. Here, again, is an unprecedented experience for man, with only fragmentary sources from which to extrapolate estimates of needs and reactions.

Several additional aspects of the physical environment, which are also related to the technology, involve the distinctions between a maneuvering operation and a static environment, between extended exposure to embedded, but not intrusive stresses and occasional, insidious exposure to highly threatening conditions, and between organizations that plan and prepare means of coping with the hazards expected and those that are caught unprepared. It can be stated that the space ship is a maneuvering group, exposed to embedded, but not intrusive stresses over long periods, whose preparations for coping are exceptionally thorough and, until now, effective.

Temporal Characteristics

So far as is known, the Mars mission and others of its general class involve continuous exposure to stress for human groups of an unprecedented temporal magnitude. Further, the capsule environment fits the description of a total environment (Goffman, 1957), in which enforced assocation is continuous and without the respite of discontinuity afforded man in his accustomed habitat, in which he enjoys discontinuities of a tension-relieving quality when he moves from home to work to lunch, and so forth, in his daily life. An effect of the total environment, which may be mitigated to some extent by scheduling and by the provision of opportunities for privacy and solitude, is the magnification of interpersonal stresses generated by the enforced close contacts.

COMPARISON OF TWELVE SOCIAL SYSTEM PROFILES

On the basis of descriptive information on their generic characteristics in the literature, an attempt has been made by the writer to compare fifty-six reputed system characteristics of the extended-duration space ship with those of eleven other reference systems, each of which involves isolation, confinement, and/or stress to a high degree, and for which there is substantial information in the literature. These are:

1. Exploration parties and expeditions
2. Submarines
3. Naval ships
4. Bomber crews
5. Remote duty organizations (e.g. radar sites)
6. Professional athletic teams
7. Industrial work groups
8. Shipwrecks and disaster situations
9. Prisoner of war groups
10. Prison society
11. Mental hospital wards

The fifty-six system characteristics are subsets of the seven major categories described in the preceding section and are listed in the margin of Table 1. Taken as a whole, they constitute a preliminary effort to develop a system profile of significant aspects of a miniature social system. The entries in Table 1 represent comparison ratings of similarity to the condition of the extended duration space ship on each factor for each of the eleven comparison systems selected. Thus each column in Table 1 is presented as a system profile.

The entries in Table 1 are on a three-point scale: 2 (highly similar to the extended-duration space ship situation), 1 (moderately similar), and 0 (dissimilar or unrelated). These were inserted according to the judgment of the author on the systems compared. A maximum similarity score, for the 56 items, would be 112; scores could range from 112 to 0.

The data in Table 1 rank the eleven comparison systems on similarity to the extended duration space ship as follows:

Systems	Similarity Rank	Similarity Score
2. Submarines	1	79
1. Exploration parties	2	68
3. Naval ships	3	61
4. Bomber crews	4	60
5. Remote duty stations	5	59
9. POW situations	6	39
6. Professional athletic teams	7	37
11. Mental hospital wards	8	23
10. Prison society	9	20
7. Industrial work groups	10	16
8. Shipwrecks and disasters	11	11

Table 2 is interesting in that it indicates areas of similarity and dissimilarity among the eleven comparison systems with the space ship system by major category of comparison. Submarines are most similar overall, but match the space ship situation more closely in respect to goals, value systems, and organization, than on the other factors. POW situations, mental hospital wards, and prison groups are low in profile similarity, but are nevertheless high with respect to similarity of physical environment and temporal characteristics. In terms of overall closeness of fit, submarines, exploration parties, and bomber crews are most similar to the social system of the extended-duration space ship, while industrial work groups and shipwreck and disaster situations are most dissimilar. Nevertheless, it is of interest that the latter situations have been so frequently cited as significant literatures source for the present problem, without concern for the appropriateness of such generalization.

DISCUSSION

The foregoing analysis represents a preliminary attempt to compare the social system of the extended-duration space ship with several other types of social system that have been suggested as background sources for extrapolation of observations and generalization of principles. Although based on subjective judgment and on an unweighted and preliminary set of factors, the results demonstrate widespread differences among the twelve selected social systems compared, thus raising questions that invite serious concern about the utility to studies of the extended duration space ship problem of some of the most frequently suggested sources, as well as greater interest in others.

As a result of the favorable position of exploration parties, submarines, and naval ships (which would come out even more favorably if confined to the sailing ship era), several profitable historical studies of these literatures have been undertaken within our research group. The results of the present analysis also enhance the importance of certain contemporary studies, such as those of Emerson (1965) and Lester (1965) on the Mount Everest Expedition, of Weybrew (1963) and others in the submarine service, and of Gunderson and Nelson (1963) in the Antartic. Until adequate evaluation is made of the influences of variations in major system characteristics on behavior of groups and individuals in these groups, extreme caution is indicated in making generalizations from experimental and field observational results.

Table [illegible]. Comparison of Social System Profiles of Eleven System Patterns with that of the Extended Duration Space Ship. Comparison Syste[illegible] are identified as follows: 1. Exploration Parties and Expeditions, 2. Submarines, 3. Naval Ship[illegible]mber Crews, 5. Remote Duty Stations, 6. Professional Athletic Teams, 7. Industrial Work Grou[illegible] Shipwrecks and Disaster Situations, 9. Prisoner of War Situations, 10. Prison Society, 11. Mental Hospital Wards. Ratings indicate degree of simi[illegible]rity to the Extended Duration Space Ship social system on a three-point scale: 2 (highly similar), 1 (moderately similar), 0 (dissimilar or unrelated).

System Characteristics	Comparison System 1	2	3	4	5	6	7	8	9	10	11
I. Objectives and Goals											
1. Formally Prescribed	1	2	2	2	2	2	2	0	1	1	1
2. Mandatory	1	2	2	2	2	1	1	0	1	1	1
3. Formal Authority	1	2	2	2	2	1	1	0	1	1	1
4. Polarization	2	1	1	2	1	2	1	0	0	0	0
5. Remoteness of Goals	1	2	2	0	2	1	1	0	2	0	0
6. Success Criteria	2	2	1	2	0	2	1	0	2	1	1
7. Success Uncertainty	2	2	2	2	1	2	1	2	2	0	0
II. Value Systems											
8. Obedience to Command	1	2	2	2	2	1	1	0	1	0	0
9. Mission Emphasis	1	2	2	2	2	1	1	0	0	0	0
10. Respect for Indiv. Lives	2	2	2	2	2	0	1	0	1	0	1
11. High National Priority	0	1	1	1	1	0	0	0	0	0	0
12. Military Trad. in Pers. Attits.	0	2	2	1	1	0	0	0	2	0	0
13. Accept. of Amer. Way of Life	0	2	2	1	1	0	0	0	0	0	0
III. Personnel Composition											
14. Intellectual	1	1	0	0	0	0	0	0	0	0	0
15. Educational Level	1	1	0	0	0	0	0	0	0	0	0
16. Extent of Relevant Training	1	1	1	0	1	1	1	0	1	0	0
17. Extent of Relevant Experience	2	1	1	0	0	1	1	0	0	1	0
18. Personality Selectivity	1	1	0	1	0	0	0	0	0	0	0
19. Moral Selectivity	1	1	0	1	1	0	0	0	0	0	0
20. Physical Selectivity	1	1	1	1	1	1	0	0	1	0	0
21. Possession of Requisite Skills	2	1	1	1	1	2	1	0	0	0	0
22. Motivation to Participate	2	1	0	0	0	1	0	0	0	0	0
23. Sex of Participants	2	2	2	2	2	2	0	0	2	0	0
24. Age Range	1	1	0	0	0	2	0	0	0	0	0
25. Presence of Non-Crew Pers.	2	1	0	0	0	0	0	0	0	0	0
26. Rank distribution (all "officers")	1	0	0	0	0	0	0	0	0	0	0
IV. Organization											
27. Formal Structure	1	2	2	2	2	1	1	0	1	0	0
28. Prescribed Roles	2	2	2	2	2	1	1	0	1	0	0
29. Command Structure	1	2	2	2	2	1	0	0	1	0	0
30. Centralized Authority	1	2	2	2	2	1	0	0	0	0	0
31. Chain of Command with Provision for Succession	1	2	2	2	2	0	0	0	1	0	0
32. Extensive Back-up Organization	1	2	2	2	2	0	0	0	1	0	0
33. Low Autonomy re Goals	1	2	2	2	2	0	1	0	0	0	0
34. Group Size (8-12)	0	0	0	0	0	0	0	0	0	0	0
35. Prescribed Discipline	1	2	2	2	2	1	0	0	1	2	1
36. Low Prescribed Social Distance Among Crew	2	0	0	0	2	0	0	0	0	0	0
37. Congruency of Rank and Status	2	2	1	1	1	0	0	0	0	0	0

Table 1. Continued

System Characteristics	Comparison System 1	2	3	4	5	6	7	8	9	10	11
V. Technology											
38. High Technologic Complexity	1	2	1	1	1	0	0	0	0	0	0
39. Relation to Aviation Tradition	0	1	1	1	2	0	0	0	0	0	0
40. Use of Simulators and Other Technical Training Devices	0	1	1	1	1	0	0	0	0	0	0
41. Extensive Preparation for Missions	2	1	1	1	0	1	0	0	0	0	0
42. Use of Technical Language in Execution	2	2	1	1	1	1	0	0	0	0	0
43. Physical Preconditioning	1	1	1	1	0	1	0	0	0	0	0
44. Scientific Principles Involved	1	1	1	1	1	0	0	0	0	0	0
VI. Physical Environment											
45. Required Physiol. Protection and Life Support	1	2	0	0	0	0	0	0	0	0	0
46. Extreme Remoteness from Base	1	1	1	1	1	0	0	1	2	1	1
47. Presence of Unknown Environmental Hazards	2	1	1	1	0	0	0	2	2	0	1
48. Extreme Confinement in Capsule	0	1	0	0	1	0	0	0	2	2	2
49. High Endurance Demands	2	1	0	0	0	1	0	2	2	0	0
50. Reduced Communication	1	1	1	1	1	0	0	2	2	2	2
51. Social Isolation	1	1	1	1	1	0	0	2	2	2	2
52. Maneuvering Situation	2	1	1	1	0	1	0	0	0	0	0
53. Embedded Environmental Stresses	2	2	1	1	1	0	0	0	2	0	1
VII. Temporal Characteristics											
54. Long Duration of Exposure	1	1	1	1	1	0	0	0	2	2	2
55. Total Environmental Situation	2	2	0	0	2	0	0	0	2	2	2
56. Remoteness of Goals	1	1	1	1	1	1	0	0	2	2	2

Table 2. Analysis of System Similarties by Descriptive Category. The numbers 2,1, and 0 are used here to indicate similarity on the following basis: 2, for matching over 70 per cent of items in the category (Table 1); 1, for matching 31 to 70 per cent; and 0, for matching less than 30 per cent.

Comparison Systems	System Description Category: Objectives and Goals	Value Systems	Pers. Comp.	Organiz.	Technol.	Phys. Envir.	Temporal Chars.
2. Submarines	2	2	1	2	1	1	1
1. Explorat. Parties	2	1	1	1	1	1	1
3. Naval Ships	2	2	0	2	1	1	0
4. Bomber Crews	2	2	1	2	1	1	0
5. Remote Duty Stas.	2	2	0	2	1	0	1
9. POW Situations	1	1	0	0	0	2	2
6. Prof. Athl. Teams	2	0	1	0	0	0	0
11. Ment. Hosp. Wards	0	0	0	0	0	1	2
10. Prison Society	0	0	0	0	0	1	2
7. Industr. Work Grs.	1	0	0	0	0	0	0
8. Shipwrecks and Disasters	0	0	0	0	0	1	0

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Living Conditions and Standards in Multiman Spacecraft

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I. Frame of Reference

A. Dependence of "Living Conditions and Standards" on all other aspects of the space mission.

B. Objectives.
Mitigation of Stress
Skill Maintenance
Habitability
Group Effectiveness

C. Salient Considerations.
Multifactor Situations
Mission Characteristics, including duration, size of group (crew), prior experience, national interest and support, group psychology problems

D. Sources of Information.
Historical
Laboratory Studies
Field Experience

E. Research and Development Perspective.
Dynamic, Emergent Nature of the Problem
Relations Among Criteria; Selection of Criterion
Problems of Extrapolation and Generalization
Interdisciplinary Cooperation
Definition of Research Problems, Optimal Design Characteristics

II. Conditions Related to Effective Performance

A. Characteristics of Individual Participants (Individual Differences).
Health, Fitness, Aptitude, Training, Adaptation, Conditioning, Prior Experience, Motivation, Defenses Against Threat, Relations to Other Participants, Role, Relations to Task and Mission

B. Characteristics of Tasks.
Task Components: difficulty, load, homogeneity, autonomy, transferability, redundancy, risk, reward
Task Organization: relations to other tasks and to Mission

C. Characteristics of Environs (Micro- and Macro-environment).
Physical: Temperatures, Atmospheric Components, Noise, Vibration, Acceleration, Radiation, Zero-g
Social-Environmental (aspects of task and location) Isolation, Confinement, Task Load, Sleep-Rest, Privacy, Group Interactions, Mission Accomplishment (success-failure)
Psychophysiological: Fatigue, Diurnal and Other Cycles (Work-Rest organization), Nutrition, Adaptation, Acclimatization
Social: Formal Structure, Role Relationships and Concomitants, Responsibility Patterns, Interaction Patterns, Discipline, Mutual Support, Resistance to Disorganization, Cooperation, Conflict, Cliques, etc.

III. Tolerance Limits to Stress and Factors Deleterious to Reliable Performance
A. Limitations of the Concept of Tolerance Limits.
B. Lack of Relationship between Physiological and Performance End Points.
C. Special Problems of Group Stress.

IV. Approaches to Optimization of Individual and Group Performance
A. Cumulative vs. Alternative Measures.
B. "Making up the Difference."
C. Discussion and Illustration of Major Measures.
Personnel Selection
Physiological Adaptation
Realistic Training, Conditioning, and Accustomization
Nutrition
Psychopharmacology
Individual Protective and Supportive Equipment
Environmental Engineering
Human Factors Engineering
Task Systems Engineering
Psychophysiological Monitoring
Organizational Management
Leadership and Group Direction

V. Management and Leadership Problems in Multiman Spacecraft
A. Formal Organization Requirements.
B. Role Definition and Relationships.
C. Command, Discipline, Conformity.
D. Problem and Conflict Resolution.

E. Superior-Subordinate, Interpersonal Relationships.
F. Crew Training, Crew Integrity, Crew Identification.
G. Communications Problems Requiring Special Consideration.

VI. Trading-Off Problems, Priorities, Compromises

VII. Conclusions and Recommendations for Follow-up

Ross A. McFarland, Ph.D.
Guggenheim Professor of
Aerospace Health and Safety
Harvard School of Public Health

Engineering Aspects of Space Medicine

Psychological Factors with Special Reference to Human Performance in Space Flight

I. The Relative Advantages of Men and Machines

A. A brief analysis of the superiority of men or of machines, depending upon the mission, or objectives to be accomplished.

B. The advantages of manned spacecraft.

1. Sensors and computers alone do not tell where to go, and if failures occur, man can take over.

2. Examples from the Mercury flights.

3. Man's ability to reason, use judgment, to make decisions, and to analyze and report.

C. The limitations of the human operator.

1. The impact of environmental factors, such as prolonged weightlessness, radiation, extremes of temperatures, fatigue, and loneliness.

2. The cost and excessive precautions which must be used for human subjects on dangerous missions.

D. Since the decision has been made to send men into space, solutions must be reached to achieve success in a wide range of missions.

1. The engineer should be informed of human capabilities and limitations in the design and operation of all types of equipment in the early stages of each project.

II. Sensori-motor Functions and Skills

A. <u>The role of psychophysical methods in determining design requirements.</u>

1. The relative human sensitivity for various sensory categories.

2. Three kinds of sensory measures, i.e., discrimination, category, and magnitude scales.

3. Threshold studies in relation to long exposures to adverse environments.

4. Combination of multiple variables in the environment.

   a. Use of nomograms

B. <u>The application of data from psychophysical measurements of selected sensory functions.</u>

1. Differential light sensitivity in relation to seeing at sea level and at altitude.

2. The combined effects of altitude and selected toxic agents, such as carbon monoxide.

3. Examples from the fields of a) ventilation, temperature, and humidity, and b) noise and vibration.

C. <u>Measurement of skill in sensori-motor performance.</u>

1. Reaction times in the fields of vision and distance travelled in a) low altitude high speed flight, and b) at increasingly higher altitudes and speeds.

2. The effects of accelerative stress on sensori-motor skill and performance.

3. Studies of the effective field of view during visual fixation on displays of various sizes and shapes.

III. The Measurement of Complex Mental Functions and Abilities

A. The importance of understanding higher mental functions involved in the interpretation of data, information processing, and decision making during space flight.

B. The influence of adverse environmental factors and stress on cognitive abilities.

1. The effects of variation in altitude, temperature, and vibration, singly and in combination.

2. Workloads and channel capacity, including vehicle environment in relation to safety and efficiency.

C. Examples of objective measurements in the field of visual perception and interpretation.

1. Eye movement studies in relation to field of view, pattern recognition, and interpretation of the visual scene, including the phenomenon of "looking without seeing."

2. The recognition of patterns in relation to complex stellar and lunar formations.

D. The effects of confinement and isolation on higher mental abilities.

IV. The Implications of the Above Findings for the Design and Operation of High-Performance Aircraft and Space Vehicles.

ENGINEERING ASPECTS OF SPACE MEDICINE

OUTLINE OF

MAN-MACHINE SIMULATION

By

Milton A. Grodsky, Ph.D.

I. INTRODUCTION

A. What is man-machine integration? - The development of a system in which the capabilities of both the man and the machine are coupled appropriately so that the maximum performance of the overall system is obtainable.

B. In the development of a man-machine system, one must differentiate between inherent capability and ability to perform in certain environments.

C. Major variables under consideration in man-machine systems.

1. Habitability variables.

2. System or mission variables.

3. Task variables.

D. Importance of man-machine integration to the system.

1. Cost

2. System effectiveness.

3. Mission success.

4. Crew safety.

5. Overall system reliability.

II. SYSTEM INTEGRATION TECHNIQUES

A. Analytical Approach

1. Useful in an ill-defined area.

2. Use of mathematical or quasi-mathematical techniques to determine generalized factors.

3. Useful in early design.

4. As valid as the assumptions made.

B. Laboratory Approach

1. Experimental demonstration of man-machine performance capability.

2. Systematic approach when system problem is sufficiently defined.

3. Artificial in the sense that laboratory performance may differ from flight performance.

C. Simulation Approach

1. Test of concepts and a realistic approach for the collection of data on man-machine problems.

2. Provides a mode of investigation at a similar level to actual flight. Realism of actual flight can be simulated in most areas.

3. Types of simulations.

   a. Part-task.

   b. Integrated mission.

4. Provides training and selection data and can be used as a precursor to actual trainers.

D. Measurement Systems

1. The development of measurement schemes which are unique to man-machine problems.

2. The development of useful conceptual models which are fruitful in the conceptualization of man-machine system problems.

III. SYSTEM INTEGRATION PHASES

A. Conceptual design.

B. Phase I design.

C. Hardware design.

D. Factory test.

E. In-flight evaluation.

F. Personnel training.

The discussion will center on the type of system integration technique suitable for each of the design phases and the particular problems associated with each of these design phases.

IV. EXAMPLES OF PROBLEM AREAS & TECHNIQUES UTILIZED FOR THEIR SOLUTION

A. Pilot Performance Level During Flight

1. Importance of the problem.

   a. Man's role in the system.

   b. Support equipment for man.

   c. System reliability.

   d. Mission success.

2. Measurement of pilot performance. - Use of an integrated mission simulation technique which allows for the collection of a large amount of data on a variety of measures.

3. Results of studies performed.

   a. Capability studies.

   b. Laboratory studies.

   c. Simulation studies.

B. Weightlessness Effects

1. Determination of possible effects and the validity of the available data.

2. Engineering and systems solution to these possible effects.

   a. Artificial gravity.

   b. Exercise.

   c. Drugs.

3. Variables which will determine the engineering approach to be implemented.

   a. Cost and weight.

   b. Physiological protection and performance.

   c. Valid data prior to design.

V. CONCLUDING REMARKS

A. The future of man-machine integration is dependent upon the:

1. Increased complexity of the machine systems.

2. More system automation.

B. Areas such as intelligent machines and automata will eventually become a serious problem area in space flight. Will require inputs from a discipline which can design and put into being the intellectual and decision-making capabilities of man and the strength, endurance, and general tolerance of the machine into a working system.

Marvin Rosenbluth

TELEMETRY AND STORAGE OF INFORMATION

Introduction - a brief discussion of the definitions, history and application of telemetry. A simplified "block diagram" discussion of the elements of an aerospace telemetry system will be included.

Acquisition of Data - a discussion of principles of transducer operation as applied to telemetry.

- Engineering Sensors - a description of the types of sensors employed in the collection of engineering data.

- Aeromed Sensors - a description of the types of sensor in current use for collection of biomedical information.

Multiplexing Techniques - considerations of the effective utilization of communications facilities and bandwidth. General considerations of bandwidths required for data transmission will be included.

- Frequency Division Multiplexing - a description of the technique for frequency sharing a communication channel for simultaneous use by independent information sources. An explanation of frequency modulation and of IRIG standards is included.

- Time Division Multiplexing - the principle of time-sharing multiplexer techniques based on the sampling of continuous data by the commutating of signal sources. A description of mechanical and solid state commutators with a discussion of commutation, sub-commutation and super-commutation will be provided.

Telemetry Modulation Techniques - a description of modulation techniques currently employed.

- Pulse Amplitude Modulation (PAM) - a description of a modulation format which varies the amplitude of each pulse in a pulse train in correspondence with the values of measured parameters.

- Pulse Duration Modulation (PDM) - a description of a modulation format which varies the time duration of each pulse in a pulse train in correspondence with the values of measured parameters.

- Pulse Position Modulation (PPM) - a description of a modulation format which varies the interval between subsequent pulses in a pulse train in correspondence with the values of measured parameters.

- Pulse Code Modulation (PCM) - a description of a modulation format in which the value of a measured parameter is converted to an encoded series of binary digits corresponding to the analog value of the date sample. A discussion of analog to digital conversion and digital handling techniques as well as a description of a typical PCM format will be included.

Transmission Techniques

Wire Transmission: The manner in which telemetry data is transmitted over long distances by use of "wide band data", "high speed data" and "low speed data" techniques will be presented. Long distance transmission of aeromedical data by special facilities will also be discussed.

R.F. Telemetry Links: A description of the UHF telemetry link used in Project Mercury and the UHF link planned for Project Gemini will be presented. The "Unified S. Band" RF link planned for use on Project Apollo flights will be covered.

Demultiplexing Arrangements - A description of the various arrangements used to separate composite telemetry into independent signal channels will be provided. Included will be a description of a typical FM/FM station, a PAM decommutator as well as a discussion of a "hardwire" vs. a stored program PCM ground station.

Display Techniques - A general description of conventional analog display devices for telemetered information will be presented. Project Mercury display methods will be discussed as will the recently implemented Gemini remote site display console group. Generation and display of computer processed telemetry information at the Manned Spaceflight Control Center will also be included. Typical aero-medical display formats will be presented.

Data Storage and Recording

Delayed Transmission Techniques - spacecraft recording of telemetry data for delayed transmittal to ground stations or post mission analysis will be discussed.

Ground Station Recording Devices - a comprehensive survey will be made of magnetic tape and oscillographic recording devices currently in use. Included will be a discussion of pre-detection and post detection recording arrangements as well as Visicorder, events recorder and strip chart records which can be employed for near real-time analysis of telemetered data.

NASA MEDICAL DATA ANALYSIS PROGRAM

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OUTLINE

1. Three Main Objectives

   a. Safety of Astronauts
      (1) While Mission is in Progress
   b. Scientific Products
      (1) Derivable from Total OMSF/NASA Program
   c. Standardization of Medical Data
      (d) For Computer Inputs and Analysis

2. First Objective - SAFETY - Involves

   a. Acquisition and Utilization of Data by Physicians
      (1) In Real-time(almost Instantaneous)(Displays)
      (2) While Mission is in Progress
   b. Readily Intrepretable Form
      (1) Both In-Flight and Ground-Based Medical Data
      (2) All Pertinent Medical Data about the TOTAL Individual and Environmental Conditions

3. Second Objective - Scientific Products

   a. Also Involves Acquisition and Utilization of Data
      (1) Near Real-Time Desirable
      (2) Real-Time Displays not Manditory
   b. Data Applicable to Longer Range Goals
      (1) Advances in Medical Science and Technology
      (2) Increasing the Safety of Space Crews
      (3) Prerequisites for More Extensive Flights
      (4) Development and Design of Spacecraft Equipment
      (5) Improved Criteria for the Selection of Future Space Crews

4. Third Objective - Standardization of Data for Computer Utilization

a. Involves Preparing All Types of NASA Medical Data on Magnetic Tape
   (1) In Interchangeable Form for Inputs to Computers
   (2) For Immediate Retrieval, Analysis and Application

5. Actions Necessary to Satisfy Objectives

   a. Determine Types of Data to be Standardized
      (1) In-Flight
         (a) Physiological
         (b) Environmental
         (c) Activity
      (2) Astronaut Clinical
      (3) Centrifuge
      (4) Baseline, etc.
   b. Develop Standard Format
      (1) Place Emphasis on Safety-Type of Data First
         (a) In-Flight Highly Important
   c. Prepare all Data in Standard Form for Computers
      (1) Assure Interchangeability of Types
         (a) For Purposes of Comparison and Prediction
      (2) Store on Magnetic Tape
         (a) For Computer Inputs Retrieval and Analysis
   d. Develop and Implement Computer Programs and Systems
      (1) For Analysis and Presentation (Display)
   e. Evolve and Coordinate ALL with Users (MSC)
      (1) Medical Research and Operations
      (2) Crew Systems Division
      (3) Appropriate Data and Computer Sections

6. Reasons for Preparing Data in Standard Form for Computer Inputs

   a. Interchangeability of Various Types
      (1) For Analytic Purposes
   b. Quick Retrieval and Analysis
      (1) Can't begin to Analyze Data Stored in Cabinets
   c. Broad Applicability
      (1) Applicable to one Type of Data
      (2) Applicable to all in Standard Form
   d. Selection of Best Methods of Various Diciplines
      (1) Sets and Sub-sets, Fourier Analysis, Factor Analysis, Rate of Change Analyses, etc.
      (2) Physicians, Engineers, Psychologists, Mathematicians, etc.
   e. Pay for Computer Program and System Once-Use Repeatedly
      (1) In Service Costs once <u>only</u>
      (2) Contractural Costs once <u>only</u>

7. Example concerning Principle of Interchangebility

a. Various Types of Data in Standard Form
   (1) Pre- and Post-Flight Laboratory, Clinical, Simulation, Baseline, etc.
b. Development of Computer to Analyze one Type
   (1) Best of All Diciplines
   (2) Applicable to all Types and all Missions
c. Contract for Testing Hypothesis, Analyzing, Interpreting, and Reporting Results

8. Current Status-Progress Towards Integrated System at MSC

(a) In Flight
   (1) Computer Program Already Developed for Time-Line Presentation of Data
      (a) Considering Total Individual
   (2) Clinical History in Process
      (a) System Compatible with MSC Computers
   (3) Laboratory Data in Process
      (a) Pre- and Post-Mission Blood Chemistries, Urines, Calcium etc.
   (4) Centrifuge in Process
      (a) Employ same Format and Computer Programs as In-Flight Data
   (5) EKG Pattern Analysis
      (a) Real time Analysis of EKG Patterns
      (b) Ready for Apollo (Nov/Dec)
   (6) Baseline
      (a) Comparisons
   (7) EEG Pattern Analysis
      (a) Objective Analysis-Computers
      (b) Consensus
   (8) Experiments
      (a) Computer Program Analysis
      (b) Real time for 5 Medical Experiments
   (9) Voice
      (a) Digitize with Computer
      (b) Relate to Medical Data
   (10) Contourograph
      (a) Stacking EKG
      (b) Comparison of Contours

9. Usual Ground Rules for each Contract

a. Put all Appropriate Data on Tape in Standard Form
   (1) For each Type of Data
   (2) Provide NASA with all Tapes
b. Be able to Select and Print-Out
   (1) Provide NASA with Various Listings

(2) Applicable to Immediate and Long Range Objectives of NASA

c. Make each System Open-Ended
   (1) Accept more Astronauts
   (2) Accept more Parameters

d. Be able to Question Computers
   (1) Key Safety Questions
   (2) Long Range Applicability
   (3) Furnish NASA with Computer Programs for Analyses Employed

e. Make System Compatible with MSC Computers
   (1) Must Develop a Usable System
   (2) Correct Machine Language

f. Use AMA International Coding
   (1) All Medical Terms
   (2) Convert Data on-hand if Required

g. Describe What was Done
   (1) Why, How, Results
   (2) Suitable for NASA Publication

h. Prepare and Administer Instructional Program
   (1) Short Course
   (2) Train NASA Personnel to Implement Program

i. No Press Release on Medical Data
   (1) Confidential Nature of Data
   (2) Unprofessional Interpretations could Result in Much Trouble, Misunderstandings, etc.

10. MSC Medical Data Program for Fiscal Year 67

a. In Service Analysis of Medical Data
   (1) Mercury
   (2) Gemini
   (3) Apollo
   (4) Basis for being Knowledgeable

b. Prepare Contractural Requirements
   (1) Work Statements based on Needs
   (2) Additional Computer Utilization

c. Evaluate Unsolicited Proposals

d. Initiate and Monitor Contracts

e. Implement Systems as they Become Operational

11. Summary

D. H. Stoddard, M.D.
Director, Occupational Me

OCCUPATIONAL MEDICAL SUPPORT OF NASA

Like many of you, we feel very strongly that occupational medicine is a much broader discipline than that normally understood by the medical profession. Indeed, we subscribe to the thesis that occupational medicine is a concrete, specific, coordination activity involving at least three scientific disciplines: The science of sociology, the science of engineering, and the science of clinical medicine. We include physiology and bio-electronics under the section of clinical medicine.

Since relative good, overall surveillance of a controlled population is readily available in the occupational environment, it provides us with an unusually good opportunity to study disease and its manifestations. It should be made clear at the outset that the majority of our time in occupational medicine is spent in evaluating disease whose etiology is not found in the occupational environment. The extent of this opportunity to study disease in the occupational environment was expressed very accurately by Pell. He suggested using the captive population of industry, since epidemiological research can be undertaken with a degree of completeness and accuracy, that would, perhaps, be impossible to duplicate in the ordinary population survey.

Like all of you, we appreciate the value of quality data. A tremendous effort is being made within our organization at this time to obtain better quality and more comprehensive data so that we have more factual data available to use in problem analysis. Furthermore, we feel strongly that more rapid handling of this data is necessary so that medical appraisals are more timely. As a result of this conviction, we are beginning to computerize as much of our relevant data as possible.

In the summary of this introduction, we might suggest that our strength in occupational medicine comes not from our unique training in the discipline of medicine, but rather because of our unique position in relationship to a given population, in which we can coordinate the skills of the social scientist, the engineer and the clinical medical experts in appraising the mechanism and significance of health in the working population. Furthermore, since the manifestation of disease which we encounter in industry, has its origin outside the occupational environment so frequently, we had better not limit our medical approach to a patient's problem to the work environment only.

ANALYSIS OF SPACE FLIGHT DATA

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The immediate concern of analysts of data on space flight personnel is with the GEMINI series and the planned experiments of the Orbital Research Laboratory. As the flights are now planned there will be a minimum of two and a maximum of approximately ten astronaut subjects participating in these flights. From the statistical point of view this means that although there will be thousands of measurements taken during each flight the analyses will be, in terms of subjects, conducted on very small samples. One might well ask the question "How can data be gathered on such a small number of subjects and still yield information that is reliable and generalizable enough to permit, perhaps, life and death decisions to be made affecting future astronatus?"

As a beginning point, it is wise to ask what kinds of questions will be asked of the data, and just what kinds of data will be available for analysis. In answer to the first question we can say that securing information concerning the validity and, concurrently, the reliability of the measures themselves will be paramount. It will be useless to perform elaborate analyses and draw decisive conclusions on data that are in themselves invalid. As to the second question concerning the kinds of data available, we know that the samples will be small, the variability large, and the data often reducible only to categorical rubrics wherein the quantification is in terms of frequency of occurrence of a particular behaviorism.

To the statistician this means that small sample statistics performed on non-parametric data may form the major part of his analysis. To analyze such data the latest techniques of this area of statistics will be applied. However, where sufficient numbers of data points are retrievable, and the pertinent assumptions are met then the more conventional parametric statistical tests will be applied.

Regardless of the particular statistics chosen for treating the data, the statisticians will be interested in at least the following types of analyses: the determination of the reliability of the measurements taken; the determination of base line data; the significance of relationships between variables; the significance of differences between various conditions; the interaction of variables which produce effects not attributable to any one variable acting alone; the practicality of certain statistical differences; the problem of absolute vs relative measurements of performance in evaluating performance; the use of several variables combined in their most efficient means to predict a future condition; and, the interpretation of trends as indicative of developing adverse effects.

Each of the above statistical problems and probable solutions will be discussed in the context of the data expected from space.