

M-61-64-1-IV • 15 MARCH 1965

BIOLOGICAL MEASUREMENT OF MAN IN SPACE

FINAL REPORT
VOLUME IV

CONCEPTUAL DESIGN OF A MEASUREMENT
SYSTEM FOR A MANNED ORBITAL
RESEARCH LABORATORY

Prepared For
NATIONAL
AERONAUTICS AND
SPACE
ADMINISTRATION

BIOLABS

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

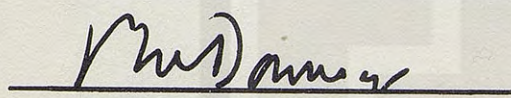
BIOLOGICAL MEASUREMENT OF MAN IN SPACE

FINAL REPORT
VOLUME IV

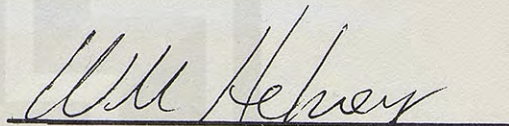
CONCEPTUAL DESIGN OF A MEASUREMENT
SYSTEM FOR A MANNED ORBITAL
RESEARCH LABORATORY

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract No. NASw-1071



V. M. Downey - Study Leader



W. M. Helvey - Manager, Bioastronautics

BIOLABS

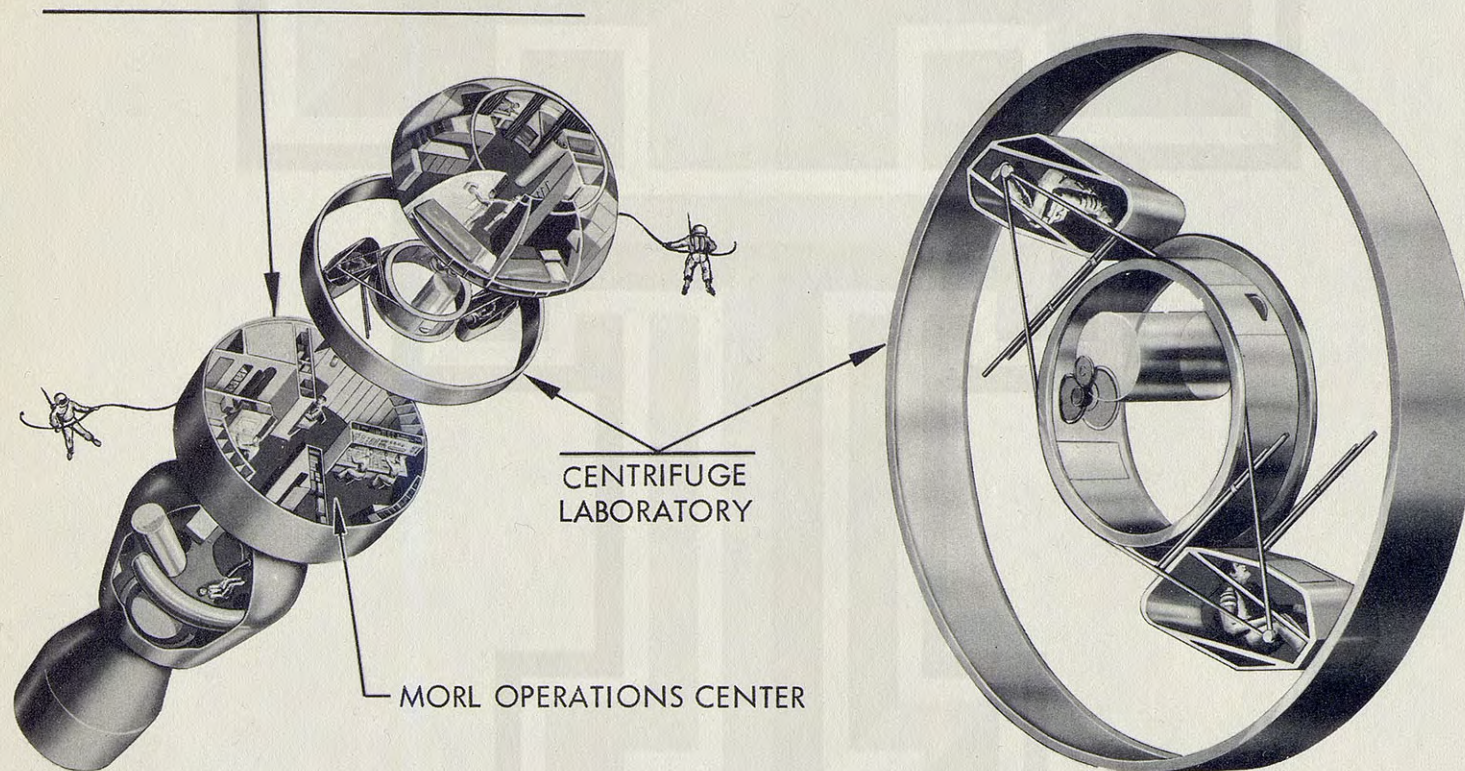
LOCKHEED MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SUNNYVALE, CALIFORNIA

NOTICE

The information and design disclosed herein were originated by and are the property of Lockheed Aircraft Corporation. Lockheed reserves all patent, proprietary, design, manufacturing, reproduction, use, and sales rights thereto, and to any article disclosed herein, except to the extent rights are expressly granted to others. The foregoing does not apply to vendor proprietary parts.

PHYSIOLOGY, MICRO-CHEM, RADIOLOGY,
AND HUMAN-PERFORMANCE LABORATORIES



CENTRIFUGE
LABORATORY

MORL OPERATIONS CENTER

Manned Orbital Research Laboratory (MORL)

LOCKHEED MISSILES & SPACE COMPANY

iii

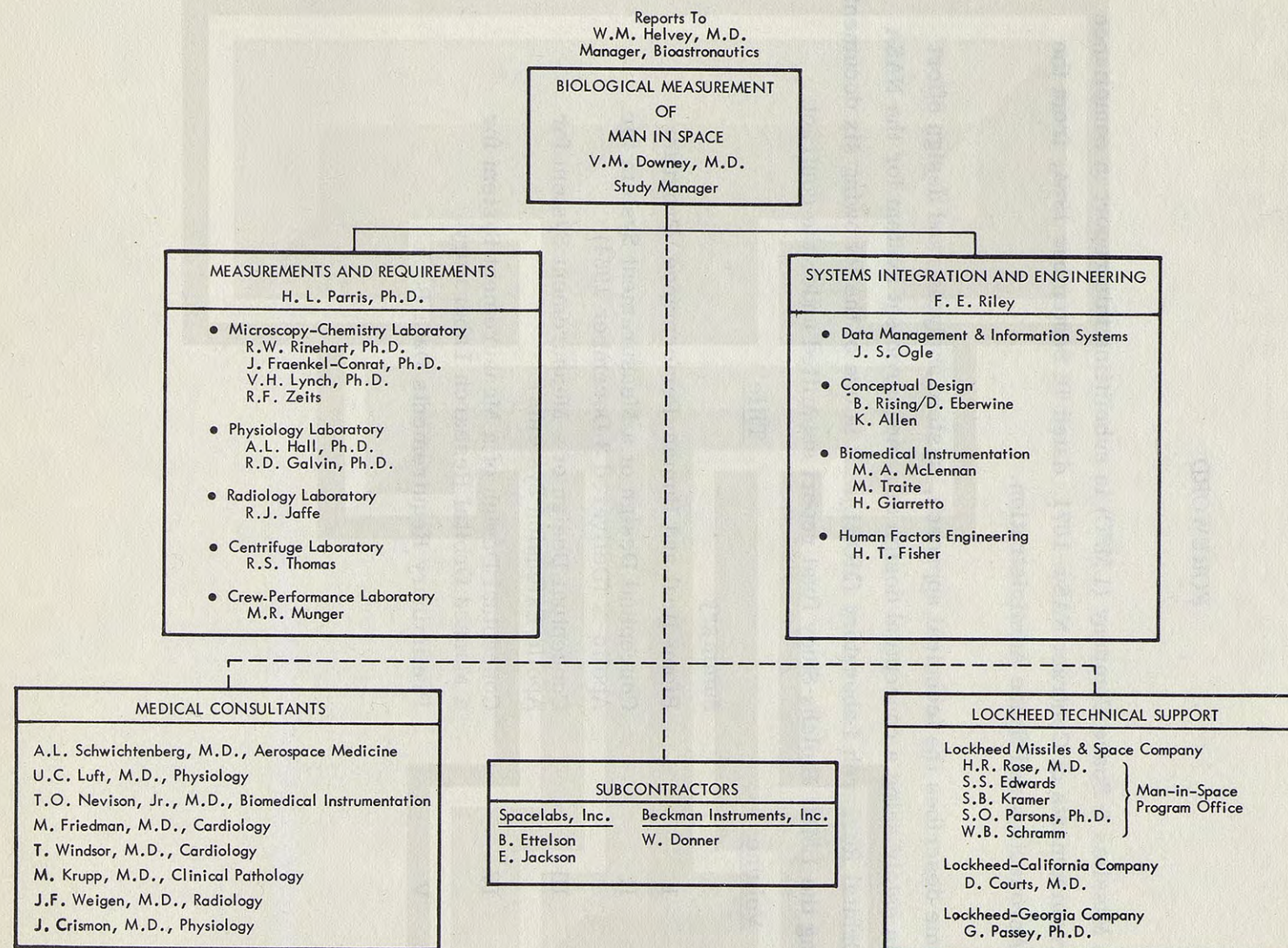
M-61-64-1
Vol. IV

FOREWORD

Lockheed Missiles & Space Company (LMSC) is submitting this report in compliance with the requirements of Contract NASw-1071, dated 10 September 1964, from the National Aeronautics and Space Administration.

This volume describes the technical approach, system analysis, and design effort involved in establishing a conceptual design of a measurement system for the NASA Manned Orbital Research Laboratory (MORL). It is one of the following six documents comprising the LMSC Biolabs Study final report submitted under the contract:

<u>Volume</u>	<u>Title</u>
	Summary
I	Biomedical and Human-Performance Program
II	Conceptual Design of a Measurement System for Apollo-X (Delivered 3 December 1964)
III	Conceptual Design of a Measurement System for Apollo Extension Systems
IV	Conceptual Design of a Measurement System for a Manned Orbital Research Laboratory
V	Preliminary Requirements Data Book



Biolabs Study Team

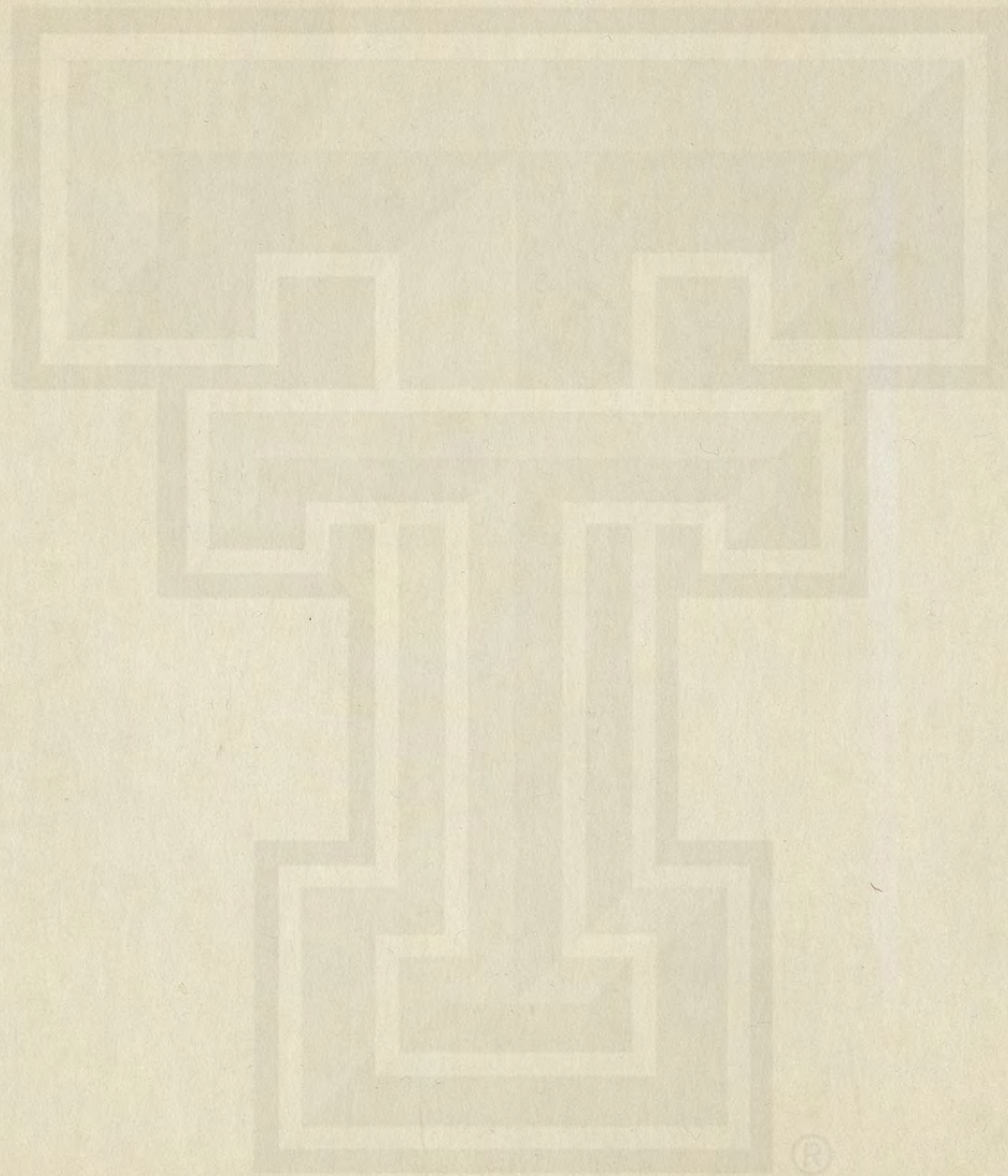
ACKNOWLEDGMENTS

This volume was prepared by a special team (indicated on the facing chart) comprising members of the LMSC Bioastronautics organization as well as representatives of Spacelabs, Inc., and Beckman Instruments, Inc., who were subcontractors for the Biolabs Study. Able assistance was also provided by other departments of LMSC and by representatives of the Lockheed-California Company and the Lockheed-Georgia Company.

A group of medical consultants (also listed on the chart) gave generously of their ideas and time to assist in the Study, and their services are deeply appreciated. Appropriate guidance was provided by Dr. E. J. McLaughlin, contract monitor for the NASA Office of Manned Space Flight, Washington, D.C.

The report preparation effort was coordinated by Frank E. Riley, under the direction of Dr. Vincent M. Downey, head of the Biolabs Study. The editor was Leon H. Goldich, who was assisted by other members of LMSC R&D Technical Publications.

SUMMARY



®

SUMMARY

Under the Biolabs Study for the National Aeronautics and Space Administration (NASA), Lockheed Missiles & Space Company (LMSC) has investigated the capability of biomedical and human performance laboratories for providing answers to questions of manned spaceflight activities. Integration of measurements and equipment into the Manned Orbital Research Laboratory (MORL) has been the principal concern of this portion of the study. The conceptual design of a measurement system for the MORL has been developed and is reported in this volume. This measurement system has evolved from a step-by-step procedure in carrying out the specific technical tasks designated in NASA RFP 10-3356 (Ref. 1-1).

STUDY RESULTS

The conceptual design of the MORL measurement system is designated as Task C of the five technical tasks defined under NASA RFP 10-3356 (Ref. 1-1). In this phase of the Biolabs Study, the physical characteristics of the MORL were reviewed, and their effects on the biomedical measurement of man in space were determined. Space available in the MORL for biomedical measurement purposes was established by a space allocation study. This study stressed the arrangement and location of larger equipment items to provide maximum space utilization and effectiveness to meet the requirements of the more demanding experiments. An outgrowth of this conceptual effort was the identification of development needs warranting fulfillment to implement the Biolabs measurement system.

A basic aspect of this task is the portion of Task E, the overall phase of the Biolabs Study that is applicable to MORL. Integrated objectives for Task C and the pertinent aspects of Task E are as follows:

- Definition of measurements and equipment for MORL
- Determination of the constraints due to the MORL System capability

- Design of a biomedical and human-performance measurement system
- Determination of an optimal data-management system
- Preparation of a preliminary operational plan

MEASUREMENTS AND EQUIPMENT DEFINITION

Under the LMSC measurement system, measurements for evaluating the effects of weightlessness can be accomplished in the following NASA-specified laboratories (Biolabs): Physiology, Microscopy and Chemistry, Crew Performance, Radiology, and Centrifuge. By virtue of its on-board centrifuge, and its airlock permitting easy egress for extravehicular activity (EVA), the MORL requires equipment for three operational modes – intrastation, centrifuge, and EVA. Physiological and human-performance measurements can be made in each of these modes.

Unique measurement requirements and equipment developed by LMSC during the study are as follows:

- Physiology
 - Body-mass measurement
 - Muscular conditioning exerciser
 - Caloric stimulator for vestibular testing
- Microscopy and Chemistry
 - Analysis of biological liquids by optical measurement
 - Telemicroscope
- Crew Performance
 - Reentry simulation
 - Centrifuge performance console
 - EVA tasks
- Radiology
 - System III, employing an X-ray tube, image intensifier, and on-board video system
- Centrifuge
 - Therapeutic, conditioning, and experiment program

The evaluation of various candidate devices proposed for obtaining the same measurement presented the greatest challenge. In some cases, the data available did not provide a clear basis for selection.

In this connection, more detail regarding specific requirements is presented in Section 8 which lists the biomedical development needs of the NASA ORL program.

SYSTEM CONSTRAINTS

The MORL design is the result of studies conducted by the Douglas Aircraft Corporation for the NASA-Langley Research Center. The current 260-in. diameter laboratory configuration was utilized as the basis for LMSC development of the biomedical measurement system for MORL.

Major characteristics and constraints of the MORL that affect the development of a biomedical and human performance program are as follows:

● Launch vehicle	Saturn IB
● Crew size	6 to 9
● Launch configuration	Unmanned
● Crew composition	3 astronauts, 2 scientists, 1 astrophysician
● Crew duty cycle	3 mo
● Total biomedical crew-performance experiment time	42 man hr/day (6-man crew)
● Ferry/resupply system	Saturn IB/Apollo
● Mission period	1970
● Total mission time	1 to 5 yr
● Weight	6,000*
● Volume	1,100 cu ft*

*Required for engineering, scientific and biomedical and human-performance experiments.

- Power 1.2 kw*
- Centrifuge (on-board) 10-ft radius

The MORL has provision for an experimental area within the operation/experiment module compartment. There is also a sealed biological/liquid compartment that can be used for the microscopy and chemistry experiments.

CONCEPTUAL DESIGN OF MEASUREMENT SYSTEM

The LMSC biomedical and human-performance measurement system for the MORL consists of six major subsystems – Biometric, Microscopy and Chemistry (Micro-Chem), Crew-Performance, Centrifuge, Extravehicular, and Laboratory. These subsystem designations have evolved from measurement requirements developed for the five laboratories specified by NASA.** In the cases of the Centrifuge, Extravehicular, and Laboratory subsystems, both biomedical and crew-performance measurements are taken.

The Biometric subsystem is a major component of the Biometric station located in the MORL forward compartment. Vital physiological measurements are taken, recorded, stored, and transmitted to ground-based biomedical monitoring personnel for each of three operational modes (intrastation, centrifuge, and extravehicular). Displays and controls for on-board monitoring personnel are provided. The system includes a special "biomedical jig" that permits easy and reliable attachment of sensors.

The Crew-Performance subsystem is the second major component of the Biometric Station. Performance measurements are conducted at the left half of a panel which contains display and controls identical to those involved in MORL crew-station operations. Also provided are controls and displays for simulating the reentry profile

*Required for engineering, scientific and biomedical and human-performance experiments.

**Lockheed Missiles & Space Company, Biological Measurement of Man in Space, Biomedical and Human-Performance Program, M-61-64-1, Vol. I, Sunnyvale, Calif., 15 Mar 1965

experienced during the Apollo logistic spacecraft reentry maneuver. The possibility of employing reentry simulation programs supplied by ground computers will greatly alleviate the power and complexity demands involved. LMSC therefore recommends utilization of this technique.

The Micro-Chem subsystem is located in two areas. Equipment and work tables used to make those analytical measurements involving body fluids or liquids that may possibly contaminate the laboratory module are located in a sealed biological liquid compartment. Adjacent to the sealed compartment is an experimental area that will be used for microscopic analysis, spectrophotometry, and chemical analysis. The sealed compartment also provides space for conducting radiology measurements. By rearranging the work tables and storage areas, enough space can be gained for conducting the body mass-measurements with the oscillating spring-mass system.

The Centrifuge subsystem is concerned with physiological measurements and human-performance evaluation. The MORL on-board centrifuge provides an excellent opportunity to conduct a comprehensive experimental program at various g levels, based on therapeutic, conditioning, and experimental conditions. The r-f telemetry system selected for this application has resulted from a detailed analysis of various techniques available.

The Extravehicular subsystem is also concerned with physiological and human-performance measurements. The physiological measurements are limited to those required to establish crew-member safety status. Extravehicular human-performance measurements are more extensive, since evaluation of man's capability to perform in the hostile space environment is of prime concern.

The Laboratory subsystem consists of the various equipment items required to complete the measurement system. Depending on its size, use, complexity, and unique requirements, this equipment is located in either the Biometric or the Micro-Chem station. The following equipment items are representative:

- Body mass-measurement system
- Urine collection and freezing unit

- Telemicroscope
- LMSC liquid-analysis system

This subsystem also incorporates a physical examination unit including an oculometer and stores chemistry supplies used in conducting on-board analysis.

DATA MANAGEMENT

The data-management system for the MORL vehicle must provide several capabilities. It must measure as many as 300 biomedical quantities of which the majority presented are voltages in the 40-mv or 5-v ranges. The combination of frequencies and numbers of quantities to be measured at any time will not exceed 2×10^5 bits/sec. The schedule of measurements will be flexible, allowing variation in the quantities measured and their order and sample rates. The spacecraft equipment will consist of a down-link data equipment system; a service, control, and up-link data system; a video system; and an audio system. In addition, data-management systems will provide two-way communication, one-way telemetry, and one-way stimulus control for both centrifuge and extravehicular activities.

The video system will provide visual data detection, display, recording, and telemetry from both spacecraft and centrifuge video pickups. These visual data will include black-and-white television of the test subjects, instrument panels, and other objects for which fine detail is less important than motion; high-resolution black-and-white facsimiles of directly viewed objects; and objects observed through a microscope or displayed on an X-ray image-intensifier screen. The video recorder will permit storage of visual data of different objects and from different operating modes for telemetry during a single pass over the Manned Spacecraft Control Center (MSCC).

PRELIMINARY OPERATIONAL PLAN

Ground rules for launch, orbital, and recovery operations were established to be consistent with NASA-MORL basic operations and to utilize the planned ground networks and ground equipment. Since the orbit characteristics influence to a high degree the selection of the data management equipment, LMSC conducted a brief study on

orbit-altitude selection. Results indicated that altitudes between 140 nm and 200 nm were consistent with orbit lifetime requirements of 45 days and a limitation of an internal radiation exposure dose rate of 0.5 rad/day through a 2-gm/cm² shield.

Two conditions were examined as to their effect on the operational aspects of the mission. The first assumed that there would be only one manned mission at a time. The second condition assumed simultaneous manned missions. In the first situation, the existing network with increased personnel will suffice. In the second, it will be necessary to establish a new Mission Operation Control Room, to increase remote-site staffs, and to provide land lines and submarine cables. The latter situation was examined, and several alternate plans were developed. Preliminary studies were conducted to determine the minimum number of stations required to maintain communication so that the spacecraft will not be out of range of the ground stations for two or more consecutive orbits. Results of this study indicated that all data readout could be handled by three stations - MSCC, Quito, and Santiago.

Preliminary requirements were established for an operational schedule-evaluation system. A plan is outlined for establishing criteria and operational procedures.

CONCLUSIONS

The MORL is designed to provide a flexible experimental facility. LMSC examined its capability to perform the recommended biomedical and human-performance program. Since the primary objective of the NASA-ORL Program is to evaluate man's adaption to prolonged exposure to weightlessness, the measurements must be of sufficient scope to provide a basis for a decision.

Based on design information made available to LMSC regarding the MORL system capability, the MORL configuration appears to provide adequate size, payload capability, personnel skills, and mission time. Although the MORL data-management system is limited in regard to data recording and storage, the storage limitation can be easily remedied by the addition of suitable equipment.

The three operational modes (intrastation, centrifuge, and extravehicular) offer a comprehensive test-bed for an experimental program. An integrated approach to the measurements, displays, and controls required for these operations has been chiefly instrumental in producing the essential results of the Biolabs Study.

The MORL is considered by LMSC as the most reasonable step beyond extended Apollo technology system toward solving the problems associated with prolonged mission times. The MORL is not in conflict with Apollo X; in fact, the MORL is predicated upon the prior 30-day duration flights of Apollo X. After the Apollo flights, a space station of MORL capability and capacity will be urgently required to obtain baseline data in earth orbit for more advanced post-Apollo missions.

CONTENTS

Section		Page
	FOREWORD	v
	ACKNOWLEDGMENTS	vii
	SUMMARY	ix
	ILLUSTRATIONS	xx
	TABLES	xxiii
1	INTRODUCTION	1-1
	1.1 Background	1-1
	1.2 Scope of Study Effort	1-2
	1.3 Conceptual Design Evolution	1-3
	1.4 Study Ground Rules	1-3
	1.5 Technical Definitions	1-4
	1.6 Summary of Contents	1-5
2	THE MANNED ORBITAL RESEARCH LABORATORY	2-1
	2.1 Background	2-1
	2.2 Description of MORL System	2-2
	2.3 Major System Elements	2-3
	2.4 Crew Rotation and Resupply	2-3
	2.5 Laboratory Module	2-4
	2.6 Environmental-Control and Life-Support System	2-6
	2.7 Power Supply	2-8
	2.8 Guidance and Navigation	2-9
	2.9 Stabilization and Attitude Control	2-9
	2.10 Data Management	2-10
	2.11 Communications	2-13
	2.12 Operation/Experimental Area	2-15
	2.13 Internal Centrifuge	2-16

Section		Page
3	BIOMEDICAL AND HUMAN-PERFORMANCE MEASUREMENT REQUIREMENTS	3-1
	3.1 General Considerations	3-1
	3.2 Biomedical and Human-Performance Monitoring	3-3
	3.3 Physiology Laboratory	3-7
	3.4 Microscopy and Chemistry Laboratory	3-8
	3.5 Radiology Laboratory	3-19
	3.6 Human-Performance Laboratory	3-26
	3.7 Centrifuge Laboratory	3-47
4	SYSTEM/LABORATORY ANALYSIS AND INTEGRATION	4-1
	4.1 General Considerations	4-1
	4.2 Biomedical Measurement System	4-2
	4.3 Centrifuge Bioinstrumentation System	4-12
	4.4 Crew-Performance Measurement - Intra-Station	4-20
	4.5 Crew-Performance Measurement - Centrifuge	4-24
	4.6 Reentry Simulation Requirement	4-24
	4.7 Crew-Performance Measurement - Extravehicular	4-31
	4.8 Laboratory Measurements	4-36
5	CONCEPTUAL DESIGN OF MEASUREMENT SYSTEMS	5-1
	5.1 General Considerations	5-1
	5.2 Biometric and Micro-Chem Stations	5-1
	5.3 Centrifuge Laboratory - Bioinstrumentation	5-12
	5.4 Crew-Performance Measurement System - Intra-Station	5-21
	5.5 Crew-Performance Measurement System - Centrifuge	5-25
	5.6 Crew-Performance Measurement System - Extravehicular	5-26
	5.7 Laboratory Subsystems	5-31
6	PRELIMINARY OPERATIONAL PLAN	6-1
	6.1 General Scope	6-1
	6.2 Operational Philosophy	6-1
	6.3 Ground Rules for Launch, Orbital, and Recovery Operations	6-2
	6.4 Flight Operations	6-3

Section		Page
	6.5 Data Acquisition and Command	6-22
	6.6 Recovery	6-24
	6.7 Operational Considerations	6-27
7	DATA MANAGEMENT	7-1
	7.1 Data-Management System Requirements	7-1
	7.2 Data-Management System Constraints	7-2
	7.3 Data-Management Equipment Systems	7-6
	7.4 Spaceborne Equipment	7-23
8	DEVELOPMENT NEEDS	8-1
	8.1 Mass Measurement System	8-2
	8.2 Exerciser	8-3
	8.3 Oculometer	8-4
	8.4 Endoradiosonde Technique	8-5
	8.5 Human Body Thermography	8-11
	8.6 Protective Adaptive Devices	8-14
	8.7 Computer Program for the Generation and Evaluation of Operating Schedules	8-15
9	REFERENCES	9-1

ILLUSTRATIONS

Figure		Page
	Frontispiece	iii
	Biolabs Study Team	vi
2-1	External Centrifuge	2-18
3-1	Radiology Laboratory Arrangement – Typical for Systems I, II, and III	3-21
3-2	Characteristics of a Centrifuge With a 10-Ft Radius	3-34
3-3	Angular Velocity ω as a Function of Radius for Various Artificial Gravity Levels	3-39
3-4	Maximum Ratio of Coriolis Acceleration to g_s Vs. Radius for $V = 4$ Ft/Sec	3-41
3-5	Maximum Ratio of Coriolis Acceleration to g_s Vs. Radius for $R\omega^2 = 32$ Ft/Sec ²	3-42
4-1	Biometric and Micro-Chem Stations Integrated Into the MORL Experimental Area	4-6
4-2	Biometric Console Display Panel and Storage Compartments	4-8
4-3	Micro-Chem Console Display Panel and Storage Compartments	4-11
4-4	Footprint Maneuver From 110-nm Orbit	4-26
4-5	Thermal Vestibular Stimulator, Using an Electrical Resistive Element	4-38
4-6	Stimulator Circuit Illustrating Peltier Effect	4-39
4-7	Mass Measurement System – Early Laboratory Test Model Using Oscillating Springs	4-45
4-8	Relationship Between Body Mass and Period as Determined by Early Laboratory Device	4-48
4-9	Mass Measurement System – Linear Acceleration Device	4-49
4-10	Relationship Between Subject Weight and Transit Time for the Linear Acceleration Device	4-54
4-11	Oculometer	4-59
4-12	Telemicroscope	4-61

<u>Figure</u>		<u>Page</u>
5-1	Physiology Laboratory – Bioinstrumentation System	5-3
5-2	Centrifuge Laboratory – Bioinstrumentation System	5-15
5-3	Ear Oximeter (NASA – Ames Research Center)	5-17
5-4	Blood Pressure and Segmental Plethysmograph – Block Diagram	5-19
5-5	Automatic Sphygmomanometer	5-20
5-6	Respiratory CO ₂ Analyzer – Recommended System	5-33
5-7	Resting $\dot{V}$ – V Loop Superimposed on Maximum $\dot{V}$ – V Loop, Showing Use of Loops for Obtaining Values for Subdivisions of Air	5-35
5-8	Respiratory CO ₂ Analyzer – Vibrator Infrared Type	5-37
5-9	Respiratory CO ₂ Analyzer – Test Data	5-38
5-10	Fast-Responding, Polarographic, Oxygen Sensor	5-42
5-11	Time Constants of a Fast-Responding, Polarographic, Oxygen Sensor as a Function of Membrane Thickness	5-44
5-12	Comparison of a CO ₂ Rebreathing Technique With Two Direct Methods of Cardiac Output Determinations	5-47
5-13	Mass Measurement System – Oscillating Springs	5-49
5-14	Urine-Collection Process Using Transparent Plastic Flask and Motor-Driven Centrifuge	5-55
5-15	Urine-Freezing Unit – Cryogenic Refrigerator Containing Solid Mixture of Ethanol and Water	5-56
5-16	Visual Hemispherometer (Wire Cage Supporting Small White and Colored Lamps)	5-61
6-1	On-Orbit Configuration for MORL – Longitudinal Axis Normal to Earth Radius Vector	6-8
6-2	MORL Orbit Lifetime Vs. Orbit Altitude	6-9
6-3	Decay History of Orbit Parameters – Initial Altitude of 130 nm	6-11
6-4	Decay History of Orbit Parameters – Initial Altitude of 160 nm	6-12
6-5	Decay History of Orbit Parameters – Initial Altitude of 200 nm	6-13
6-6	Decay History of Orbit Parameters – Initial Altitude of 230 nm	6-14
6-7	Decay History of Orbit Parameters – Initial Altitude of 250 nm	6-15

<u>Figure</u>		<u>Page</u>
6-8	Apogee Height Increase Due to a Velocity Increment Added at Perigee	6-16
6-9	Perigee Height Increase Due to a Velocity Increment Added at Apogee	6-17
6-10	Velocity Increase Due to Total Impulse Increase	6-18
6-11	Effect of Altitude, Date, and Aluminum-Shield Thickness on Trapped-Electron Daily Dose for Circular 0° Inclined Orbits (Lower Limit)	6-20
6-12	Effect of Altitude, Date, and Aluminum-Shield Thickness on Trapped-Electron Daily Dose for Circular 0° Inclined Orbits (Upper Limit)	6-21
6-13	Orbit Track and Telemetry Coverage, ETR Launch ($i = 28.4$ deg, $h_c = 200$ nm)	6-25
7-1	Spaceborne Equipment System for Biomedical Data Management	7-7
7-2	Auxiliary Data-Management Systems for Centrifuge and Extravehicular Operations	7-8
7-3	Personal Telemetry System (PTS) - Three Operational Modes	7-17
7-4	PTS Duplex Voice/Data Transmission System	7-19
7-5	PTS Simplex Mode	7-21
7-6	General-Purpose Spaceborne Computer - CDC Model 5500	7-24
8-1	Endoradiosonde Pill for Measurement of Gastrointestinal Tract Pressure, pH, and Temperature	8-7
8-2	Endoradiosonde Modulation and Transmission Technique	8-9
8-3	Infrared Human-Body Scanning Thermometer	8-11

TABLES

<u>Table</u>		<u>Page</u>
2-1	Data-Processing Storage Requirements	2-12
2-2	Gravity Gradients for Subject Seated in Centrifuge	2-16
3-1	Work - Rest Cycle	3-6
3-2	Physiology Laboratory - Bioinstrumentation	3-9
3-3	Recommended Measurements for MORL	3-14
3-4	Rapid, Prepared, Clinical Test Units	3-15
3-5	Recommended Preflight and Postflight Determinations	3-18
3-6	Radiology Laboratory Measurements	3-20
3-7	Radioisotope Measurement Techniques	3-23
3-8	Radiology Laboratory Equipment	3-27
3-9	Human-Performance Measurement and Equipment	3-29
3-10	Human-Performance Measurement and Evaluation - EVA	3-31
3-11	Centrifuge Laboratory - Bioinstrumentation	3-33
4-1	Measurement Categories	4-3
4-2	Comparison of Two Console Stations for MORL	4-10
4-3	Data and Power-Handling Solutions	4-12
4-4	Comparison of Equipment With Criteria - Extravehicular Activity	4-32
4-5	Criteria of Comparison for Alternate Mass Measurement Systems	4-55
5-1	Physiology Laboratory - Bioinstrumentation Display and Control Panel	5-6
5-2	Extravehicular Activity - Minimum Control Panel Functions	5-8
5-3	Centrifuge Laboratory - Minimum Control Panel Functions	5-10
5-4	Summary of Major Equipment, Weight, and Volume	5-63
7-1	Estimated Power Requirements for Data-Management Equipment	7-5

Table		Page
7-2	Design Considerations and Recommendations for Personal Telemetry System	7-13
7-3	Computer Characteristics	7-25
8-1	Preliminary Design Analysis	8-13

1 INTRODUCTION



Section 1
INTRODUCTION

1.1 BACKGROUND

Prolonged manned space missions pose several potentially acute bioastronautics questions. One significant unknown is the degree of influence a gravitational field has on the major human body system. Another equally important unknown is the effect of man's re-exposure to normal activity, under the customary gravitational load, following exposure to periods of prolonged weightlessness.

Actual long-term exposure to the space environment is the only valid approach for obtaining the desired information, and for establishing reliable criteria for interplanetary flight. The primary criterion is man's adaptation to prolonged weightlessness. However, the following additional factors also must be considered:

- Man's adaptation to constant or changing rotation
- Long-term effect of ionizing radiation
- Effects of closed ecological systems
- Exotic atmosphere effects
- Psychophysiological factors (combined stress effects)
- Space testing of advanced technological systems

The Biolabs study for the National Aeronautics and Space Administration (NASA) was initiated at Lockheed Missiles & Space Company (LMSC) to develop the information and concepts necessary for formulating technical decision regarding the aforementioned criteria. This report presents the conceptual design of a measurement system which has been developed by LMSC to fulfill the technical task requirement of providing such a system for the NASA Manned Orbital Research Laboratory (MORL).

1.2 SCOPE OF STUDY EFFORT

A short-term intensive study of the MORL design by the Douglas Aircraft Company (Ref. 1-2) has formed the basis for establishing specific study tasks. In addition, technical meetings were held with Douglas MORL project personnel and interface problems and possible solutions were established.

The specific Biolabs Study tasks to be accomplished by LMSC were as follows:

- Determination of the constraints and capabilities of the MORL
- Evaluation of the effect of including an on-board physician or scientist
- Design of a biomedical and human-performance measurement system
- Implication of three operational modes – intrastation, centrifuge, and extravehicular
- Determination of an optimal data-management system
- Consideration of operational interfaces and a schedule evaluation plan
- Determination of areas and specific equipments requiring further investigation and/or development

Before initiating the conceptual design phase, it was necessary to review in detail the present status of the MORL Program, examine the many parameters that could have an influence on the design, perform system analysis in areas to determine the feasibility of integrating the measurement system into existing on-board systems, and conduct space allocation studies.

A parallel effort was conducted in the further laboratory implementation of previous designs and the adaptation of equipment that had been designed under the Apollo-X portion of the Biolabs Study (Ref. 1-3). Specifically, this effort was directed toward refinement of the body mass-measurement system, the Biometric station console design, and the definition of physical-conditioning techniques. These activities culminated in designing a mass-measurement system based on a linear acceleration principle, and a crew-performance console simulating the flight-operation console.

1.3 CONCEPTUAL DESIGN EVOLUTION

Requirements and recommendations for the MORL were furnished by the Biolabs Study laboratory leaders to the study system engineering and integration group. These data, based on prior study effort, were received by the design team early in the MORL phase. This early availability allows more detailed attention to be given to the measurement implementation and permitted more consideration to be given to furnishing an integrated system for a family of biomedical measurements.

In those instances, where various candidates could be established to perform the measurement, a detail system analysis approach was used. By following an iterative process, engineering recommendations were reviewed by the appropriate laboratory leader, the Study leader, and the responsible engineer. Upon a firm recommendation, the preliminary design specifications of the selected candidate were listed, and the final design phase was initiated.

1.4 STUDY GROUND RULES

The MORL system characteristics have undergone several significant changes since initiation of the Biolabs Study, requiring corresponding revisions in the Biolabs Study effort. Major changes included in this group have been associated with the continuing study conducted by Douglas Aircraft for the NASA-Langley Research Center (Ref. 1-2). The most current configuration was released in December 1964. The changes most directly affecting the Biolabs Study were the increase in experiment payload capability from 1,847 lb to 6,000 lb and the establishment of a 6-man crew consisting of engineering and scientific skills. Other factors that influenced the measurement system design were the separated compartment concept employed in the MORL forward compartment, the 10-ft radius on-board centrifuge, and the scheduled extravehicular activity.

1.5 TECHNICAL DEFINITIONS

Certain specialized terms and titles will be found throughout this volume. To facilitate understanding and interpretation of its contents, general definitions and explanations of the more significant terms are provided as follows:

- Orbital Research Laboratory (ORL). Applies to Apollo X, Apollo Extension Systems (AES), and Manned Orbital Research Laboratory.
- Manned Orbital Research Laboratory (MORL). Designation limited, in this volume, to the 6-man stabilized laboratory module.
- Laboratories (Biolabs). Applies to the Physiology, Microscopy and Chemistry, Radiology, Crew-Performance, and the Centrifuge Laboratories in each ORL.
- Biomedical and Human Performance Program. Applicable to Technical Tasks A and B as defined in Ref. 1-1.
- Measurement System. Refers to the measurements and equipments integrated into a conceptual design for the MORL. Six subsystems have evolved during the study that define further the measurement system — Biometric, Micro-Chem, Crew-Performance, Centrifuge, Extravehicular, and Laboratory. Following are brief descriptions of these subsystems:

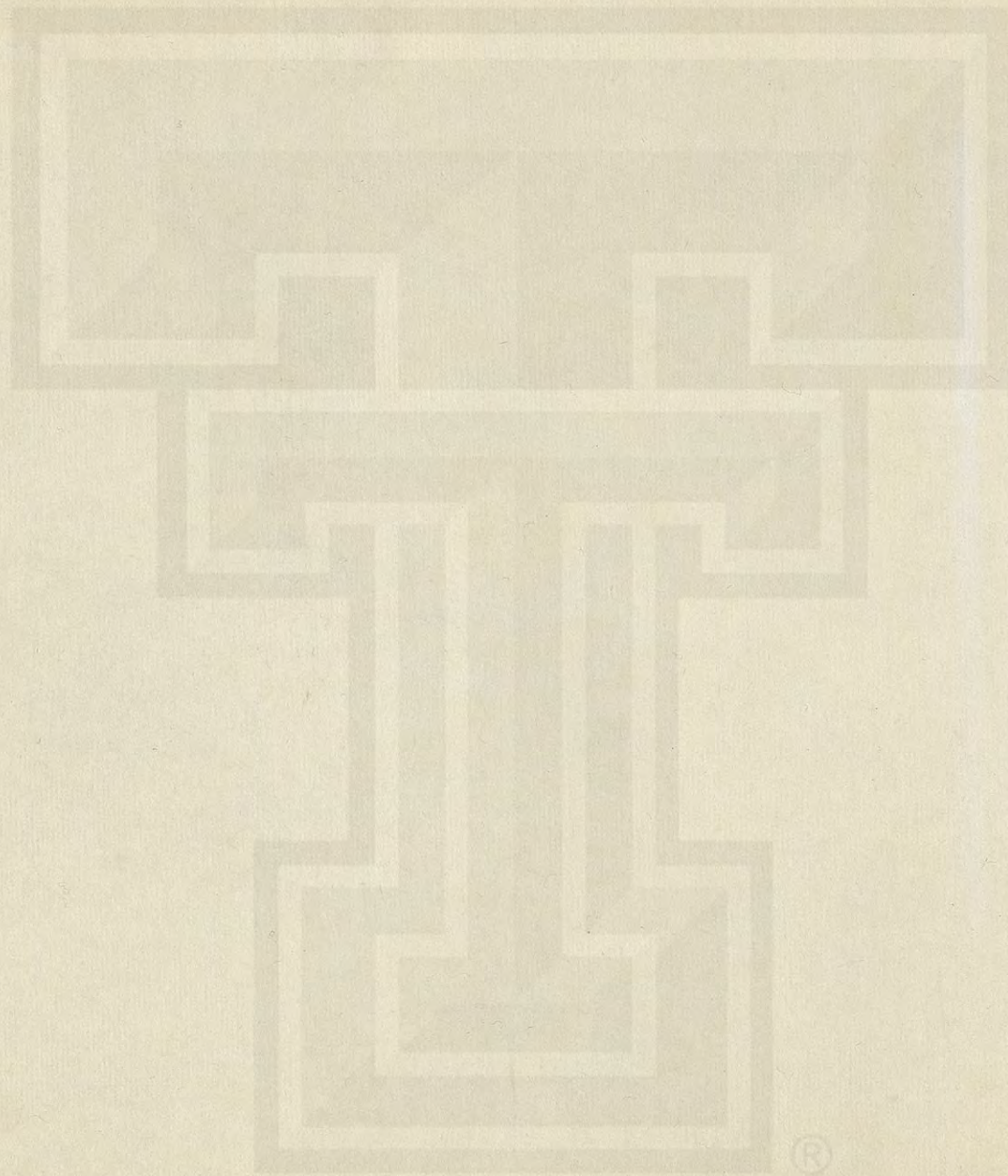
- Biometric. Provides biomedical monitoring measurements and those required for support of biomedical and human performance experiments. The Biometric station includes a "biometric jig" which is used for housing sensors and for astronaut positioning during a measurement test. The station also incorporates displays and controls for biomedical measurements made in the centrifuge and during extravehicular activity.
- Crew-Performance. Integrated into the Biometric station. It incorporates displays and controls identical to those located on the MORL operational display and control panel. In addition, it provides displays and controls identical to those employed by the Apollo logistics spacecraft for the

reentry maneuver. Displays and controls for crew-performance tasks employed on the centrifuge and during extravehicular activity are presented by the Crew-Performance Subsystem.

- Micro-Chem. Comprises a two-element subsystem to perform Microscopy and Chemistry monitoring and laboratory functions. One element consists of equipment and work tables located in the sealed biological/liquid compartment. The other element is adjacent to the sealed compartment and provides work space for microscopic analysis, spectrophotometry, and chemical analysis. Radiology measurements are taken in the sealed biological/liquid compartment.
- Centrifuge. Concerned with physiological and human-performance measurements performed by means of the MORL on-board centrifuge.
- Extravehicular. Provides both physiological and human-performance measurements. The physiological measurements are limited to those required to establish crew-member safety status. The human-performance measurement scope is much more extensive since evaluation of man's capability to perform in the space environment is of prime concern.
- Laboratory. Reserved for subsystems or equipment providing support for either the Physiology or Microscopy and Chemistry Laboratories (e.g., telemicroscope, mass-measurement system, etc.).

1.6 SUMMARY OF CONTENTS

This volume presents the various considerations, approaches, requirements, analysis, and designs involved in the Biolabs Study with respect to the MORL biomedical measurement system. Various aspects treated include a description of the MORL, measurement requirements and their implementation, system analysis and integration, and conceptual design. Data-management requirements also are discussed; operational considerations are presented; and a computer schedule evaluation plan is described.



Section 2

THE MANNED ORBITAL RESEARCH LABORATORY

2.1 BACKGROUND

The Manned Orbital Research Laboratory (MORL) Program has been established by the National Space and Aeronautics Administration (NASA) to attain the following major objectives:

- Determination of man's psychophysiological tolerance to the effects of long-term weightlessness and his capability for the efficient performance of work under such conditions
- Identification of the physical laws and phenomena which will affect the performance of future spaceborne vehicles and equipment

A number of organizations have conducted MORL studies for NASA. A MORL configuration developed by the Douglas Aircraft Corporation for the NASA-Langley Research Center (Contract No. NAS 1-2974) was designated by NASA as the concept for which a biomedical measurement system was to be developed by LMSC.

The Douglas study considered three basic configurations for MORL, as follows:

- 154-In.-Diameter Laboratory. Specified by Langley RFP; smallest diameter and least internal living space of the three configurations; similar to launch configuration of combined Apollo command and service module
- 220-In.-Diameter Laboratory. Compatible with Saturn-I launch vehicle diameter; on-board centrifuge
- 260-In.-Diameter Laboratory. Compatible with Saturn-IB launch vehicle diameter; on-board centrifuge

The parameters and features of the 260-in. configuration will be utilized as the basis for LMSC development of the biomedical measurement system for MORL (Ref. 2-1).

2.2 DESCRIPTION OF MORL SYSTEM

The MORL System consists of a 6- to 9-man laboratory module to be launched, unmanned, by a Saturn-IB vehicle into a low-inclination earth orbit. The module will be initially manned and subsequently resupplied by a combined ferry-resupply logistics system incorporating an Apollo command module and an S-IB launch vehicle. The rendezvous-and-docking, on-orbit, and recovery operations of the logistics system will be a direct outgrowth of the Gemini/Apollo programs. Initial missions will be restricted to low-inclination earth orbits while advanced missions are concerned with high-inclination earth, synchronous, and lunar orbits. The Biolabs Study is concerned only with the basic low-inclination earth orbit.

General characteristics of the MORL System are as follows:

● Launch vehicle	Saturn IB
● Crew size	6 (lower limit) 9 (upper limit)
● Manned at launch	No
● Crew composition	Astronauts/scientists
● Crew duty cycle	3 mo
● Ferry/resupply system	Saturn IB/Apollo
● Mission period	1970
● Weight	6,000 lb*
● Volume	1,100 cu ft*
● Power	1.2 kw*
● Crew time (experimental)	16,700 man hr/yr (crew of 6)
● Total volume	9,000 cu ft
● Total power	6.6 kw

More detailed physical characteristics of the MORL are contained in the Biolabs Study Progress Report (Ref. 2-2) and in Ref. 2-1.

*Required for engineering, scientific, and biomedical and human-performance experiments

2.3 MAJOR SYSTEM ELEMENTS

The two major functional elements of the MORL are the laboratory module and the logistics vehicle. The laboratory module includes two independently pressurized compartments connected by an airlock. The larger of the two compartments comprises the following areas:

- A control deck from which laboratory operations and a major portion of the experiment program will be conducted.
- An internal centrifuge in which members of the flight crew will perform reentry simulation and undergo physical condition testing. This area also may be usable for therapy, if required.
- Flight crew quarters which will include sleeping, eating, recreation, hygiene, and liquids-laboratory facilities.

The smaller compartment is a hangar/test area used for logistics spacecraft maintenance, cargo transfer, experimentation, satellite checkout, and flight-crew habitation in a deferred-emergency mode of operation.

The logistics vehicle is composed of the following elements:

- A logistics spacecraft, including Apollo command and service modules with a launch escape system and a service pack for rendezvous and reentry maneuver propulsion. This spacecraft may also carry a multimission module for either cargo, experiments, laboratory facility modifications, or a spacecraft excursion propulsion system.
- A Saturn-IB launch vehicle

2.4 CREW ROTATION AND RESUPPLY

Apollo spacecraft (command and service modules), boosted by S-IB launch vehicles, will be used for crew rotation purposes. As a conservative measure, the crew rotation period will be initially set low, and then increased in length as experience

is gained, until the allowable exposure time of crew members to the environment is established. It is desirable to rotate 12 crewmen/yr.

The docking techniques and equipment developed for Gemini/Apollo will be used. The MORL docking hangar provides a shirtsleeve environment for crew transfer operations. The logistic spacecraft will be docked to the MORL, and the cargo modules will be separated. Each module will be rotated by mechanical linkage to a parking position along the hangar/test area exterior.

2.5 LABORATORY MODULE

The interior of the MORL laboratory module is arranged in two decks, separated by the central centrifuge compartment. The "upper" deck is used as a living area and the "lower" deck as the working area.* Space and facilities for recreational and physical fitness activities are provided in the upper deck, along with the galley, two toilets, and a lavatory equipped for body-cleansing purposes.

The lower deck is divided by consoles and partitions into four bays. One console is associated with operations and command and control of the station; another is associated with experiment control; and the last two are devoted to experiment procedures.

The operations-control station incorporates control of all vehicle maneuvers. It contains displays and controls related to the following orbital functions:

- Stabilization and control
- Navigation and guidance
- Rendezvous and docking
- Orbit keeping
- Deployment
- Spin up and de-spin

*These designations refer to the arbitrary orientation indicated by the interior arrangement. The vehicle is actually inverted, in terms of its interior arrangement, on the launch pad and during boost.

- Vehicle warning and caution
- Resupply spacecraft control

The behavioral experiment control station contains all controls and displays necessary to conduct behavioral experimentation. It includes provision for a station operator and a test subject.

The subsystem and experimental test station incorporates displays and controls for the following subsystems:

- Environmental control and life support
- Propulsion
- Testing and maintenance
- Lighting
- Communications
- Data management
- Electrical power

Biomedical monitoring of all crew members is accomplished at this station. An adjacent biomedical couch permits close coordination between operator and subject. In addition, the subsystem and experimental test station display the following information:

- Status of stowed logistics and other spacecraft
- Warning and caution system for critical vehicle subsystems (duplicated from the operations-control station)
- Information for scientific and engineering tests

A work area for maintenance and subsystem testing is maintained near this station.

Two airlocks are provided adjacent to the docking lounges and the lower deck. Each lock is provided with pressurization control, emergency lighting and station controls, and intercommunication facilities.

An artificial-gravity capability is provided. It consists of an onboard centrifuge capable of providing g forces up to the point of simulated reentry. This centrifuge, accommodating one or two men, is housed between the two vehicle decks, and has a large hollow hub allowing passage between decks independent of centrifuge operation. The centrifuge speed is variable to allow for a variety of therapeutic and experimental uses, up to and including simulated reentry. This latter use will involve rotational speeds up to about 50 rpm, a rate considered by some authorities as an order of magnitude higher than the tolerance level for a human subject.

2.6 ENVIRONMENTAL-CONTROL AND LIFE-SUPPORT SYSTEM

The environmental-control and life-support system is based on Mercury, Gemini, and Apollo technology and provides a shirtsleeve atmosphere consisting of 50 percent oxygen and 50 percent nitrogen at 7 psia. Pressurized or unpressurized space-suit operation is possible in the cabin and in either airlock. The system accommodates the Apollo space suit and backpack.

A recirculating liquid-cooling system (employing Monsanto Coolanol 25) collects excess heat from the vehicle atmosphere by means of the atmospheric purification loop and from the laboratory refrigerator and the vehicle electronics. The system rejects most of this heat to space through a 380-sq-ft tubular radiator that is protected by the micrometeoroid structural shield.

2.6.1 Atmosphere Component Supply

Oxygen and nitrogen in tanks are stowed subcritically in the hangar area. Gaseous reserves are maintained in the laboratory. Resupply is accomplished by the replacement of empty tanks with full ones.

Carbon-dioxide removal is accomplished through adsorption by molecular sieves, and rejection to space when the sieves are desorbed. Water removal is accomplished by a combination of condensation and absorption by a silica-gel bed.

Trace contaminant control is provided by a combination of charcoal filtering, catalytic burning, and treatment by a chemisorbent bed.

2.6.2 Water Supply

Urine recovery for drinking purposes is accomplished by an electrodialysis batch process in conjunction with filtration and sterilization with ultraviolet radiation. A bacteria culture check is conducted daily before this water is released into the station supply for consumption.

Wash water and atmospheric condensate are processed by a simpler system using a dust filter, a mixed ion-exchange and charcoal bed, and an ultraviolet lamp.

2.6.3 Food Supply

Crew members will be supplied with food at the rate of from 2,500 to 3,000 kcal/day, with a calorie distribution of 15 percent protein, 55 percent carbohydrate, and 30 percent fat.

Food packaging, handling, and preparation methods have not been defined. Hot water for food preparation, as well as for personal hygiene purposes, will be available from a small radioisotope heater. This heater will also provide hot water for cooking.

2.6.4 Personal Hygiene

A lavatory provided in the vehicle upper deck is equipped with body-cleansing, shaving, and laundry facilities. Sufficient space is available to accommodate a shower.

2.6.5 Waste Management

Feces will be collected in polyethelene bags that are permeable to gases but not liquids. The waste will then be sterilized and dehydrated by exposure to heat. Related

gases and water vapor given off will be vented to space, and the solid residue placed in empty food containers. These containers, along with other food-based solid waste material, will be stowed aboard resupply vehicles to be destroyed with them on reentry.

2.7 POWER SUPPLY

The MORL electrical power system provides an average of 6.03 kw of primary power for 2 yr with slowly degrading values thereafter. The system, based on an oriented solar cell/battery primary power source, is divided into four, identical, independent, power sources. Any one of these sources is sufficient to support the station requirements, either manned or unmanned, in an emergency mode.

The N-on-P silicon solar cells are arrayed in 4 flat panels of 262.5 sq ft each. They are connected in parallel modules of 5 to 10 cells each. These modules are, in turn, connected in series strings of 5 to 10 modules. The series strings are connected in series and parallel until proper voltage and current are obtained.

The secondary batteries, which provide dark-side energy storage, are of the nickel-cadmium type. Four batteries are provided, with a total capacity of 300+ amp-hr, and a total weight of 590 lb.

Two types of dc-ac conversion devices are used as follows:

- A general-purpose inverter, providing low-harmonic-content, 400-cps, 115 to 200-v, 3-phase, regulated current for gyros, synchros, and high-voltage lighting and display systems
- Motor inverters providing quasi-square-wave, 3-phase, 400-cps current at battery voltage peak to drive all motors on board the vehicle

The longitudinal axis of the spacecraft is normally oriented perpendicular to the orbit plane, with the vehicle rolled so that the solar panels can be rotated about their pitch axis to point at the sun.

2.8 GUIDANCE AND NAVIGATION

The MORL is launched unmanned. The first stage of the Saturn-IB launch vehicle is altitude-programmed to staging. The second stage is guided to orbit by the Saturn inertial guidance system. Upon orbit establishment, the stabilization and control system of the MORL is immediately activated in order to null residual momentum and to achieve solar orientation.

Orbit verification and preliminary assessment of the subsystems are accomplished on the first day by means of the ground tracking network. Final checkout of the MORL critical systems is completed within three days, thus establishing readiness for manned occupancy.

The navigation subsystem provides the following information, of which the first item is most critical:

- Accurate initial-condition data for deorbit and reentry guidance of the Apollo command module
- Data necessary to program deorbit of the resupply craft to ensure the occurrence of reentry and subsequent destruction over an ocean area
- On-board data necessary to perform the orbit-keeping function
- A yardstick for conducting on-board navigation experiments

The navigation subsystem is based on ground tracking and on ground-based computation of the MORL orbit and position, transfer of these data to the on-board digital computer, and computer extrapolation of the orbit. The navigational errors accumulating over a 12-hour tracking occultation interval still allow Apollo deorbit and reentry requirements to be met.

2.9 STABILIZATION AND ATTITUDE CONTROL

Attitude control is provided by using a reaction wheel for fine roll-control and control moment gyros for fine pitch-and-yaw control. These function in concert with reaction jets for coarse control about all three axes.

Orbit keeping is accomplished every fourth day by applying thrust when the longitudinal axis of the MORL is parallel to the orbital velocity vector.

2.10 DATA MANAGEMENT

The data management subsystem enables the MORL to control and monitor experiments, to acquire and store data from these experiments and from operational subsystems, and to transfer the data to the communication subsystem for transmittal to the ground. This subsystem performs three major functions as follows:

- Data acquisition
- Data processing
- Rendezvous and docking guidance

It also includes three auxiliary systems — a data file, facsimile typewriters, and a proficiency simulator.

2.10.1 Data Acquisition

This function provides for the acquisition and storage of both operational and experimental data. Operational data are acquired continuously for eight orbits and stored on magnetic tape for subsequent transmission to the ground when telemetry coverage is available. Experimental data are encoded, formatted, and stored in the digital and analog storage units, each with a storage capacity of 1.5 hr, for subsequent transmission to ground. Data on behavioral experiments are processed and interpreted by the central computer, thus reducing storage requirements considerably.

2.10.2 Data Processing Function

A central computer, a data adapter, and an auxiliary memory provide for performance of this function.

The central computer is the triple, modular, redundant computer being developed for Saturn V. It has a memory capacity of 16,384 thirteen-bit words. The instructions and constants required for navigation, the executive routing, and the computational subroutines are stored redundantly in separate sections of the computer memory. Rendezvous and computer diagnostic test routines are stored permanently, but not redundantly, in the computer memory. These routines and others can be stored redundantly by insertion into a separate memory section from an auxiliary memory tape. A summary of data storage requirements for MORL is presented in Table 2-1.

The data adapter accepts signals from the main power supply and generates the regulated power and power sequencing required for operation of the computer, for data acquisition, and for the data adapter itself.

The auxiliary memory consists of individual magnetic tape reels from which data are read into the central computer memory by means of the medium rate recorder. During this operation, the writing capability of the recorder is automatically disabled. To assure adequate storage and insertion reliability, each data bit is stored in a 5-bit code on the tape and automatically checked before insertion into the computer memory.

2.10.3 Rendezvous and Docking

This function is performed by using the central computer to compute the commands to be sent to the resupply vehicle during the rendezvous and docking maneuvers by means of a rendezvous radar located in the MORL. Return data are transmitted through a radar transponder link.

The data-file auxiliary system provides a ready reference to microfilm cards containing maintenance and repair procedures, MORL engineering data, experiment instructions, etc. A viewer is provided.

Table 2-1

DATA PROCESSING STORAGE REQUIREMENTS
(Equivalent Instruction Words - 13 Bits Each)

Function	Core Memory		Auxiliary Memory
	Permanent	Temporary	
Navigation & Station-Keeping	+700 +700*		700
Rendezvous	2,750	2,750	2,750
Checkout		4,500	50,000
Behavioral		4,500	10,000
Scientific and Engineering Experiment		2,750	10,000
Simulation		3,040	3,040
Executive Routine	425 +425*		425
Computational Subroutines	1,175 +1,175*		1,175
MDIU	1,100		1,100
Diagnostic Test	750		750
Total Storage	9,200	17,540	79,940

*Redundant Storage

The facsimile typewriter printout prints, at a compatible speed of 15 characters/sec, ground-generated data which are transmitted to the MORL by the digital command system and stored in the computer memory.

The proficiency simulator provides for training in rendezvous and docking and ferry reentry. It uses the same MORL operational hardware as that provided for rendezvous and docking of the unmanned logistics vehicle. These displays and controls with an articulated logistics vehicle operate in conjunction with the television system to perform the simulation. The control signals are processed through the central computer, which generates the appropriate display deflections.

Similarly, the reentry simulation uses Apollo operational displays and controls in conjunction with the MORL central computer to effect the simulation.

2.11 COMMUNICATIONS

The communications subsystem for the MORL includes a variety of communications functions.

2.11.1 Voice

The voice communications group consists of a VHF and an HF transceiver. The VHF transceiver is the primary voice link between MORL and the ground stations and the ferry spacecraft. The HF transceiver serves as a secondary to the VHF, and is also used in over-the-horizon propagation experiments. A VHF power amplifier is provided for situations where communication with non-MORL ground sites is necessary.

An onboard intercommunication system is provided as part of the voice communication system, and a local RF voice system is included in the telemetry link between the MORL and astronauts engaged in extravehicular operations.

2.11.2 Command

Very-high-frequency command data transmitted from the command site to MORL are channeled to the digital-command receiver/decoder, which verifies acceptance of each command word by telemetry. The decoder distributes the command, as required, to the computer, the timing system, or actuators.

2.11.3 Television

The television system provides both a video signal for real-time transmission to the ground for monitoring behavioral and biomedical experiments, and a closed-circuit onboard TV system for observation or resupply-vehicle docking, and for centrifuge experiments, certain maintenance functions, and extravehicular operations.

Three cameras and two monitors are provided. One camera views the docking maneuver and is monitored at the main console. A second camera, located with its monitor in the biomedical and engineering control station, is used for psychological-behavioral crew interviews and in conjunction with the rendezvous and docking simulator. The third camera is a portable unit used to complete station coverage in general and to provide centrifuge coverage in particular.

Functional characteristics of the television system are as follows:

- Color – black and white
- Frame rate – 30/sec (onboard closed circuit)
- Seam lines – 525 per frame (approx. square)
- Video bandwidth – 2.1 Mc

2.11.4 Tracking

Equipment provided for tracking consists of a VHF beacon for acquisition and a standard C-band transponder compatible with the FPS-16, FPQ-6, and MPS-26 radar.

2.11.5 Telemetry

Two telemetry transmitters are used. The first transmits the following data:

- Stored PCM data from tape recorder at a rate of 67.2 kbps
- Real-time telemetry data at a rate of 2,100 bps
- Command verification data at a rate of 640 bps

The second transmitter sends the following information:

- Additional stored PCM data from tape recorder at a rate of 67.2 kbps
- Two analog data signals from tape recorder

2.12 OPERATION/EXPERIMENTAL AREA

The operations-control station incorporates control of all vehicle maneuvers. It contains displays and controls related to the following orbital functions:

- Stabilization and control
- Navigation and guidance
- Rendezvous and docking
- Orbit keeping
- Deployment
- Spin up and de-spin
- Vehicle warning and caution
- Resupply spacecraft control

The behavioral experiment control station contains all controls and displays necessary to conduct behavioral experimentation. It includes provision for a station operator and a test subject.

The subsystem and experimental test station incorporate displays and controls for the following subsystems:

- Environmental control and life support
- Propulsion
- Testing and maintenance
- Lighting
- Communications
- Data management
- Electrical power

Biomedical monitoring of all crew members is accomplished at this station. An adjacent biomedical couch permits close coordination between operator and subject.

In addition, the subsystem and experimental test station display the following information:

- Status of stowed Gemini and other spacecraft
- Warning and caution system for critical vehicle subsystems (duplicated from the operations-control station)
- Information for scientific and engineering tests

A work area for maintenance and subsystem testing is maintained near this station.

2.13 INTERNAL CENTRIFUGE

External centrifuges were eliminated from consideration as being undesirable from the crew safety standpoint. Other undesirable features were greater weight and complexity, due to the fact that an external centrifuge must carry its own pressure shell and meteoroid protection, as well as a separate life-support system.

The 154-in.-diameter MORL laboratory module, smallest of the three considered, was eliminated because of gravity gradient problems. For the three sizes of laboratory module originally considered, tabulated values of gravity gradient for a man seated in a centrifuge are as shown in Table 2-2.

Table 2-2

GRAVITY GRADIENTS FOR SUBJECT SEATED IN CENTRIFUGE

Position	Laboratory Module Diameter (in.)		
	154	220	260
Gravity Gradient - Reentry Position (%)	35.8	24	20
Gravity Gradient - Upright Position Seated (%)	72.3	49.5	41.9

The Douglas MORL centrifuge design consists of two fully enclosed cabs, supported by welded aluminum tubular trusses and located 180 deg apart on a drive ring fabricated from 4-in. aluminum tubing. This ring is 108 in. in diameter and is the

innermost moving component of the centrifuge assembly. It surrounds a 100-in. diameter stationary inner hub which serves as the passageway between compartments adjacent to the centrifuge compartment. The entire centrifuge assembly is suspended by the drive ring which rides on three sets of three rubber rollers each. The assembly is driven through one of the rollers, by a 1-hp shunt-wound d-c motor through a V-belt drive. The drive has alternate pulleys to provide the necessary ratios for two modes of operation: (1) a low-level mode providing up to 1 g (20.5 rpm); and (2) a simulated Apollo reentry using speeds up to 60 rpm.

A solid-state motor control is used to program the centrifuge operation, including dynamic braking by means of the drive motor. A mechanical brake is used for final stopping and emergency stops. A 30-in. diameter reaction wheel, mounted on the drive motor, counteracts the starting torque for the low-level mode of operation. Each cab has a couch, adjustable to accommodate the various crew members. The entire couch assembly may be adjusted to achieve various crew member positions, ranging from upright sitting to supine attitudes.

The centrifuge operating controls are in the biomedical experimental control station, with emergency controls in each cab. When the centrifuge is operated with only one man aboard, the empty cab is ballasted with station supplies to achieve rough balance of the centrifuge. A movable weight is provided to achieve fine balance of the centrifuge, whether one or two men are aboard.

A TV camera is provided to allow observation of the subject. In addition, his respiratory rate, pulse rate, blood pressure, ECG, and, possibly, galvanic skin response will be monitored. Either an FM transmitter or slip-rings may be used for transmitting these data.

An external centrifuge of the type shown in Fig. 2-1 has been proposed by the Douglas Aircraft Corporation and considered by LMSC in connection with the centrifugation aspect of the Biolabs Study.

2-18

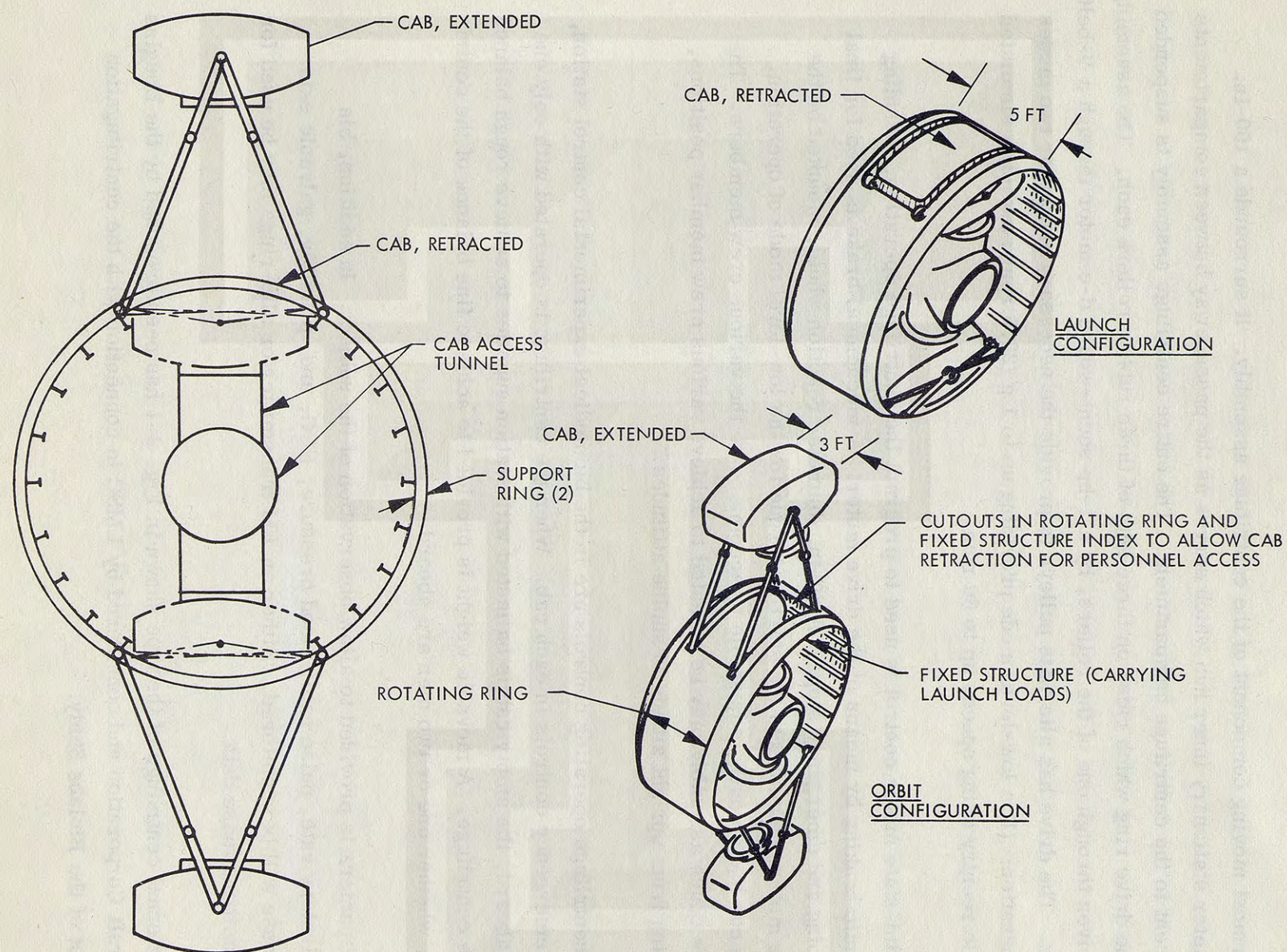
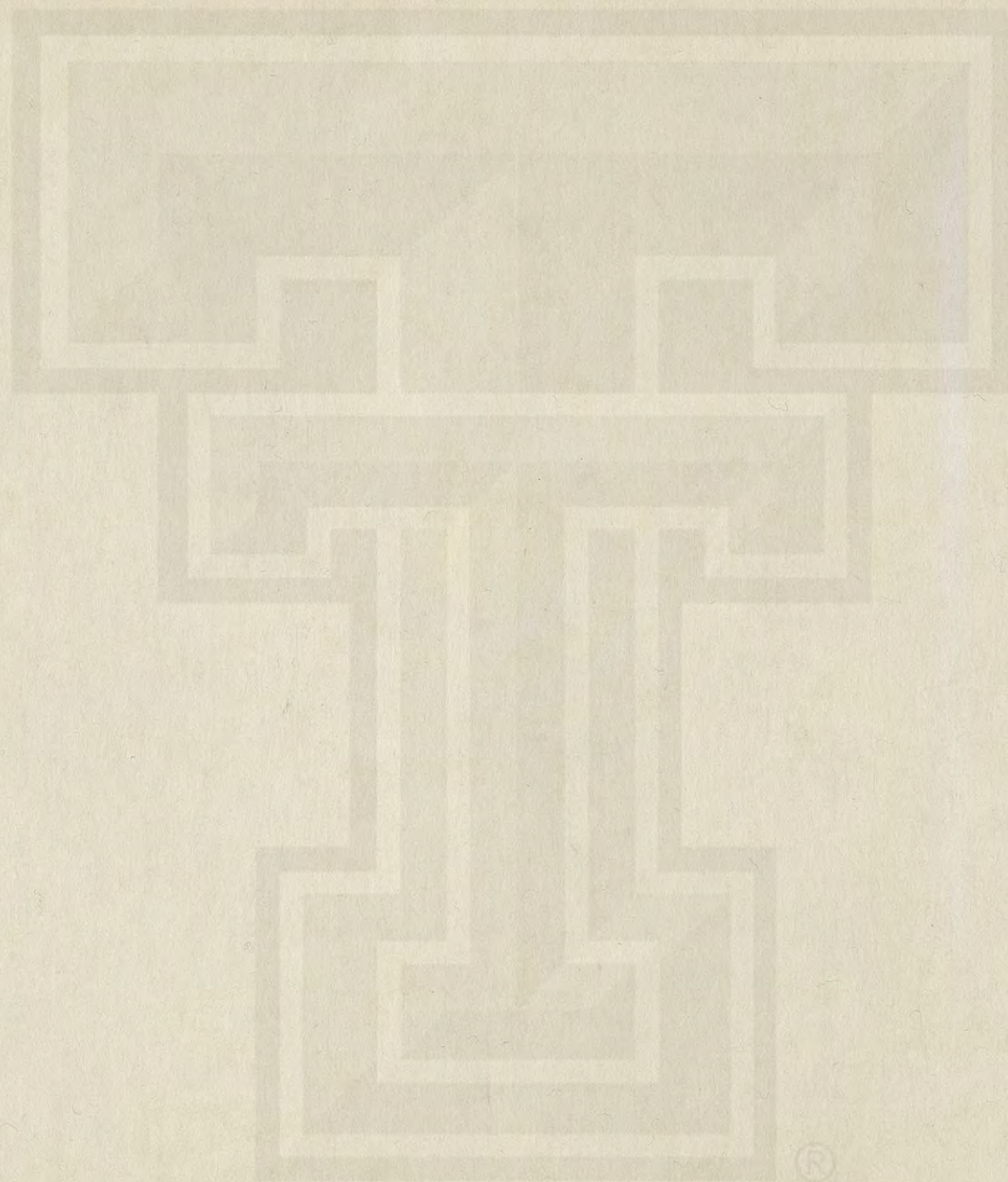


Fig. 2-1 External Centrifuge

3 BIOMEDICAL AND HUMAN-PERFORMANCE
MEASUREMENT REQUIREMENTS



Section 3
BIOMEDICAL AND HUMAN-PERFORMANCE
MEASUREMENT REQUIREMENTS

3.1 GENERAL CONSIDERATIONS

The Manned Orbital Research Laboratory (MORL) is designed to provide a versatile facility for experimental research. The principal characteristics of the MORL that permit carrying out an extensive Biomedical and Human-Performance Program are as follows:

- Skilled On-Board Personnel
 - Engineers (3)
 - Medical Specialist (1)
 - Life Sciences Specialist (1)
 - Physical Sciences Specialist (1)
- Availability of Adequate Testing Time
 - Behavioral Experiments (6 man-hr/day/crew)
 - Biomedical Experiments (12 man-hr/day/crew)
 - Contingency Factor (14.4 man-hr/day)
- Space and Equipment
 - Living and Recreational Area
 - Centrifuge
 - Operational and Experimental Area
- Payload Capability of 6,000 lb — Scientific, engineering, biomedical, and crew-performance experiments

Measurements designed to assess fully the effect of weightlessness on man's physiology and performance capability were evaluated and selected on the basis of the foregoing characteristics.

Final decisions important to the welfare and survival of the astronaut call for the attention and capabilities of monitoring medical specialists trained in medicine and measurement techniques and normally located at a ground station. Inclusion of one or more such specialists as on-board "astrophysicians" in the MORL crew, with related direct contact, offers the following significant advantages:

- Better maintenance of health and performance levels of astronauts
- A greater yield of more valid and meaningful space-based biomedical information

The first objective of the MORL design, therefore, is to enhance the efficiency of the astrophysician in sustaining the well-being and capabilities of other astronauts by means of appropriate and time-proven clinical procedures and instrumentation. A second MORL design objective, also stemming from the desirability of the on-board presence of a trained astrophysician, involves the following aspects:

- Provision of instrumentation facilitating the making of more accurate and valid measurements
- Increased measurement reliability since the astrophysician's presence permits the use of simpler instrumentation designed for direct human rather than automated or remote-control operation
- Increased versatility and flexibility in test selection, administration, observation, and evaluation

The factor of increased versatility and resourcefulness thus gained through the on-board presence of the astrophysician will be exploited to the fullest in the MORL design, particularly in view of the fact that space experiments as currently conceived are subject to modification after initial empirical findings are taken and evaluated.

Another important factor distinguishing the MORL design from more limited configurations involves the communication link with ground observers. Instead of transmitting data in the raw state, the data may be edited and processed into information by the astrophysician before transmission. The power and time saved can be used for closer and

more profitable exchanges between on-board and ground experts, for consultation on health problems, and for updating, improving, and/or devising new experiments. In this connection, complex information processing can be accomplished by ground computers and the results relayed as required to the astrophysician in the MORL.

Performance of many of the usual clinical procedures will still prove difficult because of the characteristics of the space environment. This section presents the measurement requirements for the five laboratories developed under Tasks A and B of the Biolabs Program (Ref. 1-1). The requirements have been established by considering two separate aspects - biomedical and human-performance monitoring experimentation.

In addition, this section presents measurement implementation procedures. This procedure treats the process of selection of hardware, measure by measure, in the light of all constraints. It presents alternative techniques and logical selection process through stages. The recommended technique or procedure for taking a particular measurement is discussed and the appropriate equipment is described. This section will be limited to recommending hardware/equipment that can be determined with relative ease to be an outstanding candidate for taking the required measurement. In cases where several alternative candidates are proposed which require more detail system analysis to verify the best possible candidate, such analysis, and related recommendations, is presented in Section 4 of this volume.

3.2 BIOMEDICAL AND HUMAN-PERFORMANCE MONITORING

3.2.1 Biomedical Monitoring

This aspect includes sensing, signal-conditioning, and decision-making concerning a minimal number of body functions necessary to ensure the safe and reasonably comfortable continuance of a person's well-being. The person being monitored will be encumbered under the most optimal conditions. Great effort should be taken to keep the encumbrance to a minimum, consistent with safe medical practice. Monitoring of data only of academic interest and complete diagnosis of long-range efforts are not

included in this area. Only those body functions of vital interest should be monitored. These should be ranked clearly and simply, with a "yes" or "no" conclusion by the physician, if possible. The incidence of monitoring for each function should be only as frequent as necessary. Simple, reliable measuring methods are preferred to complex, slow-resolving methods. For the MORL, the monitoring function must be carried out for three operational modes as follows:

- Intrastation
- Extravehicular
- Centrifuge

3.2.2 Human-Performance Monitoring

This phase is concerned with presenting performance data in a form which will supplement the use of the physiological measures in establishing the current status of crew members. The data will be made available for predicting future success in performing mission-oriented spaceflight tasks. These predictive measures will be provided by special-performance tasks representing basic human skills. The results of astronaut performance will be collected and displayed in conjunction with physiological data in order to gain a better understanding of the interrelation of the two types of measures.

3.2.3 Environment Monitoring

Environmental information affecting body functions should be immediately available to the monitor. He must have data on the command module temperature, humidity, absolute atmospheric pressure, and atmospheric composition. If the person being monitored is wearing a full pressure suit, the pressure and ventilation inside the suit, the suit inlet temperature, and the pO_2 and pCO_2 in the suit should be in evidence. An increase in pulse rate by itself is meaningless. It may be caused by exercise, low-oxygen tension, high temperature in the module, high carbon-dioxide tension, and even by fear or pain. It is necessary that the monitoring physician be cognizant of the contributing factors to the physiological change. Such change is a result of outside

influence to the point that the range of what is physiologically "normal" can vary by as much as 100 percent. To the engineer, the human body is a complex "machine" with practically no constants, a continuously sliding range of values, and is continuously susceptible to that most uncertain combination of regulators – the human mind and emotions.

3.2.4 Monitor Responsibility

It cannot be too strongly emphasized that, regardless of data provided by sensors, computers, displays, etc., final decisions concerning the life and welfare of the subject being monitored rests on the training and experience of the ground-based monitoring physician. After all mechanical and electronic indications have been noted and the advice of engineers, physiologists, psychologists, and other specialists considered, the "go/no-go" decision is his. The on-board physician will be available for consultation or for emergency action.

Ideally, the physician should have voice communication with the module and TV coverage capability on every orbital pass. Telemetered biomedical data should be available on every pass with emergency override of all other telemetering channels available. Data collected at the remote sites should be summarized and made immediately available to MSCC, and the real-time data should be returned to MSCC on a daily basis.

The foregoing requirements can be met by the existing and planned MSC Network, with the exception of voice and TV coverage on every orbital pass. To meet this requirement, a minimum of three stations, staffed with biomedical-monitoring personnel, will have to be provided. This requirement is discussed more fully in Section 6.

3.2.5 Work-Rest Cycle

The LMSC-recommended work-rest cycle for the MORL (Table 3-1) is based upon the assumption that the initial crew will consist of six men. Measurement Duty for engineer/astronauts is 6 hr/man/day and involves only biomedical and human-performance measurement. For the three scientist/specialists, Measurement Duty is 8/hr/man/day.

Table 3-1
WORK-REST CYCLE^{a, b}

TIME		CREW MEMBERS						
		ENGINEER	ENGINEER	ENGINEER	MEDICAL SPECIALIST	LIFE SCIENCES SPECIALIST	PHYSICAL SCIENCES SPECIALIST	
24 - 0		SLEEP	SLEEP	MEAS. DUTY	SLEEP	SLEEP	MEAS. DUTY	
1	—			REC.			REC.	
2	—		EAT, P. H. REC. SYS. DUTY	SLEEP	EAT, P. H.	EAT, P. H. REC.	SLEEP	
3	—				REC.			REC.
4	—				MEAS. DUTY	MEAS. DUTY		MEAS. DUTY
5	—				EAT, P. H.	EAT, P. H.		MEAS. DUTY
6	—				REC.	REC.		MEAS. DUTY
7	—				SYS. DUTY	REC.		MEAS. DUTY
8	—		MEAS. DUTY		MEAS. DUTY	MEAS. DUTY		
9	—		EAT, P. H.		EAT, P. H.	MEAS. DUTY		
10	—	REC.	REC.		MEAS. DUTY			
11	—	SYS. DUTY	REC.		MEAS. DUTY	MEAS. DUTY		
12	—	MEAS. DUTY	MEAS. DUTY	MEAS. DUTY	EAT, P. H. REC.	EAT, P. H. REC.		
13	—	EAT, P. H.	SYS. DUTY	REC.	MEAS. DUTY	MEAS. DUTY		
14	—	REC.	EAT, P. H.	SYS. DUTY			MEAS. DUTY	
15	—	MEAS. DUTY	REC.	MEAS. DUTY	REC.	MEAS. DUTY		
16	—	SYS. DUTY	MEAS. DUTY	EAT, P. H.	REC.	EAT, P. H.		
17	—	EAT, P. H.	REC.	REC.	MEAS. DUTY	REC.		
18	—	REC.	REC.	REC.	MEAS. DUTY	REC.		
19	—	MEAS. DUTY	MEAS. DUTY	MEAS. DUTY	REC.	MEAS. DUTY		
20	—	SYS. DUTY	EAT, P. H.	SLEEP	SLEEP	EAT, P. H.		
21	—	EAT, P. H.	REC.	SLEEP	SLEEP	REC.		
22	—	REC.	REC.	SLEEP	SLEEP	REC.		
23	—	MEAS. DUTY	SLEEP	SLEEP	SLEEP	REC.		
24 - 0	—	REC.	REC.	REC.	REC.	REC.		

^aMEAS. - MEASUREMENT
P.H. - PERSONAL HYGIENE
REC. - RECREATION
SYS. - SYSTEMS

^bCrew time available for biomedical and behavioral measurement - 42 manhours

One engineer will always be awake and available for Systems Duty if necessary. Meals are regularly scheduled, and always followed by a Recreation period. Sleep periods are always preceded by Recreation.

3.3 PHYSIOLOGY LABORATORY

The Physiology Laboratory for the MORL spacecraft is conceived as comprising a group of measurements and tests to determine the status of various physiological processes in human organ systems, with emphasis on the cardiovascular, respiratory-pulmonary, and nervous systems. Some of these measures will be the same as the biomedical measurements designed to ensure crew safety, while others will be in support of experimental programs.

The biomedical and crew-performance monitoring function has been described in Subsection 3-2. For the experimental program in this laboratory, LMSC recommends provision for a general physical examination and detailed biological measurements. The measurements include cardiovascular, respiratory, metabolic, neurological, and musculoskeletal aspects. The significant aspects of these two areas and recommendations as to specific measurements and equipment requirements are presented in this subsection.

3.3.1 Medical History and General Physical Examination

These two examination aspects, constituting essential methods for obtaining fundamental information, are described in the following paragraphs.

History. It is generally accepted that a medical history is the most important single bit of information which the physician has at his disposal to effect a medical diagnosis. An on-board astrophysician who has been trained with the astronauts selected for the mission will be able to glean information during a short conversation with his crew members. He will be able to elicit symptoms which have occurred during the past 24 hr of flight and evaluate them in the light of the personality of the individual.

It will also be possible for him to ascertain the astronaut's general emotional state for early identification of possible mental or emotional difficulty. The history will suggest more detailed areas of examination to be accomplished.

The medical monitors of Project Mercury generally agreed that their single most important source of information regarding the astronaut was the study of his voice during transmissions. It is believed that voice communication between astronaut and a ground-based flight surgeon will again prove in the MORL to be a most useful tool for determining minute-to-minute physical well-being, and for providing advice to the on-board astrophysician.

General Physical Examination. If a decision is made to place an astrophysician on board the MORL, the resulting direct personal relationship between astrophysician and astronaut can lead to good rapport, and there will be little difference from the usual medical history-taking and physical examination situation, allowing for the spacecraft constraints and the fact that the astrophysician himself will be subject to the same conditions as the astronaut.

3.3.2 Physiological Laboratory - Measurement Implementation

The techniques and equipments which implement the measurement requirements of the Physiology Laboratory are listed in Table 3-2. The principal purpose is to provide information regarding measurement techniques and characteristics of equipment and measurement schedules. Measurements requiring the development of special instrumentation systems are covered in Section 5. The individual measurement techniques form part of the Biometric station described in that section.

3.4 MICROSCOPY AND CHEMISTRY LABORATORY

The Microscopy and Chemistry Laboratory provides facilities for sample collection and storage and for several in-flight measurements of blood, urine, and parotid fluid samples under the limitations of the space environment. Critical body function areas which must be monitored in flight are the musculoskeletal system,

Table 3-2
PHYSIOLOGY LABORATORY - BIOINSTRUMENTATION

MEASUREMENT			INSTRUMENTATION				MEASUREMENT SCHEDULE ^(a) (Per Astronaut)			
Number and Title	Parameter	Technique	Equipment	Weight (lb)	Volume (ft ³)	Power (w)	Frequency	Set-Up Time (min)	Telemetry or Record Time - Max. Per Day (min)	
									Record Time	Total T/M
BIOMEDICAL MONITORING										
1 Cardiac State and Activity	ECG - 0.2 to 100 cps Heart Rate from ECG	1-lead ECG	Electrodes - Beckman Biopotential Conditioner - Spacelabs Apollo-type	0.143	0.0008	0.1	2/day for 1st wk then 1/day	3	1	2
2 Respiration Rate and Depth	Respiration waveform - 0 to 10 cps Respiration rate from waveform	Rate and depth from impedance pneumogram	Electrodes - Beckman Biopotential Conditioner - Spacelabs Apollo-type	0.143	0.0008	0.1	↓	3	1	2
3 Body Temperature	Core temp. - 95 to 105° F Skin temp. - 60 to 110° F	Thermistors in mouth and on skin	Thermistor - Yellow Springs Series 400 Conditioner - Spacelabs Apollo-type (2 req'd)	0.286	0.0016	0.2		3	1	2
4 Blood Pressure	Cuff pressure and Korotkow sounds	Aneroid sphygmomanometer	Aneroid sphygmomanometer - Tyco Co. Stethoscope - Allen Co.	1.0 0.25	0.0463 0.0023	-		5	1	2
5 Heart Sounds	Thoracic wall vibrations - 1 to 500 cps	Microphone placed over heart region	Microphone - Beckman, Gemini type Amplifier - Beckman, Gemini type	0.02 0.143	0.001 0.001	-		2	1	2
EXPERIMENTAL CARDIOVASCULAR										
6 Cardiac Output	Modified Fick Equation	Indirect Fick-Klausen method	Respiratory analyzer - LMSC/spacelabs (see Item 15) Exerciser - LMSC (see Item 9)	-	-	-	1/2 days for 1st wk, then 1/7 days	3	1	1
7 Electrocardiography	12-lead ECG analysis	12-lead ECG	Electrodes and conditioner - same as Item 1, plus selector switch	-	-	0.1	1/7 days	5	2	2
8 Vectorcardiography	Position of heart axes	Frank system	Electrodes - same as Item 1 (7 req'd) Conditioner - same as Item 1 (2 add'l req'd)	0.286	0.0016	0.2	↓	5	2	2
9 Ballistocardiography in Zero-g	Acceleration of body in 6 degrees of freedom	Body stabilizer and accelerometers	Platform - LMSC design Accelerometer - Systron-Donner, Model 4310 (6 req'd)	5.0	2.0	0.3		10	-	-
10 Exercise Tolerance	ECG, heart rate, blood pressure, and respiration rate before and after exercise	Exerciser	Exerciser - LMSC resistive device Measures as specified in Items 1, 2, and 4. Exercise tests as described in Section 5.	2.0	0.5	0.3	4/day	4	50	-
11 Cardiovascular Reflexes Venous Return	ECG, heart rate	Thigh venous occlusion; measure ECG, heart rate and blood pressure	Occlusion cuffs Aneroid sphygmomanometer - same as Item 4 ECG - same as Item 1	2.0 1.0	0.1 0.0463	-	1/7 days	2 2	- 45	-
12 Venous Distensibility	Volume changes of finger or forearm	Digital cuff and plethysmograph	Digital cuff - Beckman C-1 Plethysmograph - Electro-Med. No. 510 Digital cup - Electro-Med. No. 701-514	0.1 0.25 0.1	0.0005 0.25 0.0005	-	↓	5	2	2
13 Pulse Wave Velocity	Transit time of arterial pulse	ECG, digital cup	ECG - same as Item 1 Digital cup - same as Item 12	-	-	0.1		3 2	1 1	1 -
14 Heart Electromechanical Delay	Transit time between ECG and heart contraction	ECG, heart sounds	ECG - same as Item 1 Heart sounds - same as Item 5	-	-	0.1		2	1	-
RESPIRATORY										
15 Respiratory Mechanics to 21	Breathing pattern, expiratory, minute volume Vital capacity, tidal volume, inspiratory and expiratory re- serve, inspiratory capacity	Subject performance of various breathing maneuvers into respiratory analyzer	Respiratory analyzer - LMSC/Spacelabs; same as Items 6, 15, and 16 (see Section 5)	45	0.5	5.2	Daily for 1st wk then 1/7 days	10	5	-
22 Respiratory Gas to 25	End tidal pO ₂ and pCO ₂ alveolar pO ₂ and pCO ₂	Same as Item 15	Same as Item 15	-	-	-	↓	5	2	-

(a) 2/day = twice a day
1/2 days = once every two days
1/7 days = once every seven days
1/14 days = once every seven or fourteen days

Table 3-2 (Continued)

MEASUREMENT			INSTRUMENTATION				MEASUREMENT SCHEDULE ^(a) (Per Astronaut)			
Number and Title	Parameter	Technique	Equipment	Weight (lb)	Volume (ft ³)	Power (w)	Frequency	Set-Up Time (min)	Telemetry or Record Time - Max. Per Day (min)	
									Record Time	Total T/M
<u>MUSCULOSKELETAL</u>										
26 Muscular Status	Work capacity and strength	Single and repetitive muscle contraction, using load-cell exerciser	Exerciser - same as Item 10	1	0.02	0.1	1/7 days	3	1	1
27 Muscle Size	Dimensional changes	Tape measure Calipers	Tape measure - Bischoff (176 ME) Calipers - Bischoff (576)	0.05 0.1	0.0005 0.001	-		5	1	-
28 Total Body Photo	Dimensional changes	TV or photo transmitted	TV camera, painted grid markers	-	-	-	1/7	2	1	1
29 Body Mass	Mass of body	Mass measurement device	Spring-mass device - LMSC (see Section 5)	15	2.5	-	1/14 days	10	1	-
30 Joint Motion	Range of joint movement	Angular range of joint movement with protractor	Goniometer	0.5	-	-		1	3	-
31 Electromyogram	Muscle atrophy	Electrical stimulation	Electrode	0.05	0.0008	0.1	1/7	3	1	-
<u>GASTROINTESTINAL</u>										
32 Motility	Pressure change	Swallowed sensor	Endoradiosonde	0.005	0.00005	-	1/7	1	10	-
33 Temperature	Direct read-out	Swallowed sensor	Endoradiosonde	-	-	-	1/7	-	-	-
34 pH	Acidity	Swallowed sensor	Endoradiosonde	-	-	-	1/7	-	-	-
<u>METABOLISM</u>										
35 Metabolic Rate (Resting)	Oxygen Consumption	Calculation	Respiratory analyzer	-	-	-	1/7	-	-	-
36 O ₂ Consumption	O ₂ used per unit time	Polarographic	Respiratory analyzer	-	-	-	Daily	5	5	-
37 CO ₂ Production	CO ₂ produced per unit time	Polarographic	Respiratory analyzer	-	-	-	Daily	5	5	-
<u>BLOOD</u>										
38 Oxyhemoglobin	Light transmission through blood (earlobe)	Oximetry	Oximeter (Millikan-Woods)	0.05	0.0005	1	Daily	10	1	-
<u>NERVOUS - SPECIAL SENSORY</u>										
39 Electrical Activity of Brain	Analysis of brain waveforms - 0.1 to 100 cps	Electroencephalograph	Electrodes - sponge-type in helmet Conditioner - Beckman Gemini type (4 req'd)	0.25 0.15	0.5 0.001	- 0.8	Daily for 1st wk, then 1/7 days	10	20	2
40 Vestibular - Semi-circular canals	Nystagmus, vertigo	Caloric stimulation of semicircular canals; body rotation	Caloric stimulator - LMSC (see Section 5) Rotatable stool - LMSC Electronystagmogram (see Section 3)	2 5	0.1 0.5	3 -		10	15	-
41 Vestibular - Otoliths	Threshold of linear acceleration	Mass measurement device	Spring-mass device - LMSC (see Section 5)	-	-	-		10	1	-
<u>GENERAL</u>										
42 Solids and Liquids - Intake and Output	Food and liquids ingested and excreted	Recording of own intake and output by each subject	Sealed containers	3.0	0.4	-	Daily	-	-	-
43 Body Fluid Compartments	Total Body Water	Tritium	Scintillation counter and radioisotope handling equipment	25.0	1.0	100	Daily for 1st 5 days, then 1/7	10	1	-
44 Circulating Fluid	Plasma Volume	Radioiodinated Serum Albumin (RISA)								

(a) 2/day = twice a day
 1/2 days = once every two days
 1/7 days = once every seven days
 1/14 days = once every seven or fourteen days

gastrointestinal system, and the metabolic functions, together with the endocrine and renal functions, electrolytes, body fluid shifting, and hematological responses.

3.4.1 Sample Collection

This section contains a general discussion of problems associated with collecting samples on the MORL spacecraft. Attention is also directed at the return of samples to earth for validation of in-flight analysis.

Urine Samples. Urine specimens should be collected on a 24-hr basis in heavy-duty, 2-liter plastic bags constructed in the form of cylinders and with a puncture-sampling port sealed into the wall of the cylinder. Positive containment of the urine can be accomplished by valving the neck of the collection bag so that urination can be accomplished without significant escape of urine to the atmosphere. A zero volume initial state will aid in subsequent volume determination.

Blood Samples. Blood collections in capillary tubes to be sealed with hematocrit clay appears to be adequate for this phase. Simplification of this operation to permit self-sampling of blood will allow maximum flexibility for collecting samples. This will negate a possible disadvantage of having one of the astronauts remain in a space suit at all times. Finger pricks should present little difficulty and a microanalytical approach will eliminate the need for venipuncture. The reluctance to puncture one's own skin deliberately can be relieved by the use of a spring-loaded blade. A small clip holding a battery of prepared collection capillary tubes and seals, and housed in a sterile container, will reduce collection error to a minimum.

Feces Samples. Fecal collection will be simple or difficult, depending on the quality of stools produced. This is controllable to some degree by diet but has an element of unpredictability. Assuming the worst case, it is apparent that a scheme similar to that for collecting urine must be developed.

3.4.2 Volume and Mass Determinations

Large volumes (urine) can be determined with sufficient precision by inserting the cylindrical collection bag into a light, rigid, mesh basket and producing a gas-liquid interface by imparting a small inertial force to the container. A scale will then give the desired volume data.

An alternate and probably more potentially useful method involves adding an easily measured, accurately prepared amount of coloring agent to the samples. Since this can be carried out after aliquoting samples for the analyses and for return to earth, there will be no interference with the examination of the samples. The basket will be redundant for the procedure and can be eliminated.

Capillary collection tubes for blood can be precalibrated and marked. This procedure may be applied to analytical volumes of urine also.

Mass determinations will not be necessary in the Microscopy and Chemistry Laboratory so this usual basic analytical measurement, and modifications required for zero gravity applications will not be included in this report.

3.4.3 Aliquoting and Sample Handling

Urine aliquots of 150 cc will be ample for in-flight and earth-based analyses. Validation of in-flight measurements will dictate reasonable, careful handling procedures to preserve the integrity of urine elements. Freezing of the samples appears to be the simplest solution to this problem, but lyophilization will permit more flexibility of sample handling after preparation. Time and complexity of handling equipment for the latter procedure are such that further study is needed in this area.

Return of routinely collected blood samples to earth seems pointless since the preservation difficulty would outweigh any benefits which might be derived.

3.4.4 In-Flight Analyses

Table 3-3 presents a condensed version of the measurements recommended for the MORL. This section will discuss the non-routine details worthy of consideration.

Microscopic examination of urine and blood samples requires a degree of training which may not be available for the astronauts. It would not appear to be too difficult, however, for the astronauts to learn sample preparation techniques and microscope manipulation. Coupling this portion of the examination with television monitoring of the microscope field, remote control of focusing adjustments from earth, and radio communication between earth and satellite teams, it should be feasible to obtain valid in-flight examinations of samples.

Flame photometric determinations for urinary and blood cations would be very useful. Procedures are well developed, and the only apparent stumbling block is the lack of suitable instrumentation. Briefly, the concept calls for an isolated flame system connected to the vacuum of space with electrical firing and extremely simple operation and maintenance. Optics and detector systems can be prepared in correspondingly small packages. Detector voltages can be transmitted to earth directly or with a minimum of amplification. This would reduce space and power requirements for the entire set of determinations usually carried out with the flame photometer.

Ames Diagnostic Tests. These prepared clinical test units look very promising for application to clinical evaluation problems which are a part of the Biolabs Program. Table 3-4 presents a summary of the available test packages. The general concept embodies the development of a colored product following the addition of a small amount of biological material to a tablet or reagent impregnated paper, and observing the resulting product visually. All tests are simple, the observable concentration gradations seem adequate to provide necessary warnings in the event of physiological perturbation, and the system should present no problems insofar as adaptation to use in zero gravity are concerned. Incorporation of the individual tablets or test strips in small volume plastic bags (1 to 2 cc), fitted with septums for hypodermic needle injection of samples, should be a reasonable approach to this problem.

Table 3-3
RECOMMENDED MEASUREMENTS FOR MORL

Body Function/System	Sample	Measurement	Technique	Number
Musculoskeletal	Urine	Proteins	Combistix	1
	Urine	Creatine/creatinine	Colorimeter	2
	Urine	Calcium	Flame photometer	3
	Urine	Nitrogen (total)	Automatic N ₂ analyzer or Nessler reaction	4
	Urine	Phosphorus	Colorimeter	5
	Urine	Proline	Gas chromatograph	6
Gastrointestinal	Blood	Serum proteins	Colorimeter	7
	Urine	Bilirubin	Colorimeter	8
	Blood	Serum alkaline phosphatase	Colorimeter or Calsul	9
	Blood	Enzymes SGOT or LDH	Colorimeter or Calsul	10
	Feces	Gross examination		11
	Feces	Occult blood	Hematest	12
Metabolism	Blood	Glucose (2 hr PP)	Microchem analysis	13
	Urine	Acetone bodies	Gas chromatograph	14
	Blood	Serum lipids	Gas chromatograph	15
	Blood	Urea nitrogen	Warner Chillicothe paper strip	16
Endocrine	Urine	Glucosteroids	Gas chromatograph	17
	Urine	17-ketosteroids	Gas chromatograph	18
	Urine	Catecholamines	Gas chromatograph	19
	Urine	Corticosteroids	Gas chromatograph	20
	Urine	Aldosterone	Gas chromatograph	21
Fluid and Electrolytes Genitourinary	Urine	Osmolarity	Freezing point	22
	Urine	pH	Polarographic	23
	Urine	Sugars	Combistix	24
	Urine	Microscopic	Microscope	25
	Urine	Occult blood	Hemastix	26
	Urine	Sodium	Flame photometer	27
	Urine	Potassium	Flame photometer	28
Hematology	Blood	Red blood-cell count	Microscope	29
	Blood	WBC and differential	Microscope	30
	Blood	Hemoglobin	Hemoglobinometer	31
	Blood	Hematocrit	Microcentrifuge	32
	Blood	Reticulocyte count	Microscope	33
	Blood	Platelet count	Microscope	34
	Blood	RBC mass	Cr-tagged RBC	35
	Blood	RBC lifetime	Cr-tagged RBC	36
	Blood	Bleeding time	Blotter	37
	Blood	Coagulation time	Capillary tube	38
	Blood	Abnormal pigments	Spectrophotometer	39
General	Blood	Samples for special leucocyte studies	—	40
	Throat, Skin	Cultures	Microbiological	41

Table 3-4
RAPID, PREPARED CLINICAL TEST UNITS^(a)

Test	Parameter	Sensitivity, Range, Etc.
Acetest	Ketone Bodies (Urine)	Trace (10 mg/100 ml urine), Moderate, Strongly positive
Albustix	Protein (Urine)	Zero to 1,000 mg/100 ml urine
Albutest	Protein (Urine)	Negative, large amounts of protein
Bumintest	Protein (Urine)	Turbidity, 10 mg/100 ml urine max. sensitivity
Clinistix	Glucose (Urine)	Sensitivity - 0.01 to 0.1%
Clinitest	Sugar (Urine)	0.25%, 0.5%, 0.75%, 1.0%, 1.25%, and more
Combistix	Protein (Urine)	0, trace, 30, 100, 300, and over 1,000 mg/100 ml
	Glucose (Urine)	Sensitivity to 0.01%
	pH (Urine)	5, 6, 7, 8, 9
Dextrotest	Sugar (Blood)	100, 150, and 250 mg/100 ml
Hemastix	Blood (Urine)	Small to large amounts
Hematest	Blood (Feces)	Detection of clinically significant amounts of blood in stool
Ictotest	Bilirubin (Urine)	0.1 to 0.05 mg/100 ml
Ketostix	Ketone Bodies	5 to 10 mg/100 ml
Occultest	Blood (Urine)	Negative/positive
Phenistix	Phenylketones (Urine) Phenylpyruvic Acid (Usually)	0, 15, 40, and 100-mg phenylpyruvic acid/100 ml
Uristix	Protein (Urine)	0, 30, 100, 300, and over 1,000 mg/100 ml
	Glucose (Urine)	0.01%

^(a)Ames Diagnostic Test, Ames Company Inc., Elkhart, Indiana

Employment of procedures such as these is recommended only after careful evaluation of the degree of accuracy required for the measurement of interest.

Calsuls. This is the registered trade name for a set of biochemical reagent packages for use in classical analyses. A spectrophotometer is required for the analytical endpoints, and the procedures furnished with the packages are not specifically directed at the handling of small amounts of material. The concept is interesting, however, and should be watched closely for future developments. Procedures and packaged reagents presently available cover the following:

- Fructose diphosphate aldolase (serum)
- Alkaline phosphatase
- Glucose
- Glucose-6-phosphate dehydrogenase
- α -Hydroxybutyric dehydrogenase (α -HBDH)
- Lactic dehydrogenase (LDH)
- Serum glutamic oxalacetic transaminase (SGOT)
- Serum glutamic pyruvic transaminase (SGPT)

Soon to be added to this list is the acid phosphatase. Others are expected in the future but nothing specific regarding these new areas is available.

Measurement of Osmolarity. Freezing point depression appears most feasible for this particular measurement. Thermocouple determination of this phenomenon can be carried out in the same apparatus employed to freeze biological samples for return to earth. The Mechrolab vapor phase osmometer is sufficiently sensitive and accurate to describe activity coefficients of solutes but requires further development for in-flight use.

Cationic Electrode Analysis. This type of analysis has been developed by Beckman Instruments to the point that it warrants consideration. At present, sodium, potassium, carbon dioxide, and chloride determinations are the most promising areas of attack. Analysis of divalent ions (calcium and magnesium) has not been proved to be feasible at the present time. Simplicity of application dictates that this area be examined for further development but, at present, the electrodes available do not give evidence of the reliability required for this project.

Gas Chromatography, Mass Spectrometry, and Infrared Spectrophotometry. Miniaturized gas chromatographs, mass spectrometers, and infrared spectrophotometers can increase greatly the number of determinations which can be made in flight. Training requirements for personnel and the need for supporting equipment will increase proportionally, and the return per unit effort may become unreasonable.

Microanalysis. The advantages of resorting to microanalysis for common clinical determinations may be summarized as follows:

- Decreased space, power, chemicals, and time requirements
- Increased number of tests feasible on any given mission
- Decreased possibility of infection or impaired performance of astronauts

The chief disadvantages of this technique are the tendency to require more intensive training on the part of the astronaut and the difficulty of performing the rather delicate manipulations needed under the unusual environment in the spacecraft.

Automated Data Transmission to Earth. This approach has been mentioned in connection with the flame photometer and may serve to increase effectively the number and quality of instruments which can be carried on missions. Elimination of classical recording systems on spectrophotometers, etc., by feeding detector signals directly into transmitters should significantly decrease the complexity and bulk of the analytical instruments. Spectrophotometers, gas chromatographs, pH meters, and any other apparatus which show answers as potentials could be monitored by this method.

3.4.5 Pre- and Post-Flight Analyses on Earth

These analyses will serve principally to establish baseline data for comparison with flight data and for validation of in-flight clinical determinations. Classical clinical procedures may be employed on all of these determinations, and their descriptions are felt to be redundant. It would be advisable to duplicate analyses on earth for nonstandard techniques employed in flight, but these should be correspondingly more simple on earth and should present no problems. Table 3-5 lists the measurements

Table 3-5
RECOMMENDED PREFLIGHT AND POSTFLIGHT DETERMINATIONS

Urine	Serum	Whole Blood	Misc.
Amino nitrogen	Amino nitrogen	pH	<u>Cytology</u>
Amino acids	Amino acids	Total phosphorus	Incisional healing
Urea clearance	Ammonia	Total WBC count	Buccal mucosal
Taurine	Creatinine clearance	Differential WBC	Skin scraping
Purines	Lactodehydrogenase	Total RBC	
Pyrimidines	Proteins (A/G ratio)	Hemoglobin	<u>Feces</u>
Acetone bodies	Electrophoresis for	Blood volume	Occult Blood
Thiamine	proteins & lipoproteins	Bleeding time	Chlorides
Bacterial count and culture	Mucoproteins	Clotting time	
pH	Glutathione-SH	Glucose tolerance	<u>Microbiological</u>
Sodium	Total nitrogen	Proteinuria	Throat swabs
Potassium	Nucleotides	Hematocrit	
Chlorides	DNA	Capillary fragility	
Magnesium	Lactic acid		
Phosphates	Pyruvic acid		
Bilirubin	Lipoproteins		
Occult blood	Lipids & components		
17-hydroxy corticosteroids	Thiamine		
Catecholamines	Riboflavin		
Aldosterone	Vitamin A		
Androsterone	Vitamin E		
WBC	Vitamin C		
RBC	Vitamin K		
Osmolarity	Calcium		
Color	Sodium		
Turbidity	Potassium		
	Chlorides		
	Magnesium		
	Phosphates		
	CO ₂		
	Bilirubin		
	Alkaline		
	Phosphatase		
	Transaminase		
	17-hydroxy corticosteroids		
	Catecholamines		
	Hemoglobin		

which can be anticipated as providing useful data on the physiological status of the astronauts.

3.5 RADIOLOGY LABORATORY

The Radiology Laboratory is unique in that a single set of equipment will provide for performing most of the measurements of interest. Measurements included for the MORL are shown in Table 3-6. Fewer exposures will be required than implied by the measures thus listed. A single chest exposure, for example, will provide heart size, lung status, and organ displacement data, and the kidney-ureter-bladder (KUB) exposure will also supply organ displacement information.

3.5.1 Radiological Measurements

The outstanding value of radiology is that it allows direct visualization of the body's internal status. In this manner, many of the hypotheses that have been advanced on the effects of zero-g can be subjected to an objective, unequivocal test. Such matters as the effect of space flight on the shape of the heart and great vessels, organ displacement, atelectasis, and bone mineralization can be studied and permanent visual records obtained. An in-flight Radiology Laboratory is therefore indicated as several of these phenomena are dependent on the low-g state. The time sequence of changes induced by spaceflight can be recorded using an on-board system. In addition, X-ray equipment available on board the MORL may be of value for diagnostic purposes, e.g., a chest film can confirm the presence of atelectasis.

Four measurements can be made with a simple isotope system (System II in Fig. 3-1). A P.A. chest film can provide the first and third measurements in Table 3-6, namely, heart size and lung fields. In addition, this system can provide simple bone-density studies such as step-wedge exposures and films of the joints. The principal advantage of this system is the fact that no power is required for isotope radiological examinations. A conventional X-ray system (System III in Fig. 3-1) can provide all eight measurements listed in Table 3-6.

Table 3-6

RADIOLOGY LABORATORY MEASUREMENTS

Body System	Measurement	Technique	Time Required (min)	Frequency	Remarks
<u>Cardiovascular</u> Heart and Aorta	Size and Shape Transverse diameter Lateral and frontal	P. A. and lateral chest roentgenogram	10	Days 1, 3, 5, 7; weekly thereafter	Take baseline data within 4 hr of attaining zero g; teleroentgenogram is standard method for heart size; typical skin dose - 25 mr/view
<u>Pulmonary</u> Pulmonary Circulation	Venous engorgement; Kerley's lines		-	Same as for cardiovascular system	Course of events in pulmonary circulation with relative incompetence of LV has been reported
Lung Fields	Atelectasis; other pathology		-		Information available from cardiovascular film
<u>Genitourinary</u> Urinary	Calcifications	Kidney-ureter-bladder (KUB). Film and flat plate of abdomen	4	Weekly (symptomatic after leaving kidney proper)	Most significant finding if possible to obtain; typical skin dose - 300 mr
<u>Gastrointestinal</u> Organ Position and Size	Diaphragm, liver, spleen, etc.		-	-	Information available from KUB and cardiovascular films; alternately, a conventional G-I series, using ingested radio-opaque material, can be employed to provide better detail.
<u>Skeletal</u> Bone Structure	Bone density	Expose fingertips and step-wedge; expose heel bone and stepwedge	4	Weekly	Requires meticulous and finite control of all factors; doubtful if usable flight procedure
	Cortex/width ratio	Expose femur and 2nd metacarpal	4	Weekly	Gross measurement, but may provide information by comparison with preflight measurement
Bone Density	Differential X-ray absorption	X-ray absorption at 50 and 250 kev	6	Weekly	Further method development required; special equipment probably needed; typical skin dose - 15 mr
Joints - Range of Motion	Range of motion of knee joint	A. P. view of knee with and without abduction stress	6	Weekly	Provides quantitative data on joint relaxation; typical skin dose - 75 mr

3-21

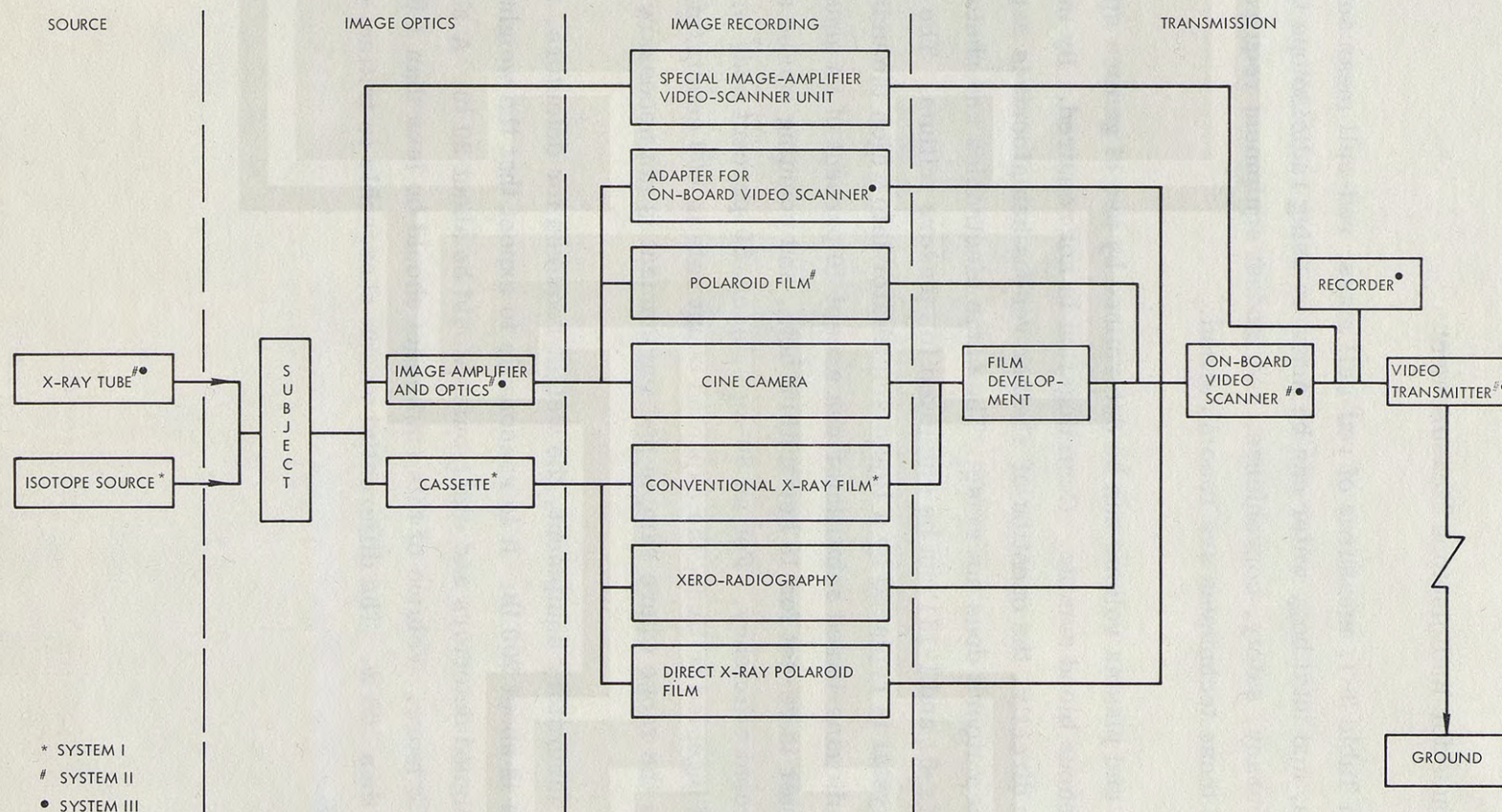


Fig. 3-1 Radiology Laboratory Arrangement—Typical for Systems I, II, and III

3.5.2 Techniques for Radioisotope Measurement

As indicated in Table 3-7, measures of red-cell mass, red-cell mean survival time, plasma volume, and total body water can be made by using radioisotope techniques. Because of accuracy, safety, convenience, and modest equipment requirements, employment of these techniques are recommended.

Red-cell mass and plasma volume can be determined by use of gamma spectrometry, and only one venous blood sample. Centrifugation is not required. By measuring plasma volume directly, the question of whether venous hematocrit is representative of whole body hematocrit does not arise. The same electronics and photomultiplier tube used for Cr-51 and I-131 can be employed to measure tritium. The well-type scintillation crystal is replaced by a liquid scintillator into which the urine sample is dissolved. (A dioxane-based scintillator can accept 10 percent of an aqueous solution.) The spectrometer is re-set for 18 kev tritium beta, and counting can be accomplished at about 10 percent efficiency. For an 80-kg subject, 50-percent body water, and 100 microcuries of ingested tritium, the expected count rate is 600 counts/min/ml of sample. This is in the range where sample pre-enrichment is not necessary.

In commercial laboratory equipment, the weight required for detectors, shields, and electronics is about 200 lb. It is reasonable to expect that the weight of similar spacecraft-designed detectors and electronics would be about 20 lb. A shield would add perhaps 5 lb more. Volume of this equipment should be less than 1 ft³. Power should be less than 100 w. The differential weight chargeable to tritium counting is less than 0.5 lb.

Table 3-7

RADIOISOTOPE MEASUREMENT TECHNIQUES

Measure	Method	Radioisotope	Half Life	Emission & Energy	Quantity Used (microcuries)	Permissible Body Burden ^(a) (microcuries)
Red Cell Mass	Inject tagged red cells. After 15 min, withdraw 5-ml blood sample, and count.	Chromium-51	27.8 day	Gamma 0.32 Mev	15	800
Red Cell Survival Time	Continue above with-drawals at weekly intervals.					
Plasma Volume	Inject radio-iodinated human serum albumin (RISA). After 15 min, withdraw 5-ml blood sample and count.	Iodine-151	8.1 day	Gamma 0.28 to 0.72 Mev (also betas)	3	50
Body Water	Ingest tagged water. After > 4 hr, take urine sample for counting.	Hydrogen-3 (Tritium)	12.8 yr	Beta 0.018 Mev	100	1000

(a) Recommended by NBS Handbook 69 for appropriate organ and radioisotopes.

3.5.3 Laboratory System Comparison

Apart from the usual criteria for space-station equipment of minimum weight, simplicity, and workability under zero g, the need to transmit the X-ray images to a ground-based radiologist for study and interpretation has influenced the choice of Radiology Laboratory equipment. (It is unlikely that even the largest ORL will include a radiologist on board.) Obtaining the image as a video signal as soon as possible is therefore emphasized. With an adapter, the video pickup is used to scan the intensifier output. The image is stored by the videotape recorder and transmitted to the ground periodically. On-board viewing of the image is possible if a monitor screen is available. The high-resolution facsimile mode of operation of the video system is used.

As the weight and volume allocation for the Radiology Laboratory is not presently fixed, it is convenient to present three systems as individual units that may be incorporated as desired in any ORL. Each system is believed to represent the best allocation of equipment for a laboratory at the total weight indicated. Figure 3-1 presents a schematic description of the three systems.

System I consists of a radioisotope source and a set of 4×6 -in. conventional X-ray films. It has an estimated weight of 10 lb and is suitable only for bone demineralization studies. With this system, periodic X-rays of the hand, heel, or forearm, plus a reference step wedge, are taken. Upon return to ground, these films are developed and the time course of possible demineralization may be determined. For Systems I and II, the weight requirement for a shielded storage location for X-ray films is not included. No power is required for these systems.

System II uses a more intense radioisotope source and 10×14 -in. X-ray film. Studies of bone density (stepwedge) and a P.A. chest film can be performed. It is anticipated that acceptable quality films can be obtained. Joint-relaxation exposures can also be taken and acceptable quality is expected, provided an exposure time measured in seconds can be arranged. It is doubtful if useful KUB, gastrointestinal series, or fine detail in chest films can be obtained. Differential bone density studies cannot be

performed. Data will be available only after completion of the flight; however, to provide for gross measures in case of emergency, direct Polaroid X-ray film packets will be included on board. Results from these films will be immediately available. System II has an estimated weight of 34 lb.

System III is based on the use of an on-board videotape recorder. It consists of the X-ray tube, image intensifier, adapter for the video pickup, and the on-board video system. It will provide for the ground-based radiologist an image quality comparable to that from 1,000 to 2,000-line/frame videotape radiographs. For two-field-per-frame video, a speed of 15 frames/sec is possible. The subject dose (required X-ray tube output) is lowest with this system because of the amplification possible in the camera electronics. System III has an estimated weight of 73 lb, excluding the video pickup, recorder, and transmitter, which are considered to be on board independent of the presence of the Radiology Laboratory. The peak power consumption is approximately 200 w. The average power required, based on six subjects and all measures shown in Table 3-6 is about 0.03 w, without accounting for the five-fold power reduction that can be obtained through use of the image intensifier.

A 9-in.-diam. image intensifier will be used. This size comfortably allows examination of the entire heart, but probably requires two exposures to view both kidneys. Should available examination time be the limit, a 12-in. intensifier could be used, at a weight penalty of about 30 lb. This intensifier would allow a single exposure for both kidneys, and a single exposure for heart and lungs.

System III is the recommended combination for the Radiology Laboratory. As shown in Fig. 3-1, it consists of an X-ray tube, image intensifier, adapter for the on-board video pick-up, the videotape recorder, and the spacecraft telemetry system. At the estimated weight of 73 lb, this system is capable of performing all measurements listed in Table 3-6. By the use of videotape recording, System III can be used to study dynamic phenomena, such as the character of heart pulsations.

For the measurement of bone density, it may be desirable to supplement the equipment by a dual radioisotope, or dual-target source.

Although several new techniques, as discussed in Volume I of this report (Ref. 3-1) may ultimately be useful for the Radiology Laboratory, it was considered preferable to maintain present state-of-the-art in ground-based radiology as the design basis. All techniques and equipment specified are therefore presently in everyday use in radiology. If newer techniques are developed and have application to the Radiology Laboratory, the present data-to-cost ratio of the Laboratory will be improved. For this reason, it is believed that the design parameters may be considered conservative.

3.5.4 Radiological Laboratory Equipment

The Radiology Laboratory equipment consists of various energy sources, different types of imaging optics, and equipment to record these images. Table 3-8 lists the characteristics of these items.

3.6 HUMAN-PERFORMANCE LABORATORY

The primary purpose for the inclusion of a human-performance program aboard the MORL is to provide measurement data on man's performance in the space environment. Specifically, the data collected must be oriented to the following objectives:

- Obtaining measures which can be used for the determination of the relationship between human performance and the physiological condition of the crew
- Obtaining measures which can sensitively detect changes in man's capability to perform mission tasks

Human-performance evaluation aboard the MORL is especially complex because of the three operational modes involved – intrastation activity, extravehicular activity (EVA), and centrifuge operation. Of particular significance are the various psychophysiological problems that face the astronaut as he emerges from the station and becomes a free-floating orbital worker/experimenter.

This section is limited to a summary description and tabulation of recommended performance measurements. Detailed system equipment recommendations and configurations are presented in Section 5.

Table 3-8
RADIOLOGY LABORATORY EQUIPMENT

Item	Weight (lb)	Dimensions (in.)	Power Required	Remarks
<u>X-Ray Source</u>				
Electronic A	25	5 × 12 × 24	2.1 kva (max.)	Output - 15 ma at 90 kvp
Electronic B	18	6(diam.) × 18(length)	240 w (max.) 0.03 w (av.)	Output - 2 ma at 120 kvp Average power (for either tube) based on 6 subjects and all measures in Table 3-5.
Radioisotope A	20	5(diam. of sphere)	None	Source - 10 mr/sec at 4 ft
Radioisotope B	5	3(diam. of sphere)	None	Source - 4 mr/sec at 1.5 ft Both - shielded to level of 0.1 mr/hr at 1 ft
<u>Image Optics</u>				
Image Intensifier	40	12(diam.) × 18(length)	None	Integral battery supplies required 25 kv; data is for 9-in.-diam. input face; includes grid for KUB
Film Cassette	10	3 × 12 × 12	None	Functions as film holder; includes intensifier screen
<u>Image Recording</u>				
On-Board Video-Pickup Adapter	3	12(diam.) × 4(length)	None	Data applies to differential chargeable to adapting on-board videotape recorder and pick-up for radiology
Polaroid Camera and Photographic Film	5 ^a	4 × 6 × 6	None	Records image-intensifier output face
Conventional X-Ray Film	2 ^a	1 × 10 × 10	None	Applies to film developed after flight
Polaroid Direct X-Ray Film	2 ^a	3 × 10 × 10	None	Inferior image quality
Xeroradiograph	-	-	-	Technique inapplicable because of required high exposure

^aWeight estimate based on assumption that radiation shielded storage location can be arranged without appreciable weight penalty by using on-board mass.

3.6.1 Human-Performance Equipment Measures

Human-performance measures for MORL intrastation and centrifuge operations are presented in Table 3-9. The following characteristics are identified for each of the measures shown:

- Master Test Number. Reference number of the test, a standard number used throughout the program
- Measurement Description. The human-performance function and parameter involved
- Measurement Method. The selected procedure or technique for obtaining the required measurement
- Frequency. Number of days between measures
- Time (min). Required to perform the test including setup and recording time
- Weight, Volume, and Power. Requirements of the equipment

Each of the measures which is considered a part of the basic safety package, is identified in Table 3-9 by means of an asterisk. This package will be measured daily and transmitted in real-time to ground readout stations for monitoring.

Use Factors. Measurement procedures must be integrated into the overall program and the time scheduling of events. Unnecessarily delicate or complicated operations must be discarded in favor of simple, rugged, "push-button" type operations or one-shot packaged tests. Physical and electrical system interferences must be considered.

Reliability. The difficulty of making adjustments and equipment repairs in the confines of the spacecraft, as well as the importance of performing certain measurements at a specific time, adds to the importance of equipment reliability. Many measurements may be declared worthless if they cannot be made at the critical time.

Table 3-9

HUMAN-PERFORMANCE MEASUREMENTS AND EQUIPMENT

Test No.	Measurement	Method	Frequency (Days)	Total Time (Min)	Weight (lb)	Volume (cu ft)	Power (w)
1a	Visual Acuity	Oculometer - LMSC	3	8	5	0.05	40
2a	Depth Perception		3	5			
8a	Vision - Phorias		3	7	↓	↓	↓
10b	Audition - Intensity	Thresholds - Tape Recordings	6	8	20	1.0	20
11b	Audition - Pitch	Thresholds - Tapes	6	10			
12a	Audition - Localization	Dichotic Tape Presentation	6	8			
13a	Audition - Patterns	Taped Patterns	6	8			
14a	Audition - Motion	Dichotic Tapes	6	6			
15b*	Audition - Speech	Perception "Clipped" Tapes	1	8			
40a,b	Vigilance - Auditory	Monitoring for Presence or Absence of Signal	3	33			
42a	Attention - Auditory	Warning Signals	3	33	↓	↓	↓
4b	Vision - Patterns	Matching on CRT Display	3	6	20	0.4	30
9b*	Vision - Reading	Comprehension - CRT	1	4			
18b	Kinesthesia - Position	Joystick Aiming - CRT	6	6			
20a	Kinesthesia - Tracking	Joystick - Visual CRT Target	6	6			
23a,c	Orientation - Temporal	Filled/Unfilled Time Estimates	6	14			
28a*	Fine Motor - Manipulation	Dial Adjustment	1	5			
29b	Fine Motor - Dexterity	Finger Dexterity in Switching	1	4			
31b	Fine Motor - Positioning	Ballistic Aiming	3	7			
32a,b	Fine Motor - Steadiness	Digit and Hand Steadiness	6	10			
34a	Continuous Process - Pursuit Tracking	CRT Display/Control	6	8			
35a	Continuous Process - Compensatory Tracking	CRT Display/Control	1	12			
36a	Discrete Process - Simple Reaction	Visual Reaction	3	4			
37a	Discrete Process - Complex Reaction	Visual CRT Signals	3	4			
38a	Discrete Process - Complex Sequence	Synthetic Operational Task	1	8			
39b	Vigilance - Visual	Drift Monitoring	3	33			
41a	Attention - Visual	Warning Lights	1	33			
43a*	Problem-Solving - Computation	CRT presentation	1	8			
44a	Problem-Solving - Symbolic	Inductive Categorization	6	15			
45a	Problem-Solving - Diagnostic	Synthetic Troubleshooting	6	15			
46 & 48	Learning and Memory - Short-Term	Alphanumeric Presentation	6	14			
49	Memory - Long-Term	Operational Procedures	6	6	↓	↓	↓
16b	Vestibular - Linear	Detection of Threshold	3	20	Mass Determination Device of Physiology Laboratory		
17b	Vestibular - Angular	Detection of Threshold	3	20			
19b	Kinesthesia - Dynamic	Limb Position - Time and Camera Recording	6	8	15	1.0	10
21a	Orientation - Position	Situational - Camera Recording	6	8			
22a	Orientation - Location	Situational - Camera Recording	6	8			
24a	Gross Motor - Locomotion	Soaring - Camera Recording	3	8			
25a*	Gross Motor - Dexterity	Pressure Suit - Don and Doff - Time and Camera Recording	1	15	↓	↓	↓
TOTAL					60	2.45	100

*Component of basic crew-performance measurement console

3.6.2 Human-Performance Measurement in EVA

Various psychophysiological problems face the astronaut as he emerges from the space vehicle and becomes a free-floating orbital worker/experimenter. These problems are as follows:

- Lack of friction
- Instability
- Reciprocal inertia between masses
- Visual fields with unstructured relationships between figure and ground

Many of these problems relate to human performance although closely allied to the physiological characteristics associated with EVA. Human-performance measurements and evaluations, therefore, are recommended for EVA which, when integrated with EVA biomedical measurements, will provide an initial although partial composite and profile of man's psychophysiological behavior outside the MORL spacecraft.

Three major categories of human performance have been identified for extravehicular activities in which astronauts will engage. These are as follows:

- Astronaut self-maneuvering
- Performance of assembly and repair tasks
- Conduct of inspection tasks

The foregoing classes of tasks appear as realistic categories for evaluation and measurement of astronaut extravehicular activities associated with resupply, repair/maintenance, inspection, service, assembly, and rescue.

Table 3-10 illustrates the measurements considered applicable to the three identified task categories. Each measurement is related to at least one of these categories. Discussion of equipment to measure, evaluate, and/or perform each of the measurements identified is presented in Section 5.

Table 3-10
HUMAN-PERFORMANCE MEASUREMENT AND EVALUATION - EVA

EXTRAVEHICULAR MEASUREMENTS	EXTRAVEHICULAR ACTIVITY					TYPES OF MEASUREMENT DEVICES AND TECHNIQUES									
	Self- Maneuvering	Assembly and Repair	Inspection	Photographic Equipment (Still and Movie)	Timers	Tape Recorder	Hand-Recording Devices	Visual-Stimulus Devices (Targets)	Transmitter	Assembly Devices	Assembly Tools	Torquing Device	Complex Assembly Device	Welding Equipment	
1. Closing the air lock and latching shut	P				X		X								
2. Initial positioning prior to maneuvering	P			X											
3. Use of body motion in translating away from spacecraft	P			X											
4. Use of propulsion aid in translation activities	P			X											
5. Time to reach desired in-space point	P		S		X										
6. Accuracy in reaching desired in-space point	P		S	X											
7. Type of maneuver required to reach point in space	P			X											
8. Judgment accuracy of distance of point in space	S		P	X											
9. Capability to stop at point in space	P			X											
10. Use of tether line/umbilical for return to spacecraft	P			X											
11. Time to return from point in space to spacecraft	P		S		X										
12. Accuracy in reaching spacecraft from point in space	P			X											
13. Capability to stop (with minimal impact) at spacecraft during return from point in space	P			X											
14. Translation maneuvers (tumble, rotation, etc.)	P			X			X								
15. Target recognition, depth/distance perception, size, shape and color judgment, and acuity			P			X		X	X						
16. Simple nut-bolt assembly		P		X	X					X	X				
17. Torqueing		P		X	X							X			
18. Complex component assembly		P		X	X								X		
19. Welding		P		X	X								X		
20. Speed of assembly, torqueing and welding		P			X					X	X		X	X	
21. Quality of assembly, torqueing and welding		P		X			X			X	X		X	X	
22. Positioning of objects	S	P		X	X								X		
23. Dexterity (gloves, and gloves and tools)		P		X						X	X		X		
24. Normal extravehicular communications						X		X							

P - Primary
S - Secondary

3.7 CENTRIFUGE LABORATORY (STIMULUS AND DATA-ACQUISITION SYSTEM)

Section 3 of Volume I (Ref 3-1) describes the physiological and human-performance parameters to be measured in the Centrifuge Laboratory and indicates the logical process by which they were selected. The related centrifuge instrumentation required to measure the parameters listed in Volume I is presented in Table 3-11, and the system analysis and conceptual design for the Centrifuge Laboratory are discussed in Sections 4 and 5.

Three uses considered for a Centrifuge Laboratory in the MORL are as follows:

- A therapeutic device to counteract possible debilitating effects of weightlessness
- A simulator of reentry-type stresses
- A provocative tool to elicit responses indicative of physiological changes due to weightlessness

3.7.1 The Centrifuge as a Therapeutic Device

The use of a centrifuge for gravity therapy will be largely confined to a nonrotating space station since the rotating space station will not, presumably, require additional gravity therapy. Discussions of a personnel centrifuge, for purposes of gravity therapy, are limited to considerations of an internal centrifuge with an extreme radius of 10 ft. Certain characteristics of such a centrifuge are shown in Fig. 3-2. The magnitude of an artificial gravitational acceleration engendered by rotation is as follows:

$$g_s = R\omega^2 \quad (2.1)$$

where

- R = distance from the axis of rotation (ft)
 ω = angular velocity (rad/sec)
 g_s = acceleration (ft/sec²) (simulated gravity)

The direction of g_s is radially outward from the axis of rotation.

Table 3-11
CENTRIFUGE LABORATORY – BIOINSTRUMENTATION

MEASUREMENT				INSTRUMENTATION				REMARKS
Title	Parameters	Signal Frequency (cps)	Technique	Recommended Equipment	Weight (lb)	Volume (ft ³)	Peak Power (w)	
Cardiac Activity	Electrocardiogram (ECG)	0.2 to 100 (2 ch.)	4-electrode (2-axis)	Two NASA-Apollo ECG amplifiers	0.286	} 0.05 Total 26 x 33% duty cycle	0.2	Total weight, volume and power
Respiration Rate and Depth	Impedance pneumogram (ZPG)	0 to 10	2-electrode (trans-thoracic)	NASA-Apollo ZPG signal-conditioner	0.143		0.1	
Nystagmus	Electro-oculogram (EOG)	0.2 to 40 (2 ch.)	4-electrode (2-axis)	Two NASA-Apollo ECG amplifiers	0.286		0.2	
Ear Oximetry	Blood oxygen saturation	0.2 to 40 (2 ch.)	Electro-optical (waters)	Modified NASA-Ames oximetry system	0.5		0.2	Only gain and frequency response need be modified
Blood Pressure	Cuff pressure and Korotkow sound	} 0.2 to 40 (Korotkow) 0 to 4 (pressure)	Auscultatory	} NASA blood pressure and Space-labs segmental plethysmograph system	6.2		0.2	
Peripheral Circulation	Lower limb plethysmogram		Boot plethysmography					
Temperature	Deep-body, skin, and environmental temperature	0 to 1 (1 ch. time-shared)	Commutated matched thermistor probes	Two modified NASA-Apollo temp. signal conditioners (wide and narrow range)	0.286		0.2	Commutate thermistors at signal conditioner input.
Vestibular Function	Vestibular reflex (nystagmus)	—	Thermal simulation in ear	LMSC vestibular stimulator	0.5	—	3.0	Stimulus is monitored on temperature channel, and reflex is monitored on EOG. Tachometer is integral part of structure and drive system
Force Fields	Accelerations	0 to 20 (4 ch.)	Compute from rotational and dimensional data. Also, accelerometers may be used on spare channels.	Transducers and sensor garment	6.0	0.6	—	
Body Mass	Body mass	—	Read manually and reported by voice	Centrifuge tachometer, Donner or Endevco accelerometers	0.5	—	0.3	
Peripheral Vision	Visual tunneling	—	Loss of peripheral vision reported by voice or switch	Strain gage and readout	2.0	—	0.1	
Oculometry	Phoria, acuity, depth, color, motion, illusions, and perception of vertical	—	Programmed film image reported by voice	Remote-controlled peripheral lamps and acknowledge switch	0.4	—	4.0	
Coriolis Neutralizer	Subject threshold tolerance	—	Visual rotation cue	LMSC oculometer	4.0	0.1	8.0	
Reentry Simulation	Human performance	—	Visual rotation cue	LMSC coriolis neutralizer	1.5	—	5.0	Detailed equipment list in Section 5. Includes only equipment mounted on centrifuge Display panels, switches, wiring, etc., on centrifuge
Television	Subject image	—	Computer-driven simulation	Reentry simulation panel	60.0	2.0	55.0	
Two-Way Audio	Quality and modulation of voice	—	On-board scan by TV monitor	Television camera	10.0	0.1	10.0	
				Microphone and headset	0.8	—	—	
				Telemetry and data-handling system	20.0	0.2	20.0	
				Auxiliary equipment	5.0	0.5	10.0	
				Power supply system	10.0	0.1	—	

3-34

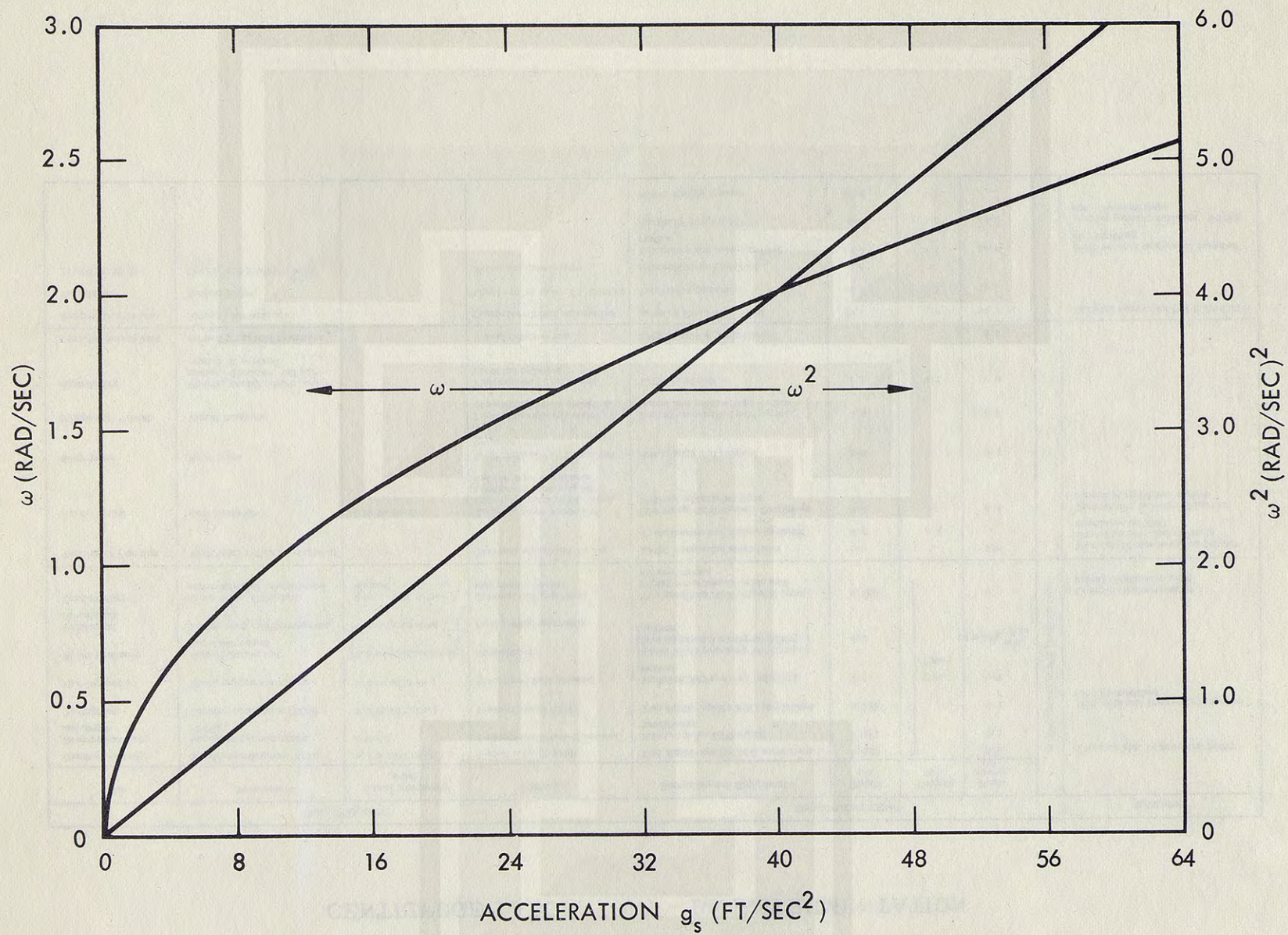


Fig. 3-2 Characteristics of a Centrifuge With a 10-Ft Radius

The other equations of interest are:

$$a_{\text{cor}} = 2VX\omega \quad (2.2)$$

$$\frac{dg}{dr} = \omega^2 \quad (2.3)$$

where

- a_{cor} = coriolis acceleration (ft/sec²)
- V = velocity relative to the spinning frame of reference (ft/sec)
- X = vector cross-product operator
- dg/dr = rate of change of g_s in the radial direction
- g_0 = 32 ft/sec²

The direction of a_{cor} is perpendicular to both ω and V , and the magnitude is equal to the absolute value of the product of ωV and the sine of the angle between ω and V .

Man's ability to endure rotation without incurring either prohibitive physiological stress or prohibitive performance loss is a function of a_{cor} , dg/dr , a_{cor}/g_s , the presence or absence of visual and proprioceptive sensory inputs, and many aspects of the individual's physiological and psychological status. One value of ω , 0.4 rad/sec, has been prominently mentioned as the maximum beyond which a substantial probability exists of canal sickness (defined as the onset of nausea). This limit has been determined by experiments involving incomplete knowledge of the velocity of head movements. It should be considered applicable to head movements made at normal velocities.

Canal sickness can result in nausea, dizziness, visual illusions, apathy, and, in some cases, collapse. It can also make coordination of arm and body movements difficult. Walking will probably not take place in a centrifuge with 10-ft radius, but arm and

head movements will have some significance. A measure of the latter difficulty is the ratio of the coriolis force to the man's local weight.

From Eqs. (2.1) and (2.2),

$$\frac{a_{\text{cor}}}{g_s} = \frac{2\omega V}{R\omega^2} = \frac{2V}{R\omega} \quad (2.4)$$

There is also some indication that this ratio is a contributing or limiting factor upon canal sickness symptoms.

To avoid exceeding an ω of 0.4 rad/sec (for $R = 10$ ft) will require a $g_s = 1.6$ ft/sec² or 0.05 g_0 (where g_0 equals 32.2 ft/sec²). Therapy, if effective at all, will very likely require many hours per day in the centrifuge under such conditions. Under such circumstances, a_{cor}/g_s will be 2, (Normal velocity V is 4 ft/sec).

Turning to the question of the acceleration gradient dg/dr , a 6-ft man lying radially in the centrifuge, head inwards, will experience a g_s of $10\omega^2$ at his feet and $4\omega^2$ at his head. For $g_s = g_0$ at the periphery, this means a gradient of 0.1 g_0 /ft. The compressive force, ignoring friction, is

$$\frac{M\omega^2}{6} \int_4^{10} Rdr = 7M\omega^2 \text{ (arbitrary units)}$$

where

M = body mass

R = radial distance from axis of rotation

In other words, the compressive force will be 0.7 times the weight of the subject if all his body mass were at the periphery. For $g_s = g_0$, a man whose earth weight was 150 lb will experience a compressive force of 105 lb. The exact parts of the

body undergoing tension or compression will be determined by the details of the restraint system. It is obvious, however, that neither blood flow, elastic deformation, nor proprioceptive response will be the same as under uniform acceleration.

The short-radius MORL centrifuge, with all its attendant limitations, will probably be a most satisfactory device for the maintenance of peripheral vascular reflexes. Although the time of exposure is undetermined at present, it is possible that a few minutes a day in such a centrifuge will prove to be the least time-consuming way to maintain the vascular system. The centrifuge will be a valuable device in the event that no other method or device is effective in counteracting the effects of weightlessness in other body systems.

3.7.2 The Centrifuge as a Simulator of Reentry-Type Stresses

Although the response to reentry is, perhaps, of greatest significance and most concern, there are some dangers in subjecting an astronaut to such severe stresses. By definition, for example, subjecting an astronaut to an acceleration at the limit of his physical tolerance involves the inherent possibility of exceeding that tolerance because sufficiently precise prediction of the physiological end point is not possible. Even present simulated Apollo-reentry acceleration histories indicate a critical nearness to the physical limitations of an astronaut in perfect physical condition. Even if bio-instrumentation, monitoring, and rescue techniques are sophisticated enough to ensure that ground-tested acceptable endpoints are not exceeded during a centrifuge run, there is no assurance that recovery would be as quick or as complete with both a weightless prehistory and a weightless recovery, nor would complete hospital facilities be available on orbit.

Present MORL plans include the fairly accurate simulation of the Apollo reentry acceleration profile. This should prove adequate for the evaluation of man's basic reentry readiness. Eventually, more stressful profiles may be of interest for interplanetary reentries.

A centrifuge of 10-ft radius will have definite limitations as a reentry simulation device. In order to develop 8 g it is necessary to develop such a high ω , a_{cor}/g_s , and dg/dr that it can only be endured with minimal head and body movements. Very little can be done while confined to such an environment.

3.7.3 The Centrifuge as a Provocative Tool

For the purposes of this study, two types of provocation are considered:

- The production of more moderate stresses to test the state and manner of function of cardiovascular, respiratory, vestibular, and central nervous systems
- Use of the centrifuge over extended periods of time at low acceleration; for example, at $0.1 g_0$ to $1.5 g_0$ to determine chronic effects as a function of acceleration level

The first use of the centrifuge to study cardiovascular, respiratory, and neurologic physiology is potentially valuable. The previous remarks made about safety on the ground versus safety in space are, however, again applicable. Rotation effects will be superimposed upon the other phenomena. There is no doubt, on the other hand, that the absence of the Earth's gravitational field will tend to increase the preciseness with which determinations in these areas can be made. A final decision on the usefulness of a centrifuge laboratory for this purpose hinges to a considerable extent on the development of safe, reliable bioinstrumentation, telemetering, and data processing equipment within reasonable weight limits.

The second type of provocation mentioned was long-term exposure to a variety of acceleration levels. Consideration has not been given to humans living in a 10-ft centrifuge for an extended period. Interest here is directed at large rotating stations and large radius external centrifuges. The data shown in Fig. 3-3 are an aid to artificial gravity design for this purpose.

3-39

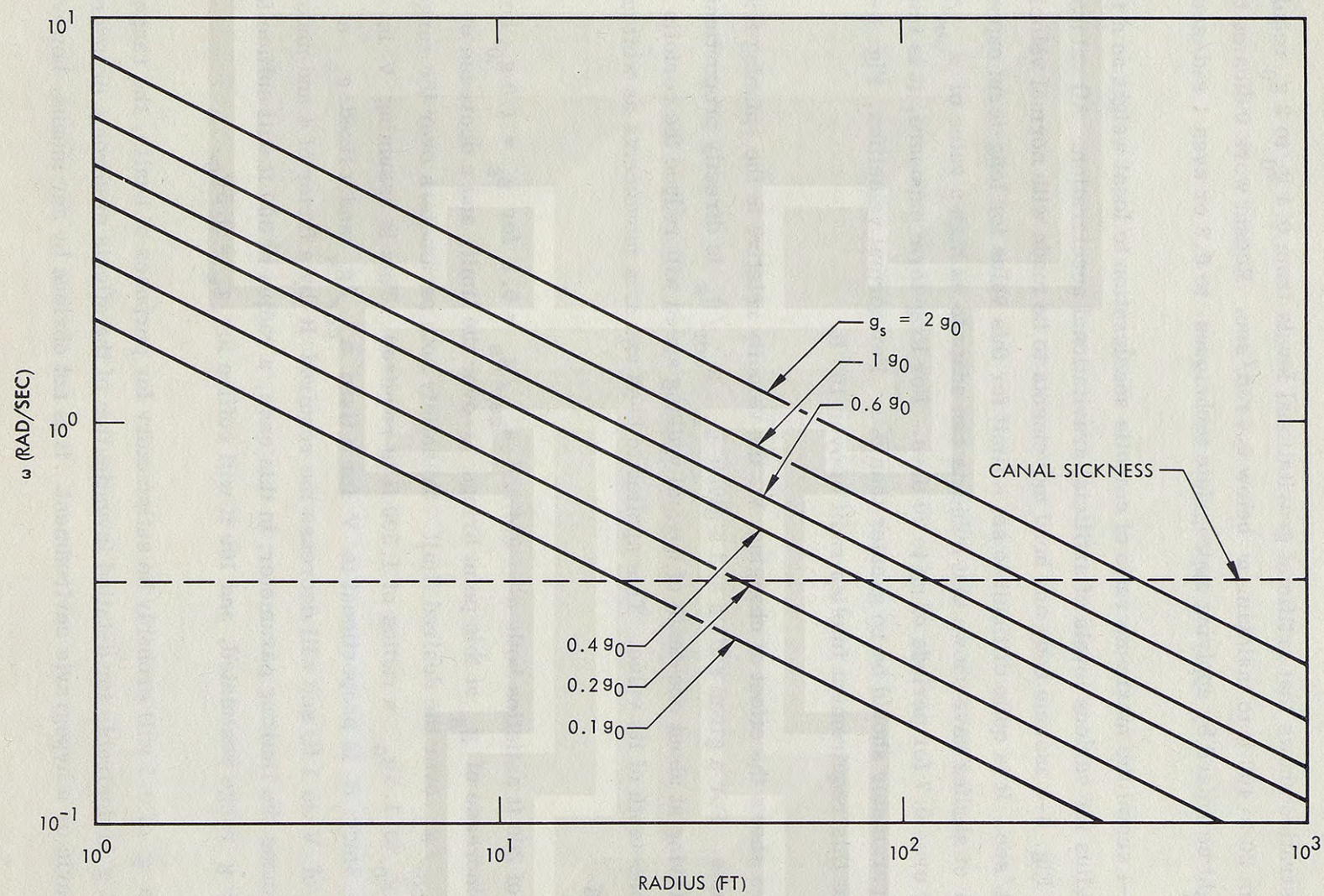


Fig. 3-3 Angular Velocity ω As a Function of Radius for Various Artificial Gravity Levels

This illustration shows that artificial gravitational levels from $0.1 g_0$ to $2 g_0$ require radii from 20 to 400 ft to maintain ω below 0.4 rad/sec. Recent work indicates this limit might be raised by applying appropriate techniques to 0.8 or even 1 rad/sec.

Figure 3-4 shows the maximum ratio of coriolis acceleration to local weight as a function of radius for various levels of artificial gravitational acceleration. All values shown in Fig. 3-4 assume body and head movements to be made with normal velocity, i.e., 4 ft/sec. It is quite difficult to set a limit for this value for long-term exposure. A number of studies have shown that subjects can adapt to as high a value of a_{cor}/g_s as 0.5 or even 0.7 for periods of up to 20 days. For long-term exposure, it is felt that this parameter should be no greater than 0.1. For normal velocities, Fig. 3-4 shows that this requirement implies radii of over 100 ft.

Figure 3-5 shows the effect of changing V , the velocity relative to the spinning frame of reference. For a given radius and a given g_s , a_{cor}/g_s is directly proportional to V . Moving at about one-tenth of normal walking speed will reduce the coriolis force to one-tenth of its value. This applies to head and arm movements as well as to walking.

A radius of 200 ft satisfies both $\omega = 0.4$ and $a_{\text{cor}}/g_s = 0.1$ for $g_s = 1.0 g_0$; however, an increase of g_s at this point brings ω over the limit, and a decrease of g_s brings a_{cor}/g_s over the desired limit. To satisfy both parameters over the range $g_s = 0.1 g_0$ to $1.5 g_0$, a radius of 1,500 ft is required. This is assuming V is 4 ft/sec. Since R is proportional to V for a fixed a_{cor}/g_s and a fixed g_s , a reduction of V to 1 ft/sec will decrease the required R by a factor of 4 and make canal sickness the limiting parameter; in this case, a radius of 300 ft will suffice for the entire g range postulated, and 100 ft will suffice for $g_s = 0.5 g_0$.

Although a g of 0.5 will probably be satisfactory for purposes of health, the range of 0.1 to 1.5 g is desirable for detailed investigation of the effects of chronic exposure to a hypergravic or a hypogravic environment. It is not obvious by any means, however,

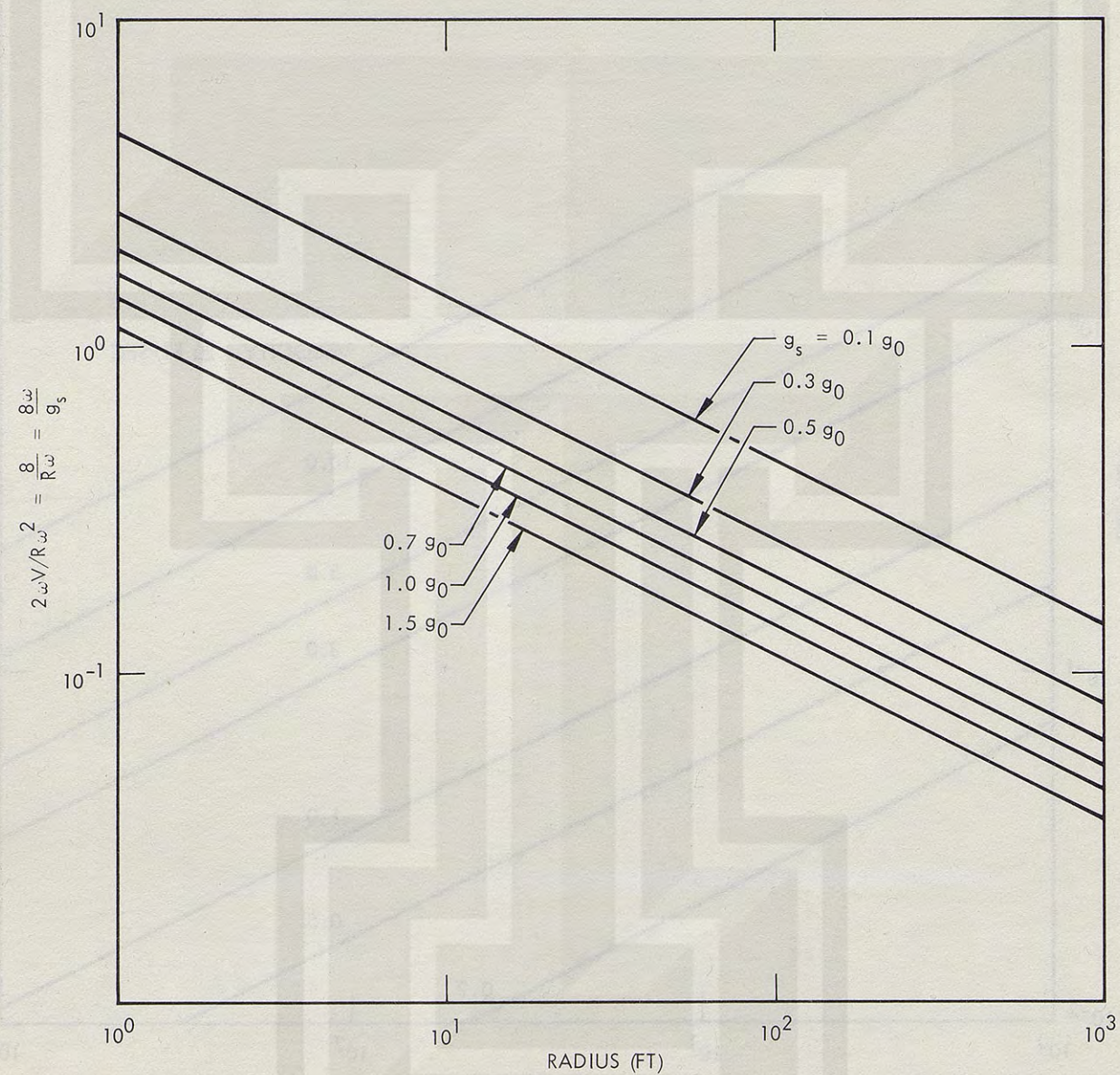


Fig. 3-4 Maximum Ratio of Coriolis Acceleration to g_s
Vs. Radius for $V = 4$ Ft/Sec

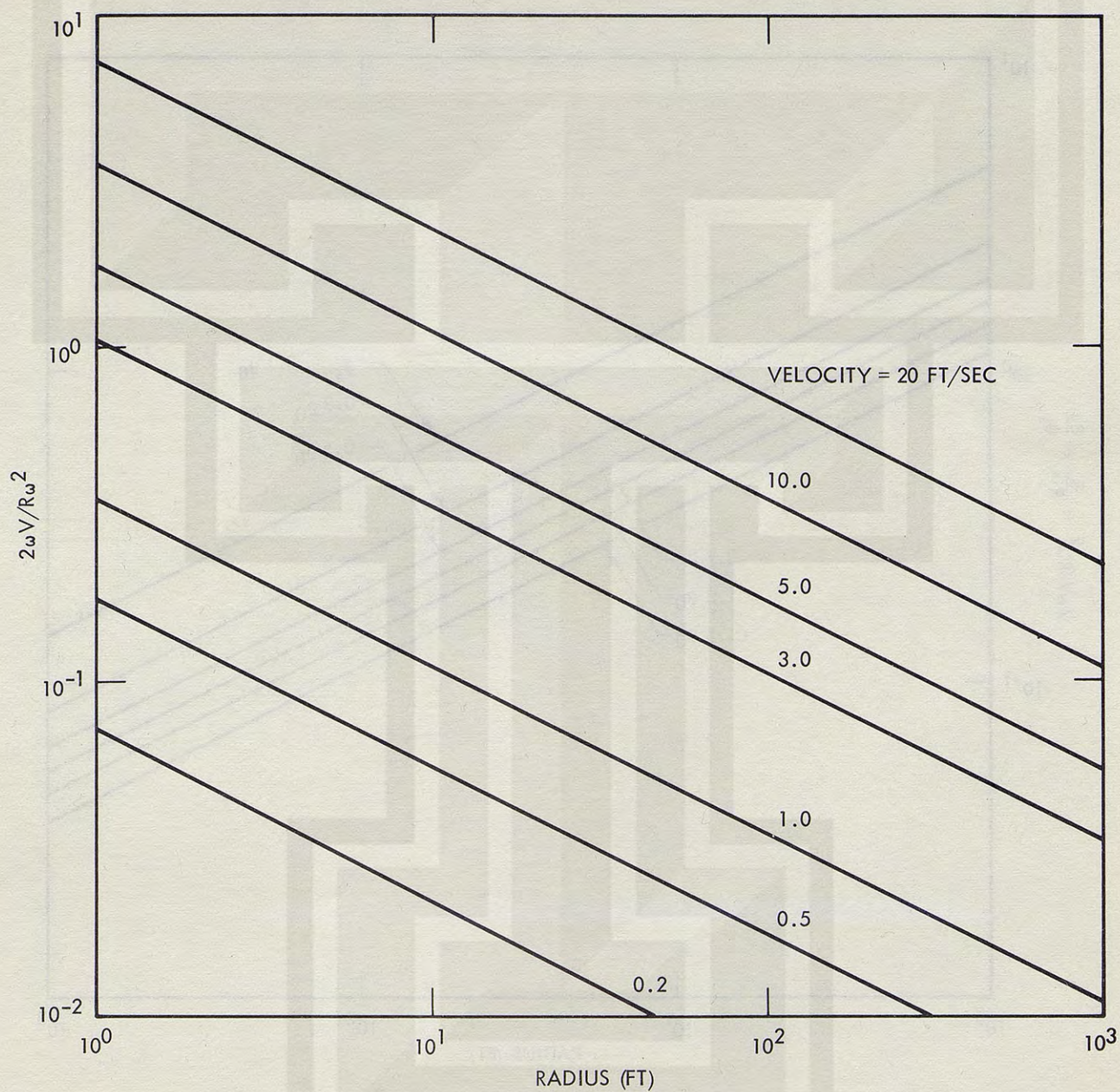


Fig. 3-5 Maximum Ratio of Coriolis Acceleration to g_s
Vs. Radius for $R\omega^2 = 32 \text{ Ft/Sec}^2$

that an approximate 75 percent reduction in velocity in all body and head movements is an easily made adaptation, not to mention the problem of emergency movements which, if made at, say 20 ft/sec, will be more meaningful from the information standpoint.

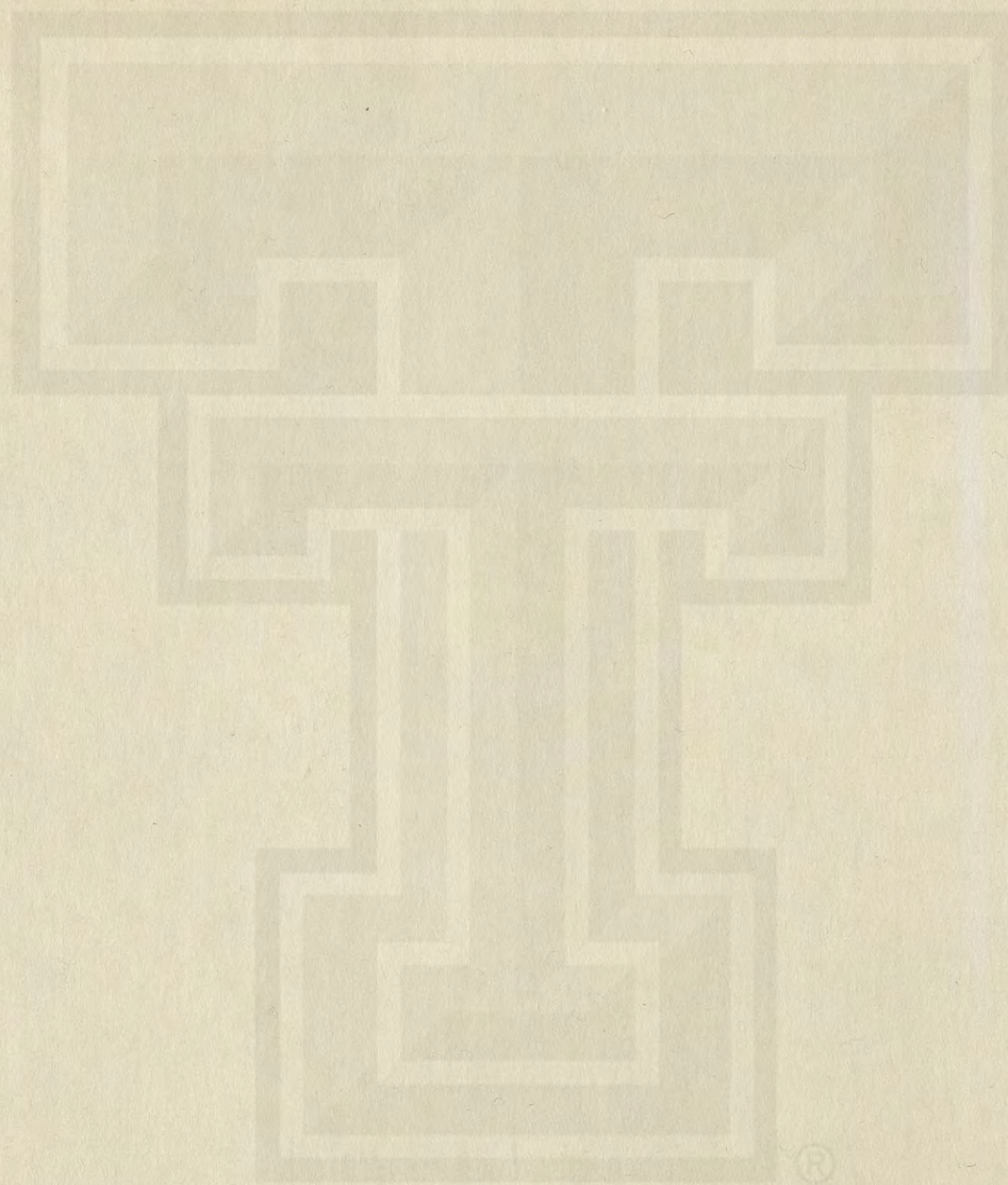
3.7.4 Conclusions

For the Centrifuge Laboratory to be sufficiently versatile to permit investigation of all physiological parameters which appear to be of interest, a number of modifications to the present MORL design will be necessary. A centrifuge cab design which permits yawing, sealing, and darkening of the cab interior will be desirable for vestibular studies.

Operation in a pressurized suit will permit better evaluation of reentry readiness since reentry will involve such conditions.

On the basis of the evidence now at hand, LMSC feels that the MORL internal centrifuge offers an effective provocative tool for investigating the effect of low to moderate centrifugal accelerations $1 g_0$ on the major body systems. The internal centrifuge has limited use as a therapeutic device because of its short radius, and has very little potential as a reentry simulation device. At this time, it appears to present dangerous and disquieting conditions with respect to reentry simulation. Further ground tests with short-radius centrifuges are indicated before final decisions are made as to its use for this latter purpose in-flight.

4 SYSTEM/LABORATORY ANALYSIS
AND INTEGRATION



Section 4
SYSTEM/LABORATORY ANALYSIS AND INTEGRATION

4.1 GENERAL CONSIDERATIONS

System analysis and integration required for the successful definition and development of a conceptual design of measurement system for the MORL encompasses the following aspects:

- Review of MORL constraints and capability
- Space allocation study
- Delineation of the instrument and equipment requirements
- Functional analysis, trade-off studies, and performance evaluation

For the foregoing activities, it was necessary to determine the interface problems between the measurement system and the spacecraft, and the interrelationship between the various biomedical laboratories. The approach to the design was to explore a minimum of two alternate candidates (where possible) which differed in complexity and the degree of astronaut management required. The final recommended designs are treated in detail in Section 5.

Four major subsystems were established to represent the total measurement system. They are designated in terms of the types of measurement with which they are concerned – biomedical, centrifuge, crew performance, and laboratory.

- Biomedical Measurement. The candidates for this system, differing principally in capacity, are as follows:
 - Biomedical safety measurement system (discussed in detail in this Section)
 - Biometric and Micro-Chem stations

- Centrifuge Bioinstrumentation. The candidates for this system are concerned primarily with the transmission and handling of data. Candidates considered are as follows:
 - Slip rings
 - Telemetry
 - On-board power
- Crew Performance Measurement. The candidates for this system, differing primarily in degree of portability and operational mode, are as follows:
 - Crew performance monitoring system
 - Crew performance measurement station
- Laboratory. This category is reserved for equipment or subsystems that provide support for either the Physiology or Microscopy and Chemistry Laboratories. Following are typical support equipment in this category:
 - Telemicroscope
 - Mass measurement system
 - Infrared respiratory CO₂ analyzer
 - Oculometer

4.2 BIOMEDICAL MEASUREMENT SYSTEM

An analysis was performed based on the lower limit of minimum measurements to satisfy safety requirements and an upper limit of the optimal measurements to determine the physiological effects of weightlessness. This section discusses various techniques, measurements, and equipment arrangements.

4.2.1 Biomedical Safety Measurement System

The minimum measurements to be made by this system are identified, in part, in Ref. 1-1, Annex F. The system presented in the following paragraphs satisfies the requirement identified in Annex F and includes several additional measurements.

Annex F has been divided into the five categories of measurement listed in Table 4-1, of which only two are included under the general heading of Biomedical Safety.

Table 4-1
MEASUREMENT CATEGORIES^a

Category	Type of Measurement
A BIOMETRY (Instrument Measurements)	1. Blood pressure 2. Cardiac activity and state (ECG) 4. Pulse rate 11. Respiratory rate 12. Body temperature 19. Voice 21. Metabolism 20. Pulmonary respiration
B VISUAL OBSERVATION	17. Cardiopulmonary symptoms (Dyspnea) ^b 3. Venous Distention 13. Muscle size 22. Venous pressure
C CREW PERFORMANCE (Experiments)	16. Computation 14. Arm-hand manipulation 15. Speech perception
D IN-FLIGHT LOG-VOICE LINK/ MANUAL ENTRY KEYBOARD/ TAPE RECORDER	5. Food intake (eating habits evaluation) 6. Bowel habits (function evaluation and stool) 7. Regurgitation and nausea 8. Fluid intake and output 17. Cardiopulmonary symptoms (Dyspnea) ^b 18. Voiding Evaluation
E GROUND LABORATORY	9. Urinalysis 10. Hematocrit and hemoglobin

^aReference 1-1, Annex F

^bDuplicated

These measurements are: (1) those essential to the determination of astronaut safety and state of well-being and measurable by instrumentation and (2) those which can be observed visually or aurally.

Various techniques and methods for measuring the minimum biomedical parameters presented in Table 4-1 were reviewed. Numerous NASA and NASA contractor reports, industry reports, current Gemini, Apollo, and MORL plans, and LMSC in-house studies were reviewed and analyzed. From this effort, detailed techniques and methods were listed. Based on these considerations, three distinct approaches have been identified for performing minimum biomedical system measurements. The first two are presented as approaches for accomplishing intra-MORL biomedical measurements. The third approach is directed to the concept of measuring biomedical parameters during extravehicular activities.

The first approach is to provide the astronaut with body-worn garments, which are donned or doffed for measurement within the spacecraft, and an umbilical cable connected to provide input signals to the computer. The second approach is to provide a special biomedical "jig" in the Biometric station. The jig contains the biosensors which the astronaut affixes to his body. Signals are processed through these sensors to the computer.

The third approach is to provide the astronaut with the body-worn garments identified in the first approach and a telemetry-belt which connects to the umbilical of the body-worn garments (this enables extravehicular measurement).

The major problem of providing the minimum biomedical measurements revolved about the problem of providing sensors which are capable of obtaining biomedical measurements to the degree of reliability required resulting in maximum validity of measurement and reproducibility. Astronaut comfort also was considered, since current techniques for electrode attachment to the skin generally involve cements or adhesive tapes. Repeated measurement may cause considerable skin irritation resulting in real discomfort to the astronaut.

Consideration of the various factors requires a recommendation to proceed to the design and development of a hard-wired biometric station concept in order to permit the performance of repeated measurement. This design concept also permits integration of the crew-performance measurement requirements. Reliability can be met by allowing the astronaut to monitor and maintain the station. Sensor attachment problems can be alleviated by providing a pressure differential at the electrode face and by providing a special jig.

The safety monitoring feature of the portable system can still be utilized in the MORL, and the requirement for extravehicular and centrifuge activity can be fully met through use of this concept. In the case of EVA, the Apollo bioinstrumentation incorporated in the pressure suit will be used. For centrifuge application, a coverall garment with sensors integrated will be used.

4.2.2 Biometric and Micro-Chem Station

The MORL interior configuration is predicated on the separation of work and living areas. It is oriented to be compatible with either zero-g or artificial gravity. Stowage and location of the biomedical, crew performance, and laboratory equipment required to conduct the comprehensive biomedical program proposed by LMSC has been conceived in the light of such consideration.

The Operational Experimental area is the working area of the laboratory. The work stations designated for behavioral/biomedical experiments and microscopy/chemistry purposes are provided with all monitoring display and controls necessary to direct the performance of scheduled experiments. Two major stations are required; these are located as shown in Fig. 4-1. Biometric station contains all controls and displays necessary to conduct the biomedical/crew performance program, including the centrifuge measurements. This station is designed for two-man occupancy with provisions for a third in a standing position to perform biomedical monitoring.

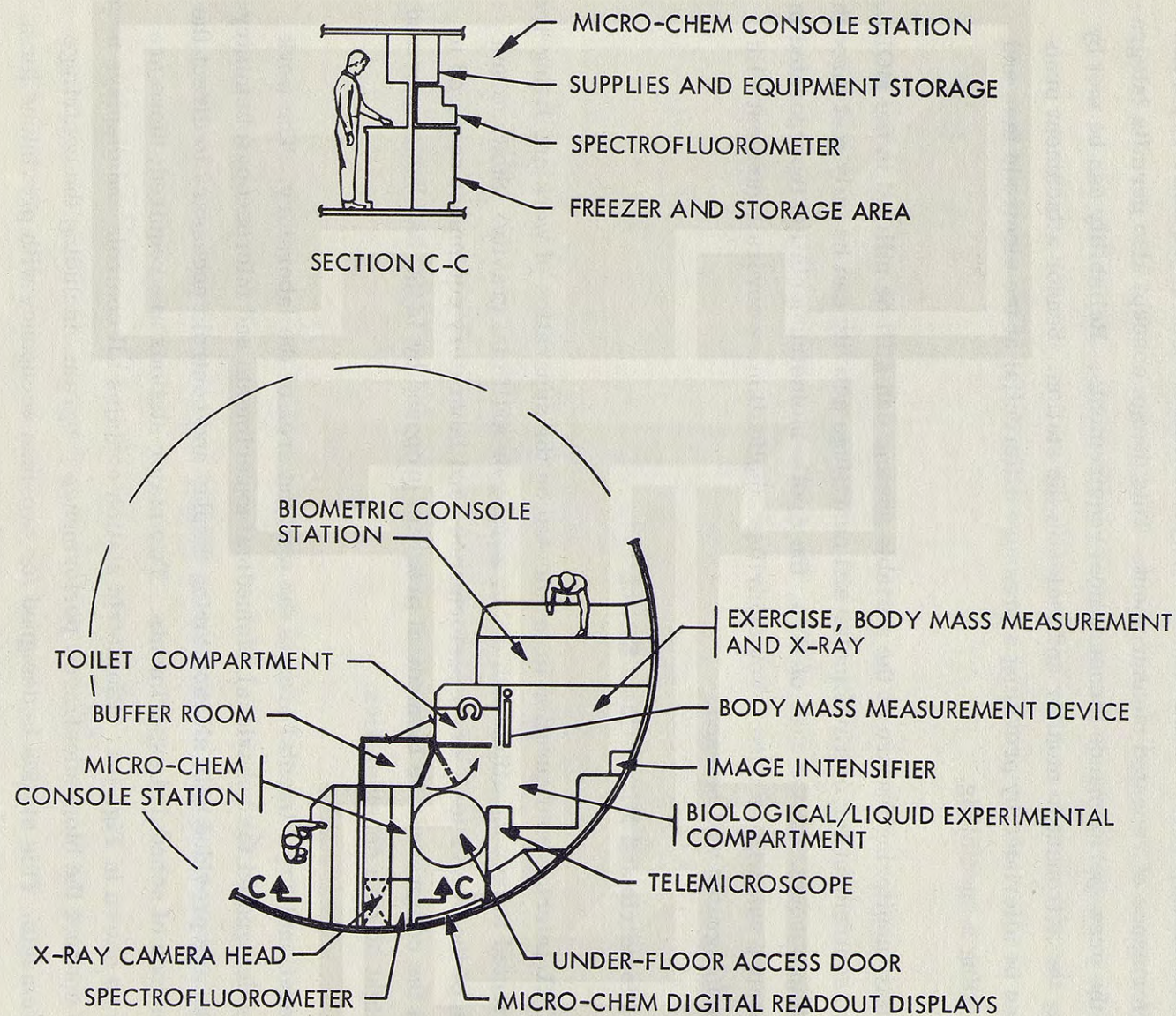


Fig. 4-1 Biometric and Micro-Chem Stations integrated into the MORL Experimental Area

The Micro-Chem station is located in the biological/liquid experimental compartment. This compartment is a separately enclosed area with provision for biological and liquid experiments. It contains a controlled ventilation buffer room and area for biological sample experiments. Refrigerators, sterilizer, access to the waste disposal unit, and a liquids-test bench are the main features of this facility. Among the equipment at the Micro-Chem station are major units, such as a spectrofluorometer and a telemicroscope.

Two biomedical console station designs were considered during the conceptual design stage of MORL. Either design concept appears feasible for the human performance-physiological console station. In addition, the initial design concept was a standard sit-type console designed to permit astronauts to perform tasks comfortably when dressed in a full pressure suit or in shirt-sleeve attire. The console station design emphasized a modular remove-replace approach for either concept. In the initial design, maximum utilization for storage was made of the area above the workshelf and the display and control area. The volume and area beneath the workshelf were considered generally inaccessible and therefore relegated to use for storage of hardware components not requiring access. The workshelf is designed to accomplish the three following purposes:

- Provide a writing-work area
- Supply a unit for storing the biomedical "jig" in a drawer-like manner
- Provide a unit in which plug-in receptacles can be mounted

The second console station design concept is illustrated in Fig. 4-2. This console is designed to permit a sit-stand crew interface. However, a unique design feature is presented in this concept. A second major display-control panel area is provided directly beneath the workshelf. This concept permits a zero-g advantage in that the console can be utilized in an "upside-down" fashion. The astronaut can stand on the ceiling and utilize the display and control area located beneath the workshelf (as viewed from the "normal" position of standing on the deck floor). A storage area is provided above the workshelf, and display and control panel.

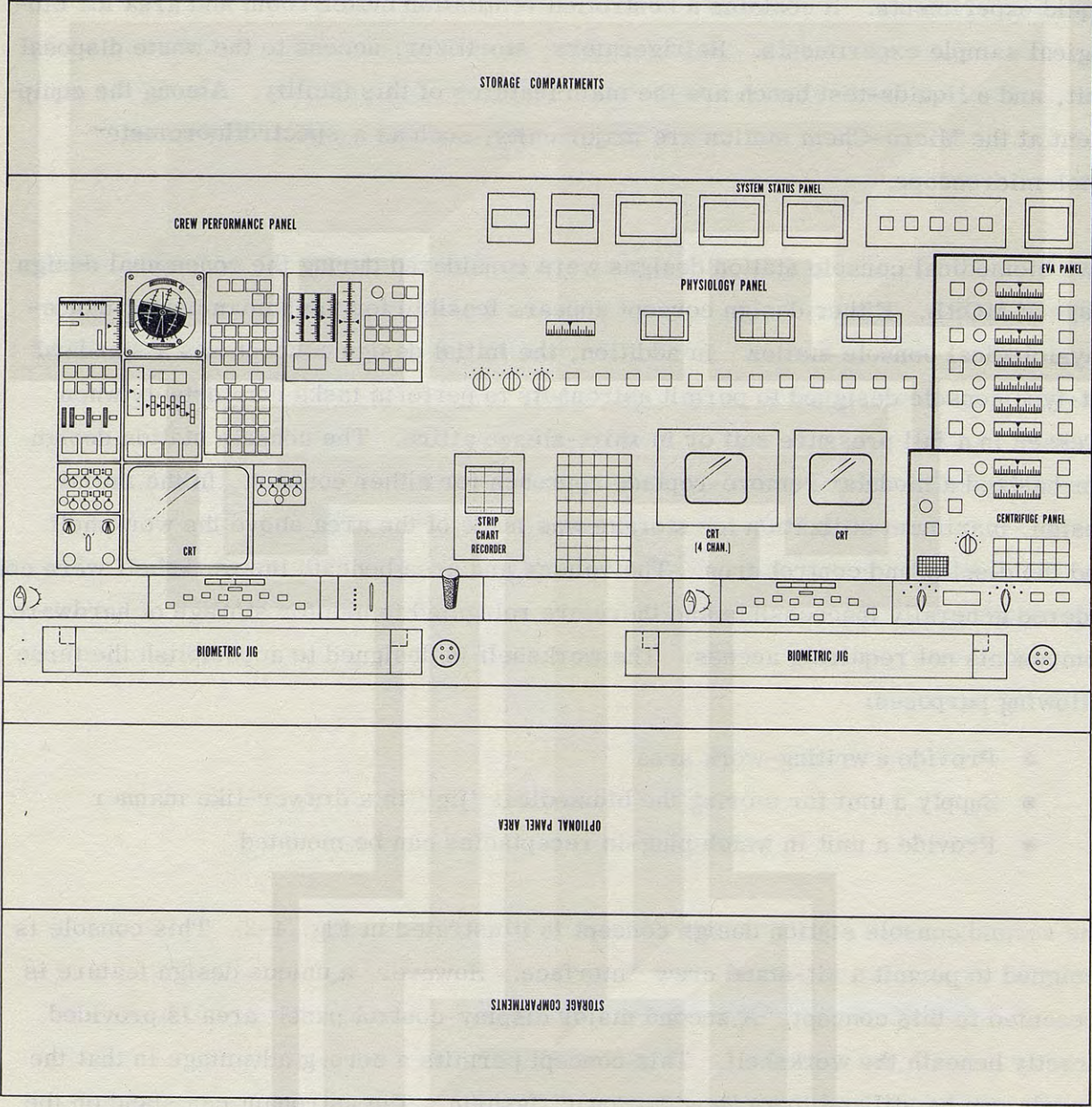


Fig. 4-2 Biometric Console Display Panel and Storage Compartments

These two concepts do not lend themselves to satisfactory fulfillment of the Micro-Chem station console functional requirements. A standard cabinet, work surface, and storage area appear more appropriate for this console station.

4.2.3 Selection of Preferred Approach

Console selection criteria were developed, and each conceptual console was compared (Table 4-2) with respect to the Biometric station console.

The sit-stand console station emerges as the most versatile type and, in all probability will be less difficult to check out of the launch site. (It should be noted that the configuration of the spacecraft at launch will require that the position of the Operations and Subsystems Control station be upside down; checkout activities therefore will be somewhat difficult in this mode.) Since one-half of the console will be right-side-up in the launch position, a panel module can be provided for total console checkout that is in the "normal" position at launch.

The console also permits two additional panel areas for measurement and experimentation. Their use will be contingent upon the scheduling of console activities occurring in the right-side-up position when the MORL is in orbit.

This flexibility and ease of checkout, coupled with the lack of foreseeable problems if artificial gravity is provided for the MORL, indicate that the sit-stand console be provided. The lower panel area beneath the workshelf (that panel area which is upside down) allows flexibility in design. This area is available for expansion, system redundancy, or immediate use. This console concept seems particularly applicable to the Biometric station console (physiology and human performance) although practical utility for the Micro-Chem station console is doubtful.

As previously stated, a standard laboratory type cabinet-work area station is suggested as the most optimum approach to the configuration of the Micro-Chem console station in MORL. (See Figs. 4-1 and 4-3.)

Table 4-2
COMPARISON OF TWO CONSOLE STATIONS FOR MORL

CRITERIA	SIT CONSOLE		SIT-STAND CONSOLE	
	Yes	No	Yes	No
Maximum ease in crew interface permitted	x		x	
Storage area provided (front and side)	x		x	
Display-control modules easily removed and replaced	x		x	
Functional location of module in console possible	x		x	
Permits two crewmen to work simultaneously at console	x		x	
Equipment and components located to ensure their maximum protection	x		x	
Exterior and modules (sharp corners, protrusions, etc.) designed to prevent injury to crew	x		x	
Functionally adaptable to a variety of performance tasks	x		x	
Equipment easily checked at launch site		x	x	
Designed for "any-position" use		x	x	
Adaptable to operation under artificial-gravity condition	x		x	
Two crew work areas available		x	x	
Adequate space for mounting all equipment and modules	x		x	

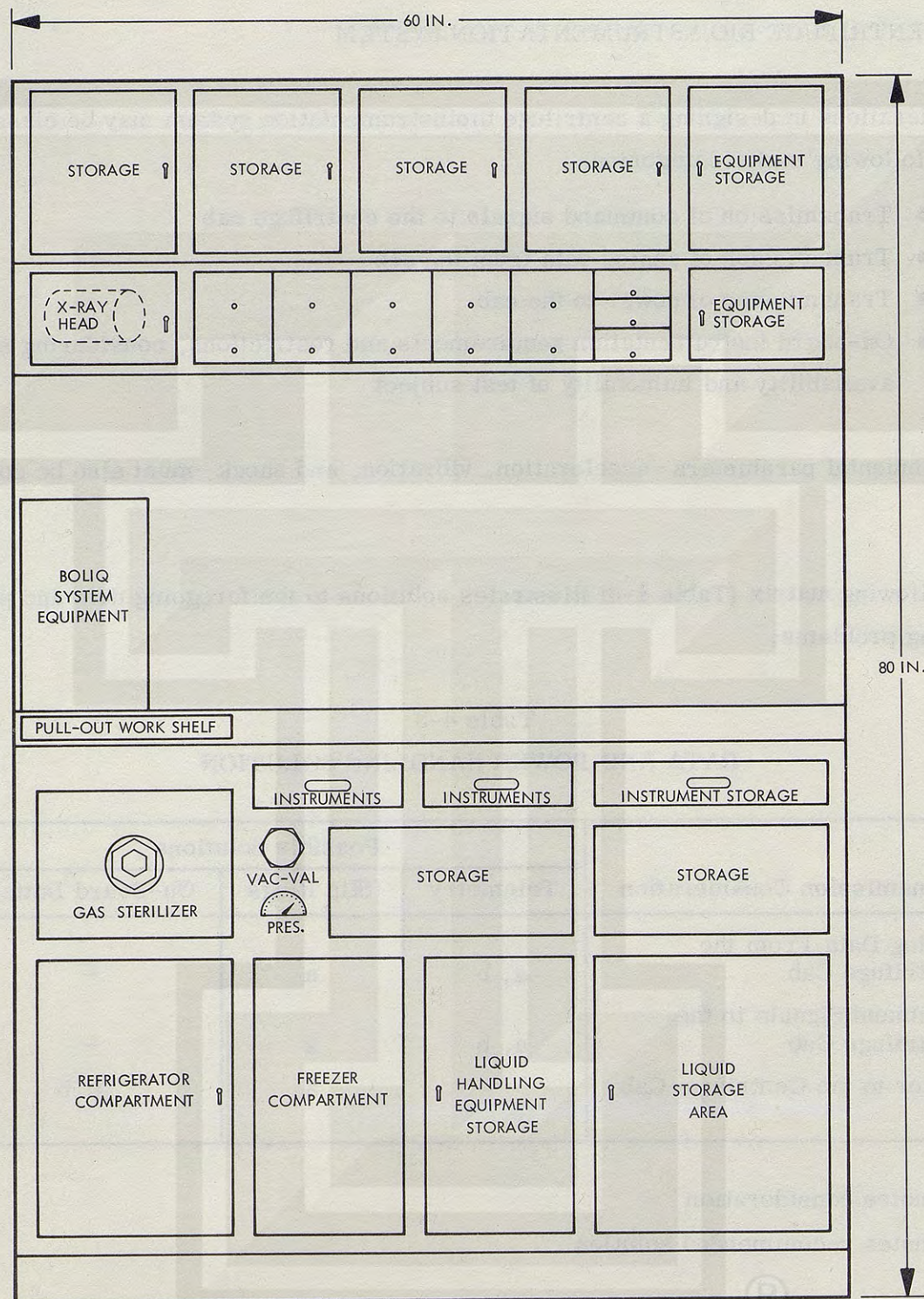


Fig. 4-3 Micro-Chem Console Display Panel and Storage Compartments

4.3 CENTRIFUGE BIOINSTRUMENTATION SYSTEM

Considerations in designing a centrifuge bioinstrumentation system may be classified in the following major categories:

- Transmission of command signals to the centrifuge cab
- Transmission of analog data from the cab
- Transmission of power to the cab
- On-board instrumentation requirements and restrictions, considering space availability and immobility of test subject

Environmental parameters—acceleration, vibration, and shock—must also be considered.

The following matrix (Table 4-3) illustrates solutions to the foregoing data and power handling problems:

Table 4-3
DATA AND POWER HANDLING SOLUTION

Transmission Consideration	Possible Solutions		
	Telemetry	Slip Rings	On-Board Battery
Analog Data From the Centrifuge Cab	a, b	a	—
Command Signals to the Centrifuge Cab	a, b	a	—
Power to the Centrifuge Cab	—	a	a, b

^aDenotes consideration

^bDenotes recommended solution

Possible solutions are described in the following paragraphs.

4.3.1 Slip Rings

Table 4-3 shows that slip rings can possibly be used to solve all of the listed transmission problems.

Analog output slip rings will require precious metal surfaces to keep noise at a minimum. With the large radius and high surface speed of the MORL slip rings, slip-ring manufacturers estimate it will be impossible to bring noise level down to less than $200 \mu v$, even by using precious metal.

Eccentricity will also present a major problem. This, however, could be minimized by mounting the pick-off brushes in a carriage which, in turn will ride against a special slip-ring track. The distance between the brush bearings and the slip ring surfaces will therefore always remain constant. All motion due to eccentricity will be taken up in the brush carriage.

Since the command signals to the centrifuge will, in general, be of low current, slip rings similar to those first described can be used for this purpose. Because the command signals will generally be of constant amplitude, noise will not be as much of a problem in this case. Silver rings with low friction plating or impregnating compounds, and brushes of silver graphite or silver metal impregnated with molybdenum disulfide, can be used.

Power will have to be transmitted on to the centrifuge with heavy-duty rings and brushes. Beryllium-copper rings and carbon brushes can be used, but electrical arcing will present a real EMI problem.

About 15 input, 24 output, and 3 power functions would have to be brought on and off the centrifuge to satisfy present requirements. Although multiplexing schemes can be employed to reduce the number of slip rings required, the slip-ring requirement for the MORL centrifuge will still be considerable.

From the foregoing discussion, slip rings have generally been eliminated from consideration.

4.3.2 Telemetry

Near-field telemetry appears to be the solution to data transmission to and from the centrifuge cab. Although the complexity of telemetry appears, at first, to weaken the case for its use, this disadvantage is offset by the quality of the data which it transmits. Telemetry, rather than a slip-ring system, is strongly recommended for data transmission from the cab.

The proposed centrifuge telemetry system is discussed in detail in Section 7.

4.3.3 On-Board Battery Power

Since power input by means of slip rings can present a severe EMI problem and will require considerable noise filtering, an on-board battery is proposed as a reasonable alternate. This rechargeable battery will be charged when the centrifuge is not in use. In examining centrifuge duty-cycle and power requirements (Table 3-9), it appears that a 10-lb (120 w-hr) nickel-cadmium battery will be adequate. This battery can be used as tare weight in the cab opposite the cab occupied by the test subject.

4.3.4 Measurement and Instrumentation Requirements

Instrumentation has been developed, and is well known, for many of the measurements selected for the Centrifuge Laboratory (Table 3-9). Such instrumentation includes the electrocardiograph, impedance pneumograph, sphygmomanometer, and thermometer. However, instrument selection for measuring nystagmus, cerebral blood condition, and optical image transmission are not as clear-cut.

Nystagmus Measurement. Nystagmus is an involuntary, rhythmic, movement of the eyes. It occurs in several pathological states of brain damage, in response to some drugs, and as a natural reaction to strong vestibular stimulation by motion, thermal

gradients, or vestibular disease and/or injury. There are two components to nystagmoid eye motion: a slow component, in which the eyes gradually drift away from the point of fixation, and a quick component, whereby the eye rapidly moves back to the point of fixation. The frequency at which these movements occur may vary from less than 40 jerks/min (slow nystagmus) to more than 100 jerks/min (rapid nystagmus). The amplitude of the eye movement may be coarse (greater than 3/mm excursion) or fine (less than 1 mm. excursion). (See Ref. 4-1.)

The following methods have been used for the objective study of eye movement:

- Direct Observation. If the eyes are open and visible (directly or by means of the TV monitor), the presence and duration of nystagmus may be determined. This method is subject to the usual difficulties and limitations inherent in subjective observation and recording, and does not lend itself to a quantitative determination.
- Corneal Reflection. A beam of light can be directed at the cornea, and the reflected light may be used as a measure of eye movement and direction of gaze. This method is not very appealing because of the difficulties which will arise in keeping a light source and photoelectric sensor or camera properly positioned in front of the eye during centrifugation.
- Impedance Oculography. If the a-c impedance is measured between electrodes affixed to either side of the palpebral fissure, it has been found that this impedance will vary with eye movement. This method suffers from the difficulties of complex instrumentation and maintenance of bridge balance in all body impedance measurements.
- Electro-Oculography. The association of electrical potentials with eye movements has long been known, but Mower, Ruch, Miller (Ref. 4-2) first determined that these potentials did not come from the extrinsic muscles of the eye, but were due to the presence of an electrical dipole, oriented along the axis of each eyeball which is called the corneo-retinal potential. Miles (Ref. 4-3) carried out a series of studies to determine the characteristic of this potential. He found that the potential rose slightly under emotional conditions, when the eyes closed, and from mechanical pressure on the eyeball.

The potentials are constant for a given subject over successive days, but there are marked individual differences in average amplitude.

This technique is considered to be the method of choice because it only requires the attachment of small electrodes to the skin surrounding the eye, a compatibility of the amplitude and frequency characteristics of the signal with common bio-electric equipment, a capability for quick application and removal of the electrodes with little interference with the subject, and an electrode ability to withstand centrifugation easily.

Various values have been given for the potential change per degree of eye rotation which range from $5 \mu\text{v}/\text{deg}$ to $80 \mu\text{v}/\text{deg}$. Based on these findings, it can be expected that signals of about 0.1 to 1 mv will be associated with nystagmoid movements. The onset-to-peak time of rapid eye movement is 60 to 100 μsec . and return to baseline may require from 0.5 to 2 sec , depending on the frequency of the nystagmoid movements. The source impedance depends on the skin preparation and electrodes, and may be as low as 1,000 Ω .

Depending on the electrode placement and configuration of the face, EEG potentials (usually 10 cps alpha rhythm) may contaminate the EOG. This artifact is particularly apt to be present if an ear or high forehead electrode is used. If the skin is not adequately prepared, galvanic skin reflex potentials may contaminate the record with large 1 to 5 μv signals. The method of Shackel (Ref. 4-4) is recommended for reducing this artifact. Electromyographic potentials from the extrinsic eye muscles have been reported in EOG records, but these potentials are usually not discernible.

One might expect the fields of the two eye dipoles to overlap and contaminate one another; however, quantitative measurements of the EOG in subjects who have had one eye removed have demonstrated that an EOG obtained from nasal and lateral palpebral electrodes is a function of the eye lying between the electrodes only. From the above EOG signal information, it is observed that the signal characteristic is very similar to

that of the ECG. LMSC therefore recommends a standard NASA-Apollo ECG amplifier for signal conditioning the a-c electro-oculogram.

Cerebral Blood Condition. The basic safety information required on the centrifuge includes that of cerebral blood flow. Blood oxygen saturation is also desired.

Indexes of blood flow to the head are the rheo-encephalogram (REG), ear blood pulse, and peripheral vision. The ear oximeter measures blood oxygen saturation.

Although several noted researchers in the field of REG claim that baseline data can be obtained from the measurement, LMSC is reserving the recommendation of this measurement on the centrifuge until more experimental data are published. The centrifuge data handling system will, however, accept REG signal if it does become the desired measurement for this parameter.

A photoelectric ear pulse pick-up, operating at $800\text{ m}\mu$, provides a fairly easy instrumentation technique if one desires only to know if the blood pulse is reaching the head. This instrument is recommended as an alternate candidate.

The primary candidate for measuring cerebral blood condition is the NASA-Ames ear oximeter, since it collects both blood oxygen saturation data and ear blood pulse information.

LMSC also recommends that two side lamps be used in the centrifuge cab to enable the test subject to check his peripheral vision.

4.3.5 Centrifuge Subject Image Transmission

Visual access to subjects in the centrifuge will be required at all times. A clearly defined image is necessary to detect early symptoms of loss of consciousness as a safety precaution. It would be advantageous to have this data available at the ground station. A preliminary investigation of possible methods of monitoring a centrifuge

subject revealed two systems worthy of further consideration: a TV (video) monitor and an optical monitor.

TV Monitor. A fixed TV camera with approximately 20-deg tilt adjustment will be mounted in the centrifuge cabs. The field of view will include the head and shoulders of the subject. Power for the TV camera will be provided from on-board power. The monitor will be located in the control deck area close to the centrifuge controls. In addition to this closed circuit TV mode, the signal may be recorded and transmitted to the ground through existing video-tape recorder, patch board and transmitter. The TV camera and monitor will provide a black and white picture with 30 frames per second, 525 scan lines per frame, 500 elements per line, and a 4 to 3 aspect ratio. The video bandwidth is 2.1 Mc.

The physical characteristics of the TV camera/ monitor system are as follows:

	Weight (lb)	Volume (cu in.)	Power (w)
Camera/ transmitter	10	200	50
Monitor	25	1,200	50

Optical Monitor. This system is, essentially, a periscope with a means to prevent the final image from rotating along with viewed subject. The subject will have a mirror, approximately 12 x 9 in., placed approximately 18 in. from his face. He will adjust the mirror to compensate for his sitting height and seat position. This is done by aligning his eyes with a line on the mirror and the far end of the system which may require that a light be placed at the eyepiece. The light path coming from the mirror at the subject will strike a prism placed on the axis of rotation in the plane established by the mirror. The prism rotates so as to present one face to the mirror regardless of the location of the cab. This prism will bend the light path 90 deg and along the centrifuge axis of rotation. The light path then passes through a "dove" prism which inverts the image. The dove prism rotates on the same axis and direction as the first prism but at half the speed. The image is inverted from top to bottom when the subject is inverted and from left to right when he is erect. The result is a stable image. A telescope of three to five power is placed on this axis to provide an enlarged image. A simple "astronomical"

telescope (no image erecting feature) is all that is required. The light path may be bent 90 deg within the telescope for viewing convenience.

To view the opposite centrifuge cab, it is necessary to replace the first prism with another facing in the opposite direction. This new prism will require an additional dove prism attached to it to invert the second subject since he is inverted from the first subject. The two subjects would be viewed alternately by remotely switching prisms while in motion. As alternative systems, a slightly more complex optical arrangement would present both subjects at the same time in a split image (they would appear to be side-by-side), or the two initial systems could be provided for viewing by two observers. A camera provision can be included in this system.

Centrifuge Monitor Method Analysis. The TV monitor is an accepted means of observing a subject in a centrifuge. Equipment proposed for use on the MORL mission, with the addition of a video tape recorder, will satisfy the requirement. The optical monitor provides superior definition and color allowing the observer to detect more subtle symptoms indicating the onset of unconsciousness. Optical monitoring requires no power except for a very low requirement if a strobe is used. The optical monitor requires 114 cu ft. as compared to 0.1 cu ft for the TV camera.

Incorporation of this system into the MORL station requires a 10-in. wide view path from the centrifuge hub center through the 100-in. diameter hub wall and into the cabs. This view path should be as clear of obstructions as possible.

The hub wall is primary structure, carrying boost loads and any loads caused by unbalanced centrifuge operation. A structural failure due to the latter would tend to result in a catastrophic depressurization of the station while manned.

With this in mind, the maximum recommended perforation of the hub wall would be in the form of a series of rectangular holes, 4 in. wide circumferentially by 10 in. long parallel to the hub axis, spaced 4 in. apart circumferentially around the wall. This row of holes is located 7 in. from one end of the hub, in order to clear the centrifuge bearing assemblies.

The hub interior, as configured by Douglas, houses life support and environmental control systems equipment items as well as the electrical power system's primary batteries. In order to provide the required clear optical path the following equipment items now located in the centrifuge hub compartment would have to be relocated:

- Water tanks (2)
- Accumulator tanks (2)
- Accumulator tank (hot water)
- Hot water pump
- Batteries
- Evaporator
- Heat exchanger
- Filter and debris trap
- Silica gel and zeolite canister
- Main fresh air duct

This revision together with the large volume of space required by the light path constitutes a disadvantage that is not justified to achieve the image improvement, color, power and weight advantages afforded by the optical monitor system. Therefore, the TV monitor is the recommended system for the MORL centrifuge.

4.4 CREW-PERFORMANCE MEASUREMENT - INTRASTATION

The criteria objectives and ground rules presented in Subsection 4.2 have been applied where applicable in the initial specification of equipment for measuring and evaluating crew performance in the MORL.

4.4.1 Equipment Categories

Crew-performance measurement equipment must be considered in terms of four major categories.

These categories and associated equipment are as follows:

- (1) Auditory Processes - Audio tapes and recording
- (2) Vision Processes - Oculometer and visual hemispherometer

- (3) Gross Motor Processes – Parts assembly devices and procedures
- (4) Other Processes (cognitive, reactive, motor, speech, kinesthetic) – Crew-performance console station

Other human-performance measurements and evaluations to be secured are those associated with the vestibular and orientation processes. The method of obtaining measurements and evaluations of these processes will not, in all likelihood, utilize any of the equipment specified for Categories 1 through 4, but rather, will undoubtedly be in the form of a procedural report. The method and techniques for obtaining vestibular and orientation measurements are outlined later in this section.

4.4.2 Equipment and Crew Console Selection Criteria

Criteria and objectives relevant to console selection are identified in Table 4-2. Detailed design criteria and objectives, as identified in Reference 1-3, Section 4.3, were applied in selecting equipment for process Categories 1 through 4.

4.4.3 Crew Measurement System Design Criteria

After careful examination and review of the foregoing criteria, the following design and operational conclusions were reached:

- A human-performance measuring device, referred to as the crew performance console, will be required.
- A total reentry simulation has been selected as the most optimum technique for demonstrating systems management.
- A part-task reentry simulation will serve as a systems-management demonstration technique providing relatively high face validity as well as good reliability. The capability for providing reentry simulation is contingent, however, upon several factors subsequently specified.
- Three techniques are considered feasible for providing the inputs necessary to "drive" the crew-performance console: (a) transmission of ground simulation to MORL, (b) utilization of an on-board computer simulation program, and (c) utilization of on-board tape simulation program.

- A computer program for either a ground or on-board computer must be developed and/or a simulation tape must be prepared.
- On-board magnetic tape recording must be provided to record astronaut input responses to the crew-performance console.
- An astronaut console-seating arrangement should be provided which very closely approximates the actual astronaut seat-panel configuration.
- Design of the crew-performance console, in a set-up configuration must not compromise the ability of an astronaut to respond to standard operations or contingency or emergency situations.
- Crew-performance console design and/or tasks shall not induce negative transfer of training conditions.
- The crew-performance console and tasks, in addition to being designed for reliability and validity, respectively, also must possess a high face validity for astronaut (user) acceptance.

4.4.4 Design Approach

In order to support the conclusions presented in Subsection 4.4.3, it was considered necessary to evaluate a conceptual design approach aimed at providing the minimum capability acceptable to the most sophisticated crew-performance console. Such capability is essential to satisfy the Biolabs task of monitoring human performance during in-space operations. The four crew-performance console design concepts previously identified (Ref. 1-3) are as follows:

- Basic
- Multiple-task
- Synthetic mission
- Reentry simulation

The recommended simulation approach (Fig. 4-2) consists of a compact package incorporating displays and controls identical to those located on the actual Apollo (or Gemini) command module display-control panel and utilized for the mission reentry phase. The package is composed of an 8-in. CRT, CRT display controls, SCS control-display panel, ΔV panel, gimbal position panel, flight-director indicator

display panel, computer-entry keyboard panel, time event and clock panels, reaction-control system panel, and a panel area used for biomedical testing displays and controls. The fidelity of the reentry simulation will depend on the capability of the on-board computer or the ground-computer input to the in-flight spacecraft to drive the on-board computer. The difficulty presently lies in obtaining a small space-borne computer which can compute the orbital mechanics of reentry or rendezvous and provide constant and accurate display status of the spacecraft during the complex thrust-drift attitude and altitude maneuvers. Proposed solutions are discussed in Subsection 4.6.

4.4.5 Evaluation of Preferred Concept

On the basis of the criteria and comparison analyses developed under the Biolabs Study (Ref. 1-3), it is recommended that Concept 4 (Reentry Simulation and Crew Performance Measurement Console) be developed for use in the MORL. The major advantages to be derived from this concept are as follows:

- Capability for performing all minimum required human-performance measurements and, in addition, systems-management task measurement (reentry simulation - full or part-task)
- Capability for performing reentry simulation (full or part-task) which allows for maintenance of training skills
- Capability for performing more complex human-performance measurement tasks
- A human-performance measurement system which has high face validity for user (astronaut) acceptance
- Human-performance measurement techniques which can be validated to a great extent through earth-based simulators, early earth-orbit Apollo flights, and postflight analyses
- A system providing maximum flexibility, by means of modular design, for in-flight requirements, and for modification from flight to flight

The major disadvantage is presented by the problem of developing a computer program for reentry simulation (e.g., on-board, ground based, or a combination of on-board tapes and computer program).

4.5 CREW-PERFORMANCE MEASUREMENT - CENTRIFUGE

Present MORL design permits a high g loading on the astronaut during centrifuge runs. Reentry g (in the order of 6 to 9 g) can be accomplished for lengths of time equal to or greater than the nominal reentry profile time period. Since runs of this nature will be made regularly during the MORL mission, it appears highly profitable to provide some level of human performance evaluation relative to reentry task performance.

4.5.1 Design Approach

The four crew-performance console concepts discussed for MORL human-performance measurement were considered for use in the MORL centrifuge.

4.5.2 Evaluation of Selected Concept

On the basis of the criteria and comparison analysis presented in Ref. 1-3, it is recommended that reentry simulation human-performance measurement also be developed for use in the centrifuge. The major advantages to be derived from this concept are as follows:

- Capability for evaluating human-performance parameters under varying g loadings and to compare them with zero g and earth-simulation results
- Capability for evaluating full or part-task reentry simulation
- Capability for astronaut to maintain certain skills (previously developed) during actual environmental conditions
- Capability for providing simultaneous human performance and physiological monitoring under varying g loadings

Minor centrifuge cab redesign from the present conceptual configuration will be necessary to accommodate the reentry console.

4.6 REENTRY SIMULATION REQUIREMENT

The criticality of the earth reentry phase for any manned space mission requires that astronauts be capable of operating at or near their maximum performance during all portions of this phase. The use of on-orbit simulation for reinforcing the previous

mission and/or part-task training and for providing tasks or part-tasks for crew performance evaluation warrants prime consideration.

The simulation must have sufficient fidelity to preclude the possibility of negative training. It should be realistic with regard to either or both the reentry phase sequence, or the reentry phase critical part-tasks (e.g., attitude control), and be applicable to both intrastation and centrifuge human-performance measurement.

4.6.1 General Description of Apollo Reentry

Reentry of the Apollo Command Module will be accomplished from a near-earth orbit. Reentry from such an orbit reduces the problems associated with trajectory control and guidance as compared to those for reentry from a hyperbolic or parabolic orbit. In particular, the initial capture problem which exists for hyperbolic reentry disappears in the case of reentry from near-earth elliptical or circular orbits.

The reentry can be divided into the three following modes – retrofire or deorbit mode, vacuum reentry mode, and atmospheric reentry mode.

The deorbit mode involves applying an increment of velocity ΔV_R in a manner which steepens the trajectory so that the vehicle will enter the dense atmosphere of the earth. The vacuum reentry mode is that phase of the trajectory beginning with the termination of the deorbit mode and extending to a point in the atmosphere where sufficient aerodynamic control forces can be generated. During the atmospheric reentry mode, control of the aerodynamic forces is utilized for guidance and navigation. The desired lift and drag aerodynamic forces of the vehicle are obtained by trimming the vehicle at some fixed angle-of-attack by proper location of the center of mass. The Apollo command module has a maximum lift-to-drag ratio L/D of 0.35. The maneuvering footprint capability for the vehicle is shown in Fig. 4-4 as a function of the bank angle ϕ .

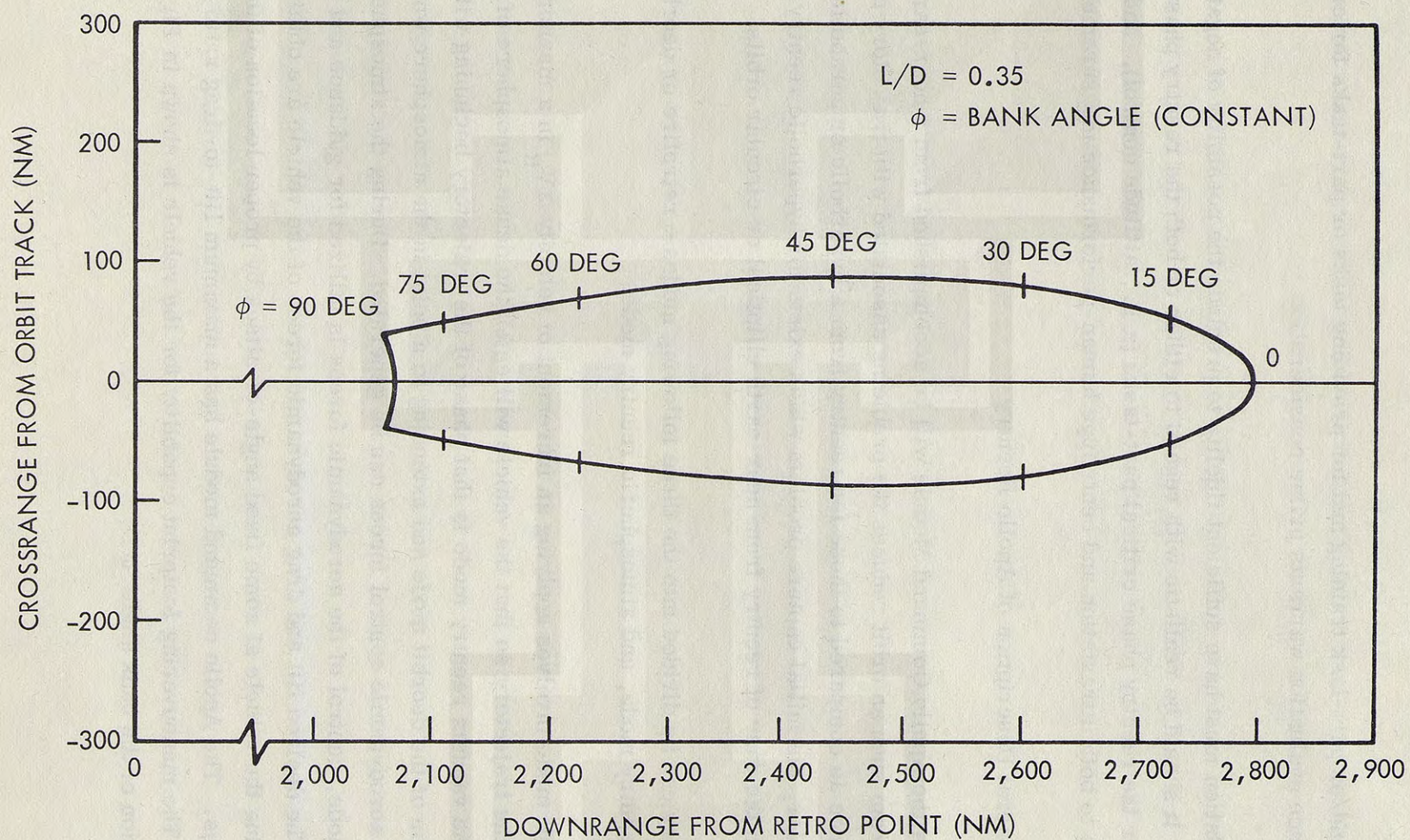


Fig. 4-4 Footprint Maneuver from 110-nm Orbit

A general description of how the guidance system and the control system will be involved in the three modes of reentry previously defined is presented in the following paragraphs:

- Deorbit Mode. This mode consists of retrofiring the command module (CM) and service module (SM) together, and then separating the CM from the SM. The guidance system determines at what point in the orbit retrofire will be initiated in order to impact at the desired location on the earth. The control system will orient the vehicle in the desired direction and maintain this attitude during the thrust phase. The thrust cutoff is controlled by the guidance system.
- Vacuum Reentry Mode. In this mode, the CM attitude is inertially fixed and controlled by the control system. The position and velocity of the vehicle are continuously determined by the guidance system; however, guidance corrections cannot be made during this phase since there are no significant control forces available.
- Atmospheric Reentry Mode. During this mode, guidance corrections are made by rolling the vehicle to direct the lift vector out of the initial reentry plane. For guidance purposes, reference trajectories may be used. However, rather than using stored reference trajectories, a nominal trajectory is computed on-board just before the start of the deorbit mode. At that time, the range to the desired landing site as well as the particular entry conditions should be well known. By iteration techniques, a reference trajectory that satisfies these boundary conditions is then generated, thus avoiding the need for stored nominals to span the entire spectrum.

The steering law used for the guidance corrections relates velocity, altitude rate, and drag acceleration to the computed nominal trajectory. The autopilot of the control systems acts on these steering laws and controls the reentry life direction, causing changes to the spacecraft attitude so as to bring the guidance errors to zero.

4.6.2 Methods of On-Orbit Reentry Simulation

The optimum method of on-orbit reentry simulation for a given mission will be dependent upon mission duration and other mission parameters and constraints, as well as on the vehicle configuration constraints, such as allowable weight, power, volume, etc. The selection of total or complete reentry simulation as the technique for demonstrating systems management allows this simulation to serve several purposes; however, it should not in any way compromise the selected simulation method.

The two major equipment classifications for the reentry simulation are as follows:

- Controls and displays, instruments, panel lights, selector switches, manual controllers, etc.
- Digital and analog computers required to simulate the reentry kinematics, the reentry-phase sequence of operations, and the vehicle dynamics

The controls and displays to be used in the simulation are described in Subsection 4.4.4. The vehicle dynamics must be simulated to whatever level of fidelity is required, using an on-board analog computer. Detailed information on the Apollo stabilization and control system and the reaction control system are needed in order to determine the reentry mode analog simulation required. These data are also needed to evaluate several techniques (e.g., all-electronic or electronic/electromechanical) for mechanizing this portion of the simulation. The major factor to be considered in establishing the analog computer requirements is most probably the vehicle rotational rates, particularly the roll rate requirement for roll modulation for a zero-lift trajectory.

The digital computer will be used in the reentry simulation to perform two primary functions:

- Simulate the reentry kinematic equations of motion
- Simulate the reentry sequence of system and subsystem operations

The following paragraphs discuss three possible methods of obtaining the required digital computations, together with some of the attributes and problems associated with each method. In order to perform a detailed evaluation of each method, descriptive information on the Apollo guidance and navigation subsystem and the communications and data subsystem, together with a probable reentry nominal trajectory and sequence of operations, is required:

- Use of On-Board Computer. A separate on-board digital computer, specifically provided for simulating reentry, and for performing other human-performance valuation logic and switching functions, has the major advantage of providing the capability of complete reentry simulation. It reduces the interface with the analog computer by packaging both computers in the same enclosure. It may also incorporate both computers in a common package with the required controls and displays.

A preliminary evaluation of the complete reentry simulation produces requirements for a considerable amount of digital computer capacity. The computer capacity and, as a consequence, the weight, power, and volume requirements for the computer, appears to be the major disadvantage of this method. However, a much more detailed evaluation of the simulation requirements is needed in order to establish the exact computer capacity required. Also, the duty-cycle of the digital computer, i. e., its time utilization out of the total mission time, may be relatively small so that only small nominal power would be required, except during actual simulation operation.

- Use of Ground-Based Computer. The use of already existing ground-based digital computers for the reentry simulation appears to offer the advantage of reduced power, weight, and volume requirements when compared with either of the other methods. Two disadvantages or problem areas which influence an overall comparison of the various methods are as follows:
 - The simulation must be scheduled for times for which there is two-way telemetry with a large ground-computer complex. This restriction will probably limit the simulation time to 5 to 10 min/orbit.

- The simulation requires utilization of telemetry and ground-computer systems which might interfere with other telemetry or data processing functions. The telemetry problem is not considered serious, however, since, the down-link and up-link data rates can probably be limited to 10^2 and 10^3 bits/sec, respectively. Scheduling for use of a ground computer capable of generating the simulation depends on the priority of this function. If the available computer is capable of interrupt operation, the scheduling problem will not be severe.
- Use of Stored-Tape Program. Use of an on-board stored-tape program for reentry simulation appears to offer the advantages of reduced power, weight, and volume when compared with the on-board computer method, and reduced interface complexity when compared with the ground-based computer method. Its major disadvantage appears to be the limitation of preprogramming only one reentry trajectory and one reentry sequence of operations on each tape. With a stored-tape program, little or no variations in the flight path due to simulated maneuvers are possible. Also, practically no variations can be made in the real-time sequence of operation from that preprogrammed on the tape.

The possibility does exist, however, for preprogramming nominal conditions and several off-nominal conditions on different tapes, and then changing tapes for different simulations. Further study would be required to determine whether this type of "linearized" simulation could be effective.

4.6.3 Recommended Approach

Based on information currently available, the optimum reentry simulation system for low earth-orbit MORL will possess the following characteristics:

- Actual duplicates of reentry controls and displays
- On-board digital computer used to drive the simulation displays based on up-link telemetry and to process the test subject inputs for down-link telemetry

- At least one large ground-based computer with an Apollo orbital reentry simulation program and providing data communication with the MORL through ground-based telemetry equipment

4.7 CREW-PERFORMANCE MEASUREMENT SYSTEM - EXTRAVEHICULAR

An analysis was made of the recommended measurements for extravehicular activities (EVA) identified in Table 3-10. From this analysis, Table 4-4 was prepared to indicate various required equipment, and each item of equipment was then considered in the light of the following criteria:

- Reliability of the device
- Fidelity of information gathered
- Previous validation
- Ease of use or application
- Speed of use
- Simplicity of signal generation
- Availability of permanent record
- Maximum sample points
- Minimum time for sampling
- Compatibility with existing systems
- Additional equipment not required
- Portability
- Stowability
- Number of uses before discard or "use-up"
- Potential alternate uses and flexibility
- Rated for space flight
- Special training not required
- Minimum set-up and take-down time
- Maximum safety
- Minimum power consumption

Table 4-4

COMPARISON OF EQUIPMENT WITH CRITERIA - EXTRAVEHICULAR ACTIVITY

Performance Criteria	Movie Camera	Still Camera	Timer (Mech.)	Tape Recorder (Voice)	Hand Recorder	Visual Target (Non-Illuminated)	Visual Target (Illuminated)	Transmitter	Nut and Bolt Assembly Device	Torquing Device	Complex Assembly Device	Welding Device	Tools
High Reliability	Y	Y	Y	Y	NA	Y	Y	Y	Y	Y	Y	Y	Y
Ease of Use or Application	Y	Y	Y	Y	No	Y	Y	Y	NA	NA	NA	NA	NA
Simplicity of Signal Generation	NA	NA	Y	Y	NA	NA	Y	Y	NA	NA	NA	NA	NA
Maximum (Adequate) Sample Points	Y	No	Y	Y	No	NA	Y	NA	Y	Y	Y	Y	NA
Minimum Time for Sampling	Y	No	Y	Y	No	Y	Y	Y	No	No	No	No	NA
Compatability With Existing System	Y	Y	Y	Y	Y	NA	NA	Y	NA	NA	NA	NA	Y
No Additional Equipment Required	Y	Y	Y	Y	Y	Y	Y	No	No	No	No	No	Y
Portability	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Stowability	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Q	Y
Number of Uses Before Discard of "Use-Up"	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Potential Alternate Uses	Y	Y	Y	Y	Y	No	No	Y	No	Y	No	Y	Y
Rated for Space Flight or Use	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Q
No Special Training Required	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Q	Y
Minimum Set-Up and Take-Down Time	Y	Y	Y	Y	Y	No	No	Y	Y	Y	No	No	Y
Maximum Safety	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Q	Y
Minimum Power Consumption	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fidelity of Information Gathered	Y	Y	Y	Y	Q	Y	Y	NA	Y	Y	Y	Y	NA
Previously Validated	Y	Y	Y	Y	Y	No	No	Y	Y	Y	Y	No	Y
Availability of Permanent Record	Y	Y	NA	Y	Y	NA	NA	NA	No	No	No	Y	NA

Y - Criteria can be met

No - Criteria cannot be met

NA - Not Applicable

Q - Questionable

4.7.1 Comparison Analyses

Table 4-4 compares the equipment with the criteria and indicates whether the criteria were met. Each item of equipment was also reviewed for the best method of achieving its integration into the MORL system on the basis of the following considerations:

- Power availability
- Weight and volume
- Packaging
- Technique of use
- Functional interface
- Location

In addition to the foregoing criteria and considerations, a mission-oriented set of criteria were established, and each measurement technique or method was again subjected to review. These mission-oriented criteria, in order of importance, are as follows:

- No compromise to mission success
- No degradation to previous astronaut training
- Reliability and validity of the measurement
- Previously established baseline data
- Performance measures which can be obtained "operationally" as well as experimentally
- A totally realistic astronaut task
- A task that reinforces or maintains previous training

4.7.2 EVA Human-Performance Measurement Design Requirements

Upon the basis of a review of current EVA literature, recommended measurements, and identification of equipment required for EVA measurements, the following EVA

performance-measurement design requirements have been developed:

- A set of visual targets is required for astronaut in-space visual evaluation.
- A simple assembly device is required of in-space use.
- A device is required which, when used with the proper tool, can provide an in-space torquing measurement task.
- A complex assembly device is required for in-space assembly tasks.

4.7.3 Design Approach

Each equipment development item in the list presented in Table 4-4 was reviewed by cognizant Biolab design personnel to determine conceptual design approaches resulting in several design goals.

Visual Targets. Two-sided visual targets are planned. The set consists of a group of small targets linked together and presenting various stimuli to be used in visual-recognition tests. The rear panel of this target is designed to accommodate target plates of a differing nature and which relate to in-space visual-task requirements. These targets are not illuminated. The front face of the target is provided with lamps that are capable of presenting various colors of illumination. Intensity variation of illumination will also be provided. Pattern recognition will be possible through multiple-lamp stimulus presentation.

Targets similar to those just discussed can be mounted in one small rectangular enclosure. The visual presentation can be preprogrammed and driven by an analog device inside the container, thus, avoiding the need for input of a pre-established program by another astronaut.

Transmitter. This device is required to activate the visual targets. Details are presented in Section 7.

Nut and Bolt Assembly. A small steel plate can be provided with varying bolt shafts welded to the surface, and varying hole sizes drilled into and through the surface.

Nuts and bolts can be packaged in special carry-out bags for purposes of assembly while in space.

Small Parts Assembly. A typical small-parts assembly kit can be provided for the assembly task. The kit will be similar to those used in industry for testing assembly line workers.

Built-On Assembly. A series of special "built-on" assembly devices can be provided which are part of the spacecraft. These can be functional for ground or launch use and purposely obsolete for in-space use, thus providing a disassembly-assembly device that is actually an integral part of the spacecraft.

Complex Assembly Device. A self-contained complex assembly kit can be provided which, when taken into outer space, will allow various detailed and complex assembly tasks to be performed. Several separate complex assembly tasks will be contained within the kit, and each will be color-coated to ensure ease of differentiation in selection for a given task.

Torqueing. A torqueing tool can be provided for use with any of the three previously mentioned assembly devices.

4.7.4 Final Design Comparison of EVA Equipment

Criteria and comparative considerations were applied to the equipment candidates specified in Table 4-4.

It is readily apparent that each equipment candidate cannot meet all criteria and considerations presented. Equipment, therefore, was selected on the basis of the maximum number of criteria met and the capability to meet spacecraft restraints, e.g., weight, volume, power consumption, and interface requirements.

4.7.5 Selection of Preferred Candidate Equipment

On the basis of the criteria and comparative considerations previously presented in this section, the following equipment selections are specified:

- Visual targets, linked together and providing both illuminated and non-illuminated visual stimuli
- A complex assembly kit including a small parts-assembly device (e.g., nut and bolt)
- Torqueing tool for use with the complex assembly kit. (It is anticipated that a tool of this nature may be provided as a standard spacecraft maintenance tool.)

Each of the foregoing items will be discussed in detail in Section 5. Other equipment items identified in Table 4-4 are considered likely to be provided as standard spacecraft equipment.

4.8 LABORATORY MEASUREMENTS

An effort was made to evaluate several equipment candidates when a laboratory measurement required a major component. All existing candidates described were eliminated for failure to comply with the weight, power, and volume limitations imposed by the spacecraft or by inability to perform in the weightless environment. As an alternative, the components of existing equipment were considered for repackaging, e.g., the telemicroscope. Failure of the components to qualify for repackaging made it necessary to investigate a complete redesign, as in the case of the oculometer. In some instances, it appeared that existing devices did not perform the intended function satisfactorily, indicating a need for an advance in the state-of-the-art.

4.8.1 Equipment Categories

This section is limited to discussion of devices or systems in the above categories requiring repackaging or redesign. Such items pertain to the following laboratories:

- Physiology (thermal vestibular mechanism stimulator; mass measurement)
- Microscopy and Chemistry (telemicroscope, urine collection and freezing)
- Human Performance (oculometer)

4.8.2 Thermal Vestibular Mechanism Stimulator

The semicircular canals require stimulation to determine if the tolerance to stimuli changes in the weightless environment. The following methods were considered for applying caloric stimulation:

- Caloric Stimulation by Electricity (Resistance). In this method, a probe fitted to the subject is inserted into the ear. A heat sensor is located at the tip of the probe with the heating element slightly behind it. The feed-back from the probe controls the input current to the heating element. (See Fig. 4-5.)
- Caloric Stimulation by Electricity (Peltier). The Peltier effect produces small areas of heat or cold by passing direct current through the junction of certain dissimilar metals. The junction becomes hot or cold depending upon the direction of the current and the temperature varies with the amount of current. In this application, the junction of the dissimilar metals is placed in ear probes prepared specifically for the subject's ears. (See Fig. 4-6.)
- Caloric Stimulation by Water (Closed System). Water or other fluid is circulated through a chamber surrounding one end of an ear probe. The ear probes are fabricated from silver or other material of high thermal conductivity prepared specifically for the subject's ears. The temperature of the entire probe quickly adjusts to the temperature of the water. The water is heated by exposing the hot side of the system to an existing heat exchanger or by its own electric heating system. The cold side of the system is exposed to some existing source of cold. The system requires a circulation pump and a mixing valve. The temperature at the tip of the probe is read by a heat sensor.

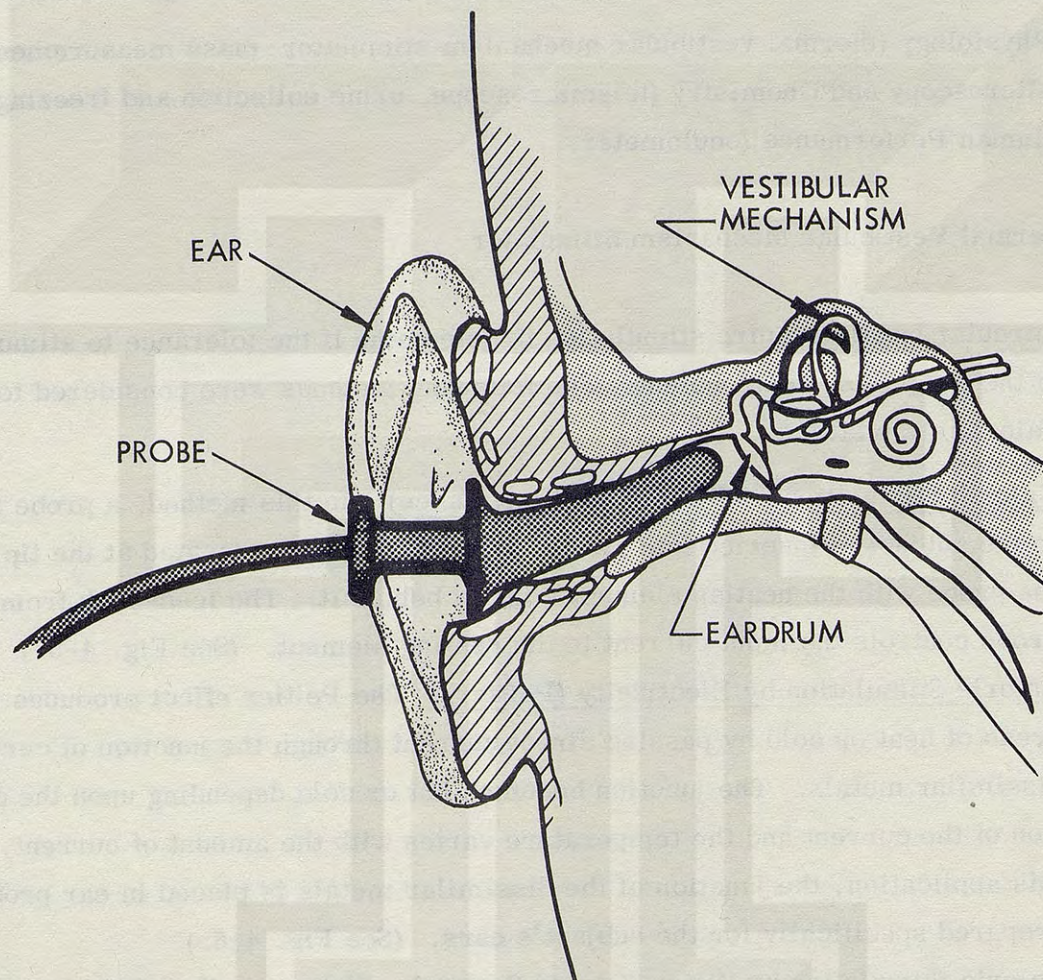


Fig. 4-5 Thermal Vestibular Stimulator, Using an Electrical Resistive Element

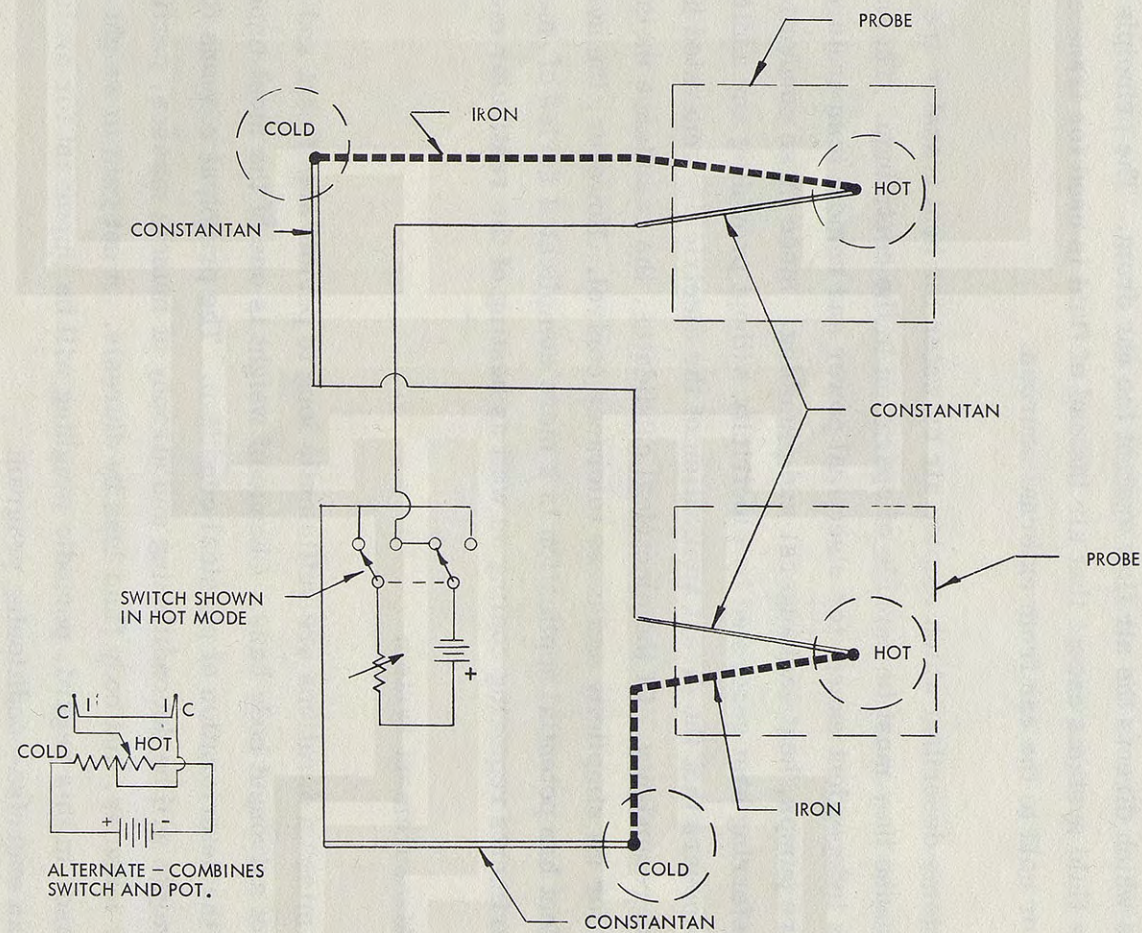


Fig. 4-6 Stimulator Circuit Illustrating Peltier Effect

- Caloric Stimulation by Water (Open System). This method is common practice in the laboratory. A small hose or syringe is placed in the ear, and the ear is irrigated.
- Caloric Stimulation by Air. This method requires a nozzle similar to the ear probe which directs the air flow against the ear drum. The principle is similar to the fluid systems except that air instead of fluid is used for transferring heat or cold to the ear from external sources.

Any of the systems described which employ air or water for heat transfer are virtually eliminated because they must be capable of operation in the centrifuge. These systems will have to be independent except for electrical power and remote temperature control, and will require pumps, heat exchangers, and plumbing. Since these conduction systems are transferring heat generated by electricity without providing any additional advantage, it appears that the direct application of the electrically generated heat will eliminate some redundancy. Of the electrical candidates, the resistance method is recommended for its simplicity and close tolerance control. However, the system using the Peltier effect has potential application in a more complicated series of measurements or experiments requiring cooling as well as heating of the vestibular mechanism.

4.8.3 Mass-Measurement System

The proposed mission durations are sufficiently long to permit significant and possibly vital changes of astronaut body mass. Change of weight is one of the most important indications of the deterioration of physical condition. The principal reasons for loss of astronaut weight will be deconditioning and atrophy of muscle masses, particularly the antigravity muscles, and body fluid loss by diuresis. A net gain in weight is also conceivable and, in this regard, periodic weighing will be important for evaluating the effects of an exercise-conditioning program.

The apparatus used to determine astronaut body weight in a zero-g environment should be capable of an accuracy of ± 0.5 lb and should be compact, light in weight and simple. Obviously, the most common means of weighing on earth—the beam balance and the

calibrated spring scale—cannot be used in an environment where there is no gravitational attraction, at least not without modification. Other properties of matter, therefore, will have to be used. Since, for example, a body's opacity to X-rays varies with the mass of the body, it might be possible to determine body mass by the strength and area of an X-ray shadow. However, this will require complex, sensitive, and delicate apparatus, and an extensive development program. Moreover, even "soft" X-rays may have undesirable cumulative effects on the human body. It will be less hazardous to determine mass by inertia—another of its properites. Some of the conceivable means of using inertia to determine mass are as follows.

Torsional Pendulum. This device has a frequency $f = \frac{1}{2\pi} \sqrt{\frac{\tau}{I}}$ where $\tau = \frac{\text{restoring torque}}{\text{angle}}$ and I is proportional to the product of (mass) times the square of the radius of the path of the mass center. Since the latter term enters as a second power, very small changes in location of the mass center will cause appreciable errors unless the radius is very large. However, an apparatus with a very large radius will exceed the size limits of a spacecraft

Centrifuge. The equation for centrifugal force is $F = M\omega^2 R$ where M is mass, ω is angular velocity and R is radius of the path of the mass center. Since R enters this equation linearly, a small error in assumed mass-center location will not be as serious as in the case of the torsional pendulum. However, angular velocity enters quadratically, and therefore will have to be closely controlled. It will not be difficult to measure centrifugal force, but a seat or couch having radial freedom of movement along one arm of the centrifuge will be required.

Impulse Momentum. The equation for this impact action is $F(\Delta T) = M(\Delta V)$. F is a force which is applied over a time period ΔT . M is the mass which is being accelerated from its initial velocity to its final velocity ΔV . In other words, $F(\Delta T)$ represents an impulse which changes momentum $M(\Delta V)$. Both F and (ΔT) will be difficult to determine because of their transient nature. The presence of random g forces will adversely affect accuracy; therefore, precautions will be required to ensure that no such disruptive forces exist during astronaut mass determination. Further, in a zero- g environment, an astronaut will not be bedded down firmly on the

apparatus at the first instant when acceleration starts. Even though he is strapped or clamped into the apparatus, his weightless configuration relative to the apparatus will not be identical to that which his body will assume after inertia forces are present. These considerations make the impulse-momentum method quite impractical.

Conservation of Momentum. The equation for this phenomenon is $MV_1 + mv_1 = MV_2 + mv_2$. It represents a controlled collision in which a smaller known mass m traveling with a known initial velocity v_1 strikes the unknown mass M which is standing still ($V_1 = 0$). A device will be provided to lock the two masses together upon impact so that $V_2 = v_2$. The equation thus becomes $M = (m/v_2)(v_1 - v_2)$. To determine the unknown mass M , the final velocity v_2 must be measured. This can be accomplished by timing the passage of the locked-together masses over a known distance. The disadvantages of this conservation of momentum method are that an appreciable auxiliary mass m is needed, and that a considerable jolt will be caused by the impact. Since the presence of random g forces can cause inaccuracies, mass determination should not be attempted unless such forces are absent. The foregoing remarks regarding bedding down apply also to the conservation-of-momentum method and make it impractical.

Linear Acceleration. This method is represented by the equation $F = Ma$ where F is a known, constant force; M is the unknown mass; and a is an acceleration which must be measured. This acceleration can either be measured directly, using an accelerometer, or indirectly by determining the time t to traverse a known distance s ; thus, $a = \frac{2s}{t^2}$. Obviously, time must be measured very accurately since it enters to the second power. If any random g forces are present, they can cause inaccurate results.

The bedding down aspect previously noted (the impulse-momentum system) does not apply very strongly to this system ($F = ma$) because it involves a far longer period of acceleration, and the bedding down will take place at the start of motion. Further, the acceleration will be low, and, consequently, the bedding down effect will be smaller in magnitude.

Frequency of a Spring-Mass System. The frequency of an oscillating spring-mass system is

$$f = \left(\frac{1}{2\pi} \right) \sqrt{2K/M}$$

where

- f = frequency (cps)
- K = known spring constant
- M = unknown mass

One need only provide a single-degree-of-freedom (i.e., straight back-and-forth linear motion) mounting for the unknown mass, provide a spring system to keep the mass oscillating in simple harmonic motion, and measure the system frequency. Timing can be performed with great accuracy because an average of a large number of cycles can be obtained. Further, the presence of random g forces will have little or no effect on accuracy. With respect to the bedding-down effect, the spring-mass system will probably not be quite as good as the straight linear acceleration system.

Inertia Beam Balance. A parallel platform type of beam balance (i.e., a commercial weighing scale) can be employed by applying a momentary acceleration in line with the knife edge so that the resulting inertia force acts to replace gravitational attraction in the weighing function. The momentary acceleration can be obtained by moving the balance upward, using a man-powered lever. This system has the great advantage that no additional instruments of any kind are required since there is no need to measure time, force, acceleration, etc. The presence of a random g force will tend to reduce accuracy slightly, but its existence can be detected by making a trial balance without any subject on the platform. In order to overcome the undesirable effects of the bedding-down problem, a rather long accelerating stroke will be required, perhaps with a provision for performing the balance only during the latter part of the stroke.

Laboratory Verification—Spring Mass System. An initial laboratory experiment was conducted to evaluate the use of a spring-mass system to measure body mass. A spring-mass system will oscillate horizontally in simple harmonic motion, according to the equation

$$f = \frac{1}{2\pi} \sqrt{2K/M}$$

where

f = frequency (cps)

K = spring constant of each spring (lb/ft)

M = mass (slugs)

For a given pair of springs, the frequency will vary with changes in mass. If such a system is calibrated, it provides a means of determining mass simply by measuring the system frequency. Moreover, the system utilizes only spring forces and the inertia forces of the mass and is completely independent of gravity.

- Description of Experiment. In order to perform an experiment with minimum expenditure of funds and time (e.g., using available springs), an experimental configuration (Fig. 4-7) was developed. The subject sat on a platform, and the combined weight was supported by four wires hung from the ceiling 19 ft above. The combined center of gravity was approximately 18 ft from the ceiling. A spring with a constant K was attached to each end of the platform, and the outer ends of these springs were anchored so that each spring was stretched 10 in. During the experimental runs, care was taken to avoid displacing the platform more than 9 in. from its equilibrium point to prevent complete unloading of either spring, which would reduce the system spring constant from 2K to K.



Fig. 4-7 Mass Measurement System – Early Laboratory Test Model Using Oscillating Springs

The differences between the experimental apparatus and a simple spring mass system introduce two additional factors – the pendulum effect and the damping effect. These factors enter the equation as follows:

$$f = \frac{1}{2\pi} \sqrt{\underbrace{\frac{g}{L}}_{\text{Pendulum}} + \underbrace{\left(\frac{A}{L}\right)^2 \frac{2Kg}{W}}_{\text{Spring}} - \underbrace{\frac{C^2 g^2}{4W^2}}_{\text{Damping}}}$$

where

$g = 32.2 \text{ ft/sec/sec}$

$L = \text{distance from point of support to center of gravity (ft)}$

$A = \text{distance from point of support to the springs (ft)}$

$W = \text{weight (lb)}$

$C = \text{damping coefficient (lb-sec/ft)}$

- Disruptive Factors. Human error will cause inaccuracies in timing. To reduce this error, a stop watch with increments of 0.2 sec was used to time 40 continuous oscillations for each experimental point.

The maximum acceleration experienced by a subject was approximately 10 ft/sec^2 . When the subject was relaxed, the acceleration caused a forward and backward movement of his head and shoulders which resulted in a longer period (i. e., slower frequency). All data points were taken, therefore, with the subject holding a rigid position.

Oscillation of an auxiliary (hand-held) weight in the vertical direction had no effect on the frequency of oscillation, providing this motion did not result in a change in the mean vertical location of the center of gravity.

When a subject deliberately sat off to the left or right of center, the system c. g. was no longer in the same vertical plane as the springs. This change

caused side-to-side oscillation and a longer period. All data points were therefore taken with the subject seated on center.

- Results and Conclusion. Repeatability within 0.4 sec was obtained over 40 cycles. This corresponds to a total variation in apparent subject weight of 3 lb (i.e., ± 1.5 lb). Variation of any experimental point from the curve (calculated using the foregoing equation) was within ± 4 lb. This range includes the foregoing error. Figure 4-8 shows the relationship between body mass and period.

It is possible to use a calibrated spring-mass system to determine a man's weight simply by measuring the time required for a number of cycles of oscillation.

Laboratory Verification—Linear Acceleration. The second laboratory experiment, illustrated in Fig. 4-9, was performed to appraise the feasibility of measuring body mass using Newton's second law of motion

$$F = Ma$$

where

F = force (lb)

M = mass (slugs)

a = acceleration (ft/sec²)

If force and acceleration are known, mass can be calculated and a known constant force can be achieved in various ways. Acceleration can be measured directly by use of an accelerometer; however, to facilitate acquisition of test data an indirect method is used. In the case of constant force and constant acceleration, if velocity is zero at time zero, the following equation pertains:

$$S = 1/2 at^2$$

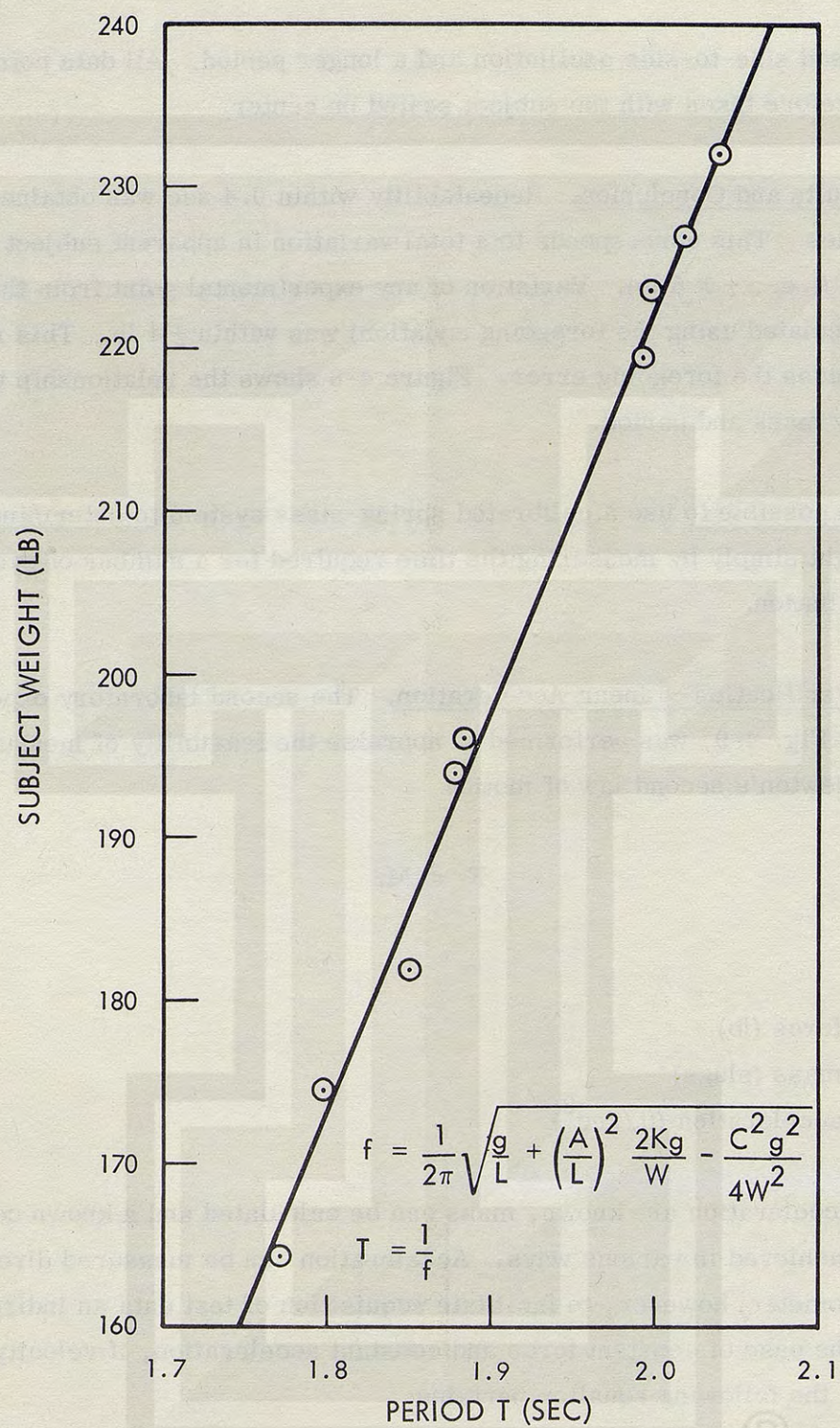
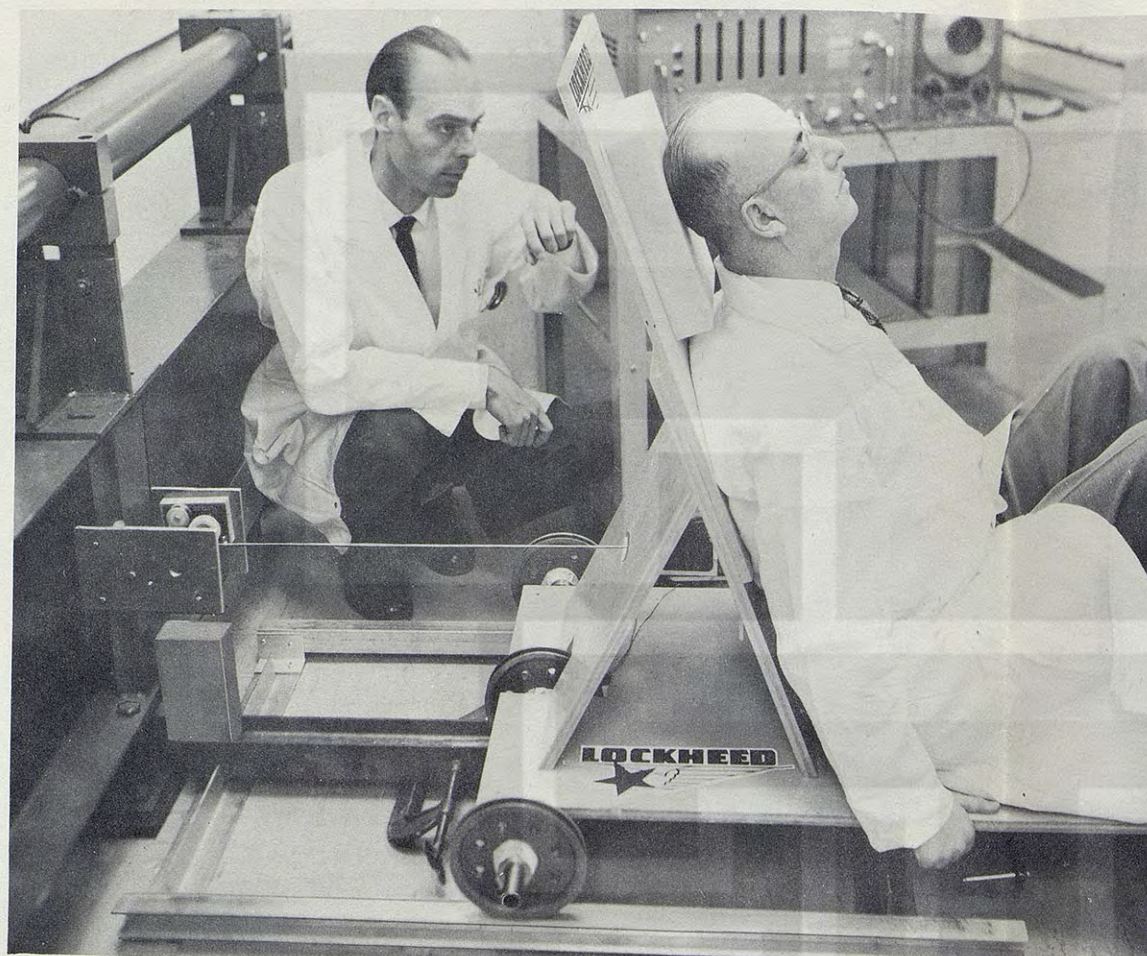
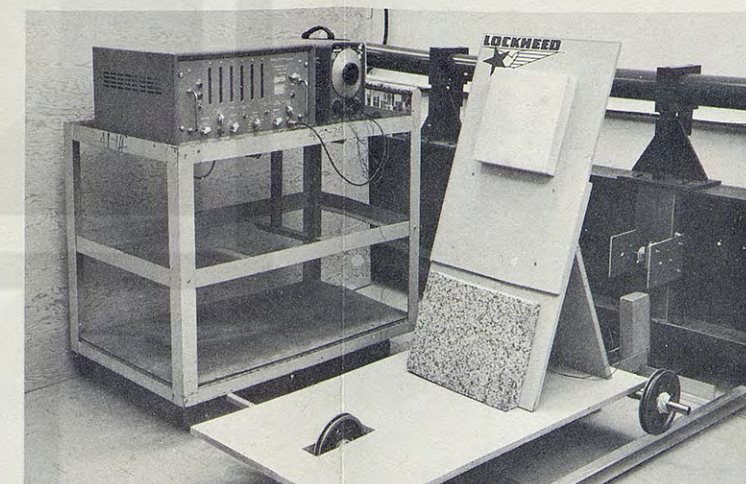


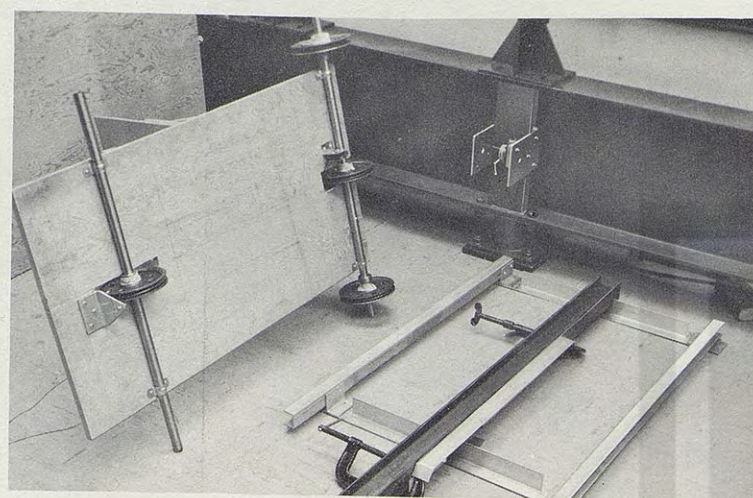
Fig. 4-8 Relationship Between Body Mass and Period as Determined by Early Laboratory Device



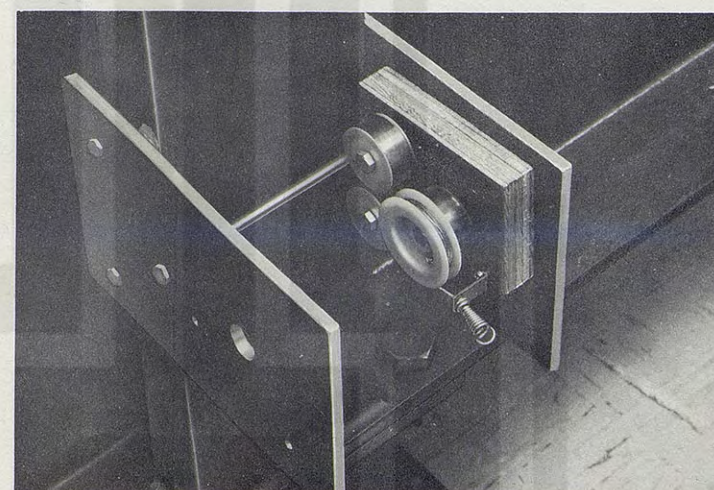
(a) SUBJECT UNDER TEST



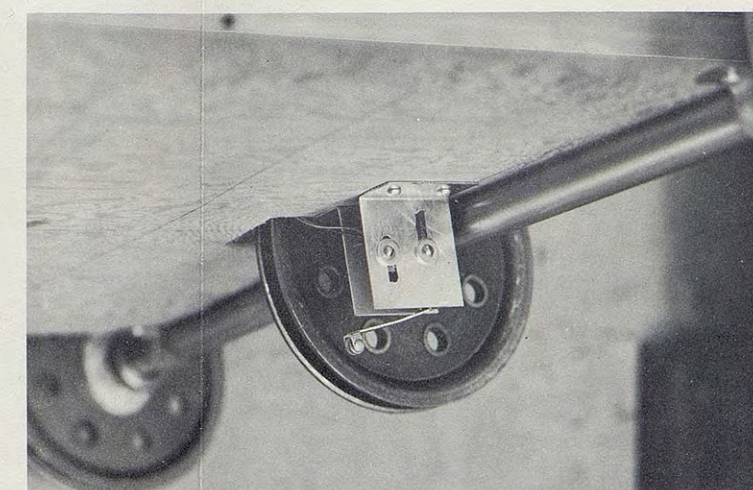
(b) LABORATORY ARRANGEMENT



(c) UNDERCARRIAGE AND FRAME



(d) CONSTANT FORCE NEGATOR DEVICE



(e) ELECTRIC TIMING SWITCH

Fig. 4-9 Mass Measurement System - Linear Acceleration Device

where

S = distance traveled (ft)

t = time (sec)

If time t is measured during a period in which the mass traverses a known distance S, then acceleration a can be calculated. Since a and F are known, the mass M can be calculated:

- Description of Experiment. In order to minimize friction drag, the subject is seated on a wooden cart with ball-bearing wheels (Fig. 4-9a). The complete laboratory arrangement is shown in Fig. 4-9b. To prevent gravitational attraction from accelerating the cart, the wheels are run on a track which is horizontally level (Fig. 4-9c). To achieve the desired constant force, a Negator spring (Ametek, Inc.) is employed (Fig. 4-9d).

Measurement of time is accomplished by using a 1-kc oscillator as a frequency standard, and counting the number of cycles as the cart travels over a known distance. An electronic counter is used and is connected to the oscillator through a switch (Fig. 4-9e). The switch closes the circuit by riding up the starting slope of a cam at the start of motion. At the end of the measured distance, the switch drops off the cam, thereby opening the circuit. An indexing surface is provided to bring the cart back to the same starting point for each test run, and a spring snubber acts to decelerate the cart after the measured distance has been traversed.

In the equation for the experiment, F is net force in pounds. It is comprised of several vectors, as follows:

$$F = f_s - f_B - f_R - f_i$$

where

$$\begin{aligned} f_s &= \text{spring force} = 12.61 \text{ lb, measured value} \\ f_B &= \text{drag due to ball-bearing friction (lb)} \\ f_R &= \text{drag due to rolling friction of wheel on track (lb)} \\ f_i &= \text{drag due to inertia of each wheel (lb)} \\ F_B + f_R &= 0.62 \text{ lb} = \text{measured value} \end{aligned}$$

The first three of these vectors are measured; however, the last vector must be calculated since it is a function of acceleration. For a wheel which accelerates,

$$T = I\alpha$$

where T = torque (ft-lb), I = rotational moment of inertia (lb-ft/sec²) and α = angular acceleration (rad/sec²); then $T = f_i R$ where R = radius of the wheel (ft), and $I = 1/2 MR^2$ where m = mass of the wheel (slugs), and $\alpha = a/R$.

Substituting the last three equations in the preceding one:

$$f_i R = (1/2 m R^2) (a/R)$$

or

$$f_i = 1/2 ma = 0.2 \left(\frac{2S}{t^2} \right) \text{ for wheels used}$$

All the required quantities can now be obtained to determine the unknown weight of the subject. Combining terms and substituting known (fixed) quantities, the $F = Ma$ equation can now be rewritten

$$f_s - f_B - f_R - f_i = \left(\frac{W_s + W_c}{g} \right) = \left(\frac{2S}{t^2} \right)$$

where W_s = weight of subject (lb) and W_c = weight of cart = 58 lb

Solving for W_s , the following is obtained:

$$W_s = \left(f_s - f_B - f_R - f_i \right) \frac{gt^2}{2S} - W_c$$

Substituting known values:

$$W_s = \left(12.61 - 0.62 - 0.2 \frac{2S}{t^2} \right) \frac{gt^2}{2S} - 58$$

Or

$$W_s = 193 (t^2/S) - 64.4$$

- Results and Conclusions. It is important that the subject take care to remain rigid during the test run to avoid disturbing his inertia. Eight subjects (ranging from 132.75 to 201.25 lb) were weighed on a medical scale, and each subject rode the apparatus five times. The root-mean-square (rms) values of transit time were plotted versus their scale weights as shown in Fig. 4-10. All these data points except one, fell within ± 2 lb of the theoretical curve. The exception was 6 lb below, and it is believed this was due to overstressing of the wooden cart which affected the position of the timer switch. If the individual test run results (not rms) are considered, an accuracy of ± 6 lb was achieved, exclusive of the suspect test. The breadboard apparatus was not sufficiently rigid, and a much closer tolerance can undoubtedly be achieved with an all-metal apparatus and better quality bearings.

It is feasible to use a linear acceleration device with an electronic timer to determine a man's mass in accordance with Newton's second law of motion.

Comparison Analysis. Of all the mass-measurement systems which have been mentioned, four appear to be feasible. A comparison of these systems with respect to some of the critical considerations is shown in Table 4-5. Using the tabulated comments as a basis of judgement, the following conclusions may be drawn:

- Centrifuge. This system provides an excellent way of determining mass if a facility the size and weight of a centrifuge is justified for other purposes; however, some crew members will be excluded from the centrifuge for control purposes so that other means of weighing them will be required.
- Inertia Beam Balance. This method is the most straightforward since secondary quantities (e.g., time, acceleration, velocity, or force) need not be measured to close tolerances. Further acceleration need not be

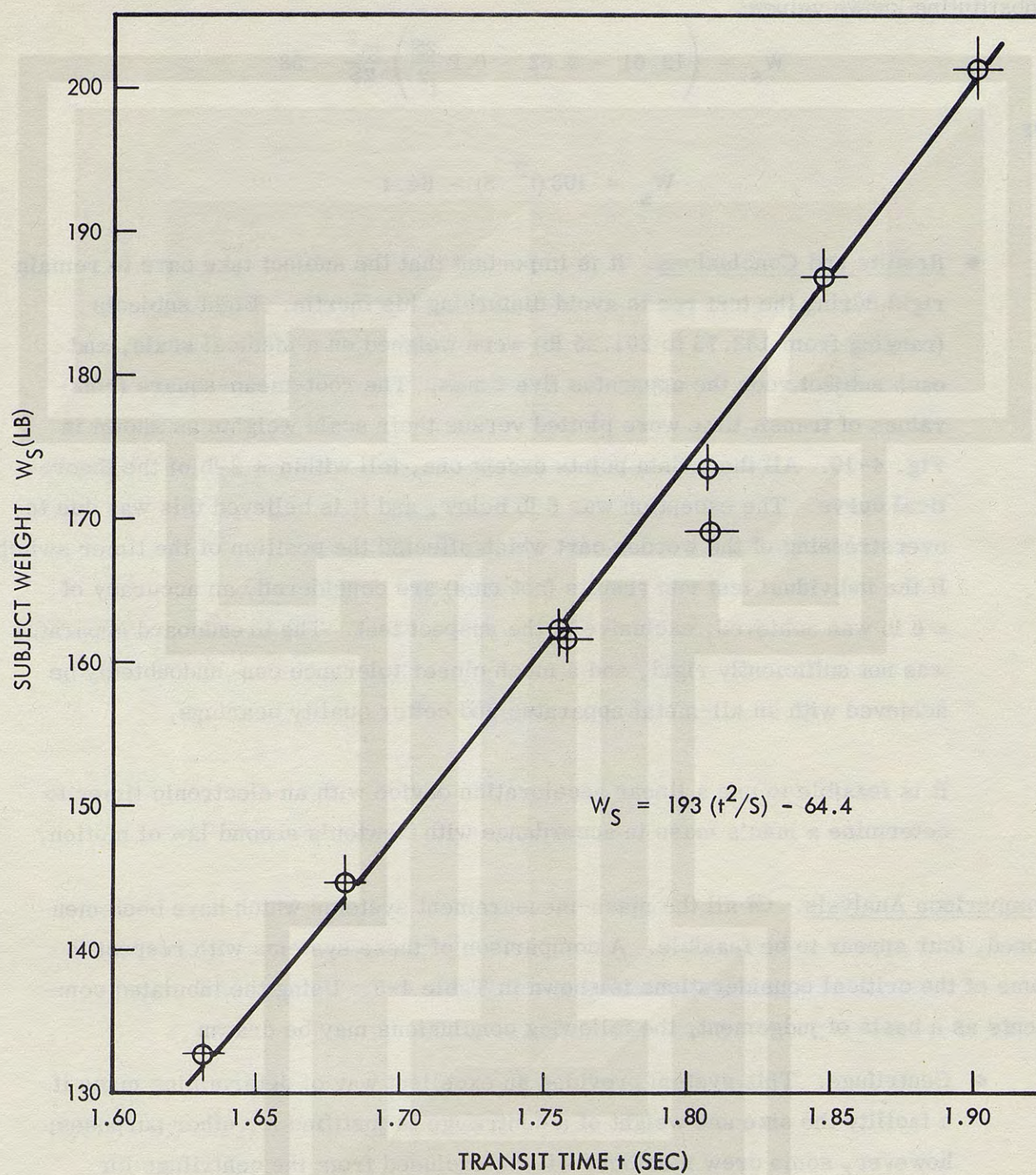


Fig. 4-10 Relationship Between Subject Weight and Transit Time for the Linear Acceleration Device

Table 4-5

CRITERIA OF COMPARISON FOR ALTERNATE MASS MEASUREMENT SYSTEMS

Mass Measurement System	Bedding Down	Apparatus Simplicity and Alternatives	Suitability for Ground Evaluation	Effect of Difference in Bearing Friction Between Ground and Orbit	Operational Considerations
Linear acceleration ($F = Ma$)	Little effect	Electronic timer moderately complex; proposed on-board computer could perform function	Ground evaluation satisfactory; may require recalibration for zero-g condition	Could be appreciable; ground calibration chart requires alteration for orbital use	One shot; a 1 man operation
Oscillating Spring-Mass System	Greater adverse effect on accuracy than linear acceleration	Electronic timer moderately complex; proposed on-board computer could perform function; if electronic timer fails, a stopwatch usable (less accuracy)	Ground evaluation satisfactory; may require recalibration for zero-g condition	Could be appreciable; ground calibration chart requires alteration for orbital use	One shot; a 1 man operation
Inertia-Beam Balance Technique	Phased-stroke solution to potential problem	Simplest system	Ground simulation difficult; elaborate means required	None	Trial and error; possible in 2-man operation
Centrifuge	No Problem	Relatively simple (if centrifuge exists for other purposes)	Ground calibration setup can simulate zero-g condition	None	Impose scheduling constraints, unless performed concurrently with other centrifuge function; involves long operating cycle

closely controlled. This method is preferable except that simulation of its response in a zero-g environment is difficult and elaborate simulation methods will be required.

- Linear Acceleration. The electronic timing apparatus for the accelerometer readout) required for this method is complex, but the proposed on-board computer can be used to perform these functions. A breadboard model of this device has been demonstrated in an LMSC laboratory. If an actual prototype model is built, tested and calibrated on the ground, however, the calibration will have to be modified to account for reduced bearing friction that will occur in a weightless environment.
- Oscillating Spring-Mass System. Almost the same comments as those for the straight linear acceleration method apply to this system. However, this oscillating spring-mass system has an advantage because in the event of failure of electronic timing apparatus, a mass determination can be accomplished by using a stop watch, even though it will be less accurate. This system therefore is recommended at this time for mass measurement purposes. Further, the system is not affected by small gravity or centrifugal forces at random orientations.

4.8.4 Oculometer

Any change in the astronaut's eyesight demands the the earliest possible detection. Not only is the ability to see vital to the mission, but ocular decline may indicate neurological defects as well as general or non-specific physical deterioration. To monitor the astronaut's visual capability, the following instruments have been evaluated:

- Ortho-Rater (Bausch & Lomb). This instrument is completely enclosed and rear-illuminated, and it provides images at near and far points. Near and far displays are mounted on separate revolving drums. Displays measure visual acuity, phoria, depth perception, and color discrimination. The optical system is manually tilted from the near-point drum to the far-point drum. Physical characteristics are as follows:

— Power — 50 w (25w with switch)

– Size – 10 in. × 18 in. × 22 in.

– Weight – 40 lb

- Sight Screener (American Optical). This instrument is completely enclosed and rear-illuminated, and it provides an image at near and far points. The displays are mounted on a sprocketed slide by which the subject's visual acuity, phoria, and depth perception can be measured. The physical characteristics are as follows:

– Power – 50 w

– Size – 10 in. × 20 in. × 20 in.

– Weight – 30 lb

Orthoscope (Keystone). The unit is an open stand, consisting of a base, viewing lenses, occluding device, and a near-far adjustable display holder illuminated by incident light. The displays are changed manually and measure visual acuity, phoria, depth perception, color discrimination and simultaneous perception. The physical characteristics are as follows:

– Power – 25 w

– Size – 8 in. × 16 in. × 18 in.

– Weight – 8 lb

None of the instruments considered qualifies for use in the MORL spacecraft without system modification. The Sight Screener presented a generally good image except for an intra-lens reflection. There was a tendency to scatter light which may have resulted from an oily substance on the lenses. The Ortho-Rater quality is comparable to that of the Sight Screener. However, the Ortho-Rater appears to present more problems in conversion to remote control. There is a significant discrepancy between the two instruments in measuring phoria. This may be the result of a lack of inter-pupillary adjustment.

There are three essential elements in these devices. They have a pair of lenses for correcting the apparent distance to the subject at near and far points, illumination, and a set of cards or films that provides the test objects.