PROCEEDINGS OF THE EXPERIMENTERS' INFORMATION MEETING ON THE APOLLO APPLICATIONS PROGRAM IN BIOSCIENCE

22-23 November 1965
Washington, D.C.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMERICAN INSTITUTE OF BIOLOGICAL SCIENCES

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Edited by

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National Aeronautics and Space Administration

and

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American Institute of Biological Sciences

Scientific and Technical Information Division 1966
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

FOREWORD

The National Aeronautics and Space Administration is currently involved in defining the program to be carried out in the period following the successful execution of the lunar landing program. The Manned Space Science Division of the Office of Space Science and Applications, in cooperation with the Apollo Applications Program Office of the Office of Manned Space Flight, has been called upon to define the scientific part of this advanced program. In recognition of the important role of the biosciences in this endeavor, representatives of the bioscience community were invited to participate in this program.

The most important factor in the achievement of our national goals in space science is the competent scientist. He is undoubtedly the most essential single factor in our planning; it is his support and cooperation that we seek—for today, for tomorrow, for next year, and for the future. His participation and the conduct of space science may involve him as an Earth-bound scientist, as a scientist-astronaut, or as simply a scientist passenger in some future space flight. His use in all of these types of functions will undoubtedly be involved in the development and operation of future space science programs.

At the present time our most urgent need is for scientific investigators to be responsible for delineating investigations and for defining the instruments and equipment needed for carrying out these investigations. These principal investigators, as they are called, are responsible for assuring that a sound research program is being planned and conducted keeping in mind the necessity to minimize cost and maximize return. In this effort they become part of a team consisting of a headquarters program manager, a center project manager, scientific and engineering monitors, scientists and astronauts. Most important of all, however, is the fact that upon the principal investigator rests the responsibility for the scientific integrity for his investigation and for the publication of the results.

The proceedings of this meeting clearly indicate the great interest which the bioscience community takes in the space program, the remarkable scientific standards which are applied to the definition and conduct of scientific experiments, and the active interplay of all members of our space science team. With this kind of cooperative effort this program cannot help being a success.

Willis B. Foster, *Director*
Manned Flight Experiments Office

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CONFERENCE INTRODUCTION

GERATHEWOHL: The main purpose of this meeting is to discuss biological experiments which may be included in the Apollo spacecraft.

The program with which we are concerned here is called the Apollo Applications Program or, in short, AAP. It replaces the Apollo Extended Systems, which was abbreviated as AES. As the new name indicates, the program deals with the use of very powerful boosters, namely, the Saturn; large space vehicles, namely, the Apollo spacecraft; and the LEM, the Lunar Excursion Module, for space and science applications.

It is now moving in the phase of flight-mission assignment for the experiments which have been proposed for this program. In order to assure continuity in the development of bioscience experiments to be conducted in manned spacecraft, we believe that it is necessary to review the present state of NASA's major flight projects in space biology.

For those who are not familiar with NASA's organizational chart, I would like to point out that we have three major efforts concerning the life sciences. The one which concerns the protection, support, and welfare of the astronauts is the responsibility of the Office of Space Medicine. This is assigned to the Office of Manned Space Flight, headed by Dr. Mueller; and the Director of the Office of Space Medicine is Dr. Lovelace.[1]

The second one, which concerns the areas of biotechnology and human research, falls under the responsibility of the Office of Advanced Research and Technology (OART), which is headed by Dr. Adams, and the Office of Biotechnology and Human Research, headed by Dr. Walton Jones. This Office is particularly concerned about long-range technology and ground support of experimentation. This also includes biosciences.

The third one, which concerns the basic biological research, is the bioscience program of the Office of Space Science and Applications. This Office is headed up by Dr. Newell; and the Office of Biosciences, as you probably all know, by Dr. Orr Reynolds.

The experiments which will be discussed fall in this last area, the area of biosciences. I would like now to call on Mr. Donald Beem, the assistant to the executive director, AIBS, for a few words of welcome and wisdom.

BEEM: I don't know how much wisdom there will be. I am here pinch-hitting for John Olive, the executive director of the American Institute of Biological Sciences, who unfortunately will not be able to be with us during this meeting. I wish to extend a welcome to all of you. You may wonder why the American Institute of Biological Sciences is involved in such a program as this. There are many reasons. Primarily, AIBS is set up to be of service to biologists, and biology in general. One way of such service is involving ourselves in such programs with national organizations such as NASA. Therefore, we have become involved in the Apollo Applications Program, the new terminology which I did not have when I sent out the letters of invitation. I called it the Apollo Extended Systems.

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[1]Dr. Lovelace died Dec. 12, 1965. Brig. Gen. Jack Bollerud is Acting Director of the Office of Space Medicine.

The first portion of the program is devoted to a general review of bioscience experimentation in Gemini and the biosatellite program. Later, two bioscience experiments that have been approved for Apollo will be discussed by the principal investigators.

This afternoon and tomorrow morning, the program will center on the concept of the Apollo Applications Program. Mr. Taylor, Mr. George, and Mr. Clemence, who is substituting for Mr. Small, will present information on the planning, engineering, and experimental design of the Apollo Applications Program.

Ample time will be allowed at the end of each session for discussion. Therefore, I would request that you hold your questions or comments until the end of the session.

SESSION I

Morning, November 22, 1965

N66 31807

1. STATUS REPORT ON BIOSCIENCE ON GEMINI

SIEGFRIED J. GERATHEWOHL
Manager, Life Science Projects
Manned Space Science Division, NASA

BEEM: I would now like to turn the program back to Dr. Gerathewohl, who will give us a status report on the bioscience in the Gemini program.

GERATHEWOHL: In organizing this meeting, I thought it would be of benefit to all of us if we would give a little history and review very briefly what has been done so far in the ongoing research. I did not want to go too far back, but at least in the ongoing life sciences or biosciences research within NASA.

The various types of experiments, which were assigned to flights GT-3 through GT-7, are shown in table I. They are grouped in accordance with the areas of responsibility, which I pointed out in my introductory remarks, or the organization which proposed them—as is the case with the engineering experiments which originated at the Manned Spacecraft Center, in Houston, Tex., and the experiments which were proposed by agencies pertaining to the Department of Defense. We are particularly interested in the S-experiments, among which we find the ones dealing with life sciences problems. They are:

- S-2 Sea urchin egg growth
- S-4 Radiation and 0-G effects on blood
- S-8 Visual acuity
- S-12 Micrometeorite collection, and
- S-3 Frog egg growth, which is not included in table I because it is scheduled for a later flight.

I would like to say now a few words about the state of each of these experiments. The list below gives the objective and a short description of an experiment to evaluate the effects of weightlessness on the processes of fertilization, cell division, and development of sea urchin eggs (S-2).

Purpose:	Evaluate effects of weightlessness on growth of simple cells
Equipment:	Cylinder having eight growth chambers and temperature recorder
Weight:	10 ounces
Volume:	0.02 cu ft
Procedure:	Operate fixing and fertilizing knobs at prearranged times
Location:	Pressurized cabin

Figure 1 shows the interior of the experimental package with the various chambers for eggs, sperm, and fixative to arrest the growth at certain times during the flight. The assembled package is shown in figure 2. The astronaut had to initiate fertilization and fixation of the eggs by turning the handle. Unfortunately, the experiment failed for mechanical reasons, but we learned a lot about technical requirements and human errors in conducting experiments under rather difficult conditions. The experiment may be repeated in one of the later Apollo flights.

Table I.—Gemini Experiments—Flights GT-3 Through GT-7

Type	No.	Title	GT-3	GT-4	GT-5	GT-6	GT-7
Medical	M-1	Cardiovascular Reflex	–	–	X	X	X
	M-2	Cardiovascular Effects	X	X	X	X	X
	M-3	In-Flight Exerciser	–	X	X	X	X
	M-4	In-Flight Phonocardiogram	–	X	X	X	X
	M-5	Biochemical Analysis of Body Fluids	–	–	–	X	X
	M-6	Bone Demineralization	–	X	X	X	X
	M-7	Gemini Calcium Balance Study	–	–	–	–	X
	M-8	In-Flight Electroencephalogram	–	–	X	–	X
	M-9	Vestibular Effects	–	–	–	–	X
Engi-neering	MSC-1	Electrostatic Charge	–	X	–	–	–
	MSC-2	Proton Electron Spectrometer	–	X	X	X	X
	MSC-3	Tri-Axis Magnetometer	–	X	X	X	X
Technical	T-1	Reentry Communication	X	–	–	–	–
Defense	D-1	Visual Definition of Objects in Space	–	–	X	X	–
	D-2	Visual Definition of Nearby Objects in Space	–	–	X	X	–
	D-3	Mass Determination	–	–	–	X	–
	D-4	Radiometric Measurements	–	–	X	–	X
	D-6	Visual Definition of Terrestrial Features	–	X	X	–	–
	D-7	Radiometric Observation of Objects in Space	–	–	X	–	X
	D-8	Radiation	–	X	–	X	–
	D-9	Simple Navigation	–	–	–	X	X
	D-13	Astronaut Visibility	–	–	X	–	X
Scientific	S-1	Zodiacal Light Photography	–	–	X	–	–
	S-2	Sea Urchin Egg Growth	X	–	–	–	–
	S-4	Radiation and Zero-G Effects on Blood	X	–	–	–	–
	S-5	Synoptic Terrain Photography	–	X	X	X	X
	S-6	Synoptic Weather Photography	–	X	X	X	X
	S-7	Cloud Top Altitude Spectrometer	–	–	X	–	–
	S-8	Visual Acuity	–	–	X	–	X
	S-9	Nuclear Emulsion	–	–	–	–	X
	S-11	Airglow Horizon Photography	–	–	X	–	–
	S-12	Micrometeorite Collection	–	–	–	X	–

Dr. Richard Young from Ames Research Center is also preparing a parallel experiment using frog eggs. The rationale of this study is given in the following:

Purpose: Evaluate effects of prolonged weightlessness on cell tissue
Equipment: Eight chambered cylinder, frog eggs
Weight: 15 ounces
Volume: 0.02 cu ft
Procedure: Preflight: Briefing
In-flight: Operate fixing knob
Postflight: None
Location: Pressurized cabin

Whereas Dr. Young does not expect noticeable effects of weightlessness on the developing sea urchin egg, he expects to detect such effects on the frog egg, the dependency of which on

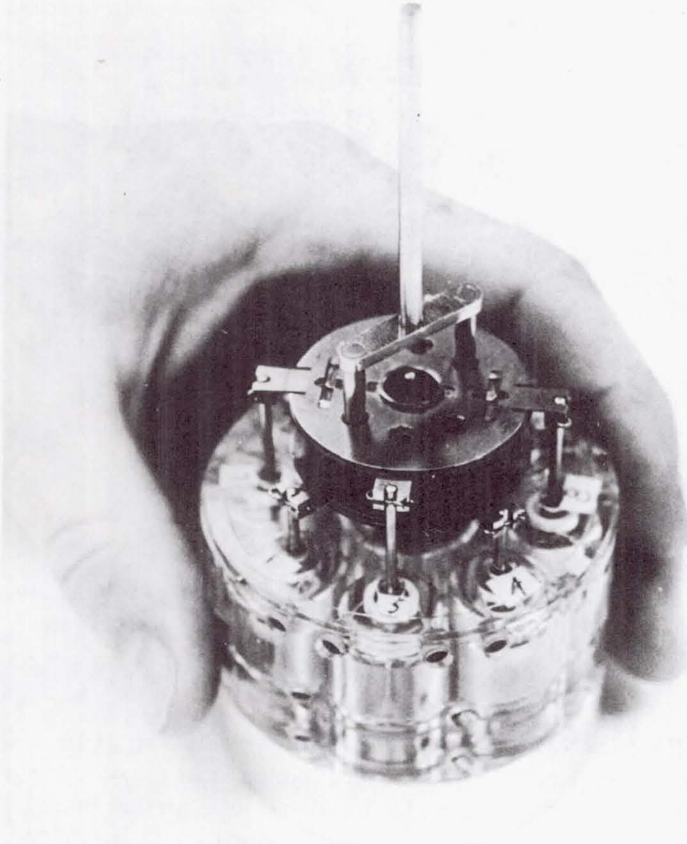

Figure 1.—Interior of experimental package.

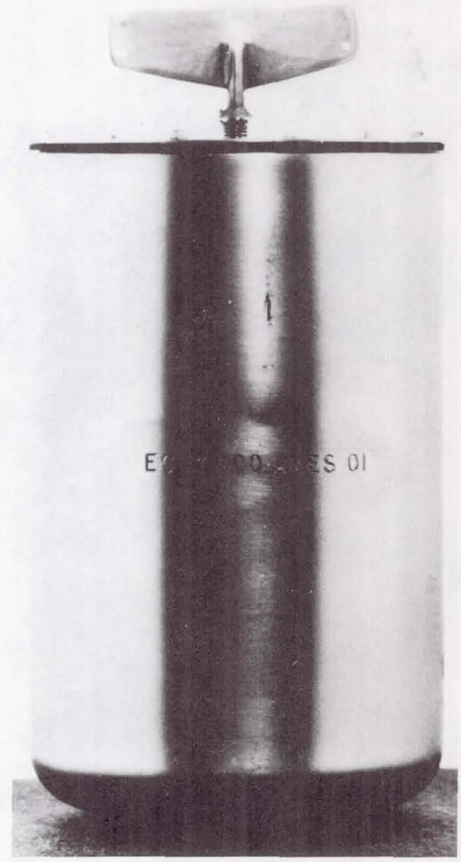

Figure 2.—Assembled experimental package.

gravity factors seems well established. The flight units, which are being built by General Electric Co.'s Missile and Space Division, have been delivered to the McDonnell Aircraft Corp. (See fig. 3.) The experiment is scheduled for GT-8, which is to fly in spring of this year. Since the biosatellite cannot accommodate the sea urchin egg experiment, frog and sea urchin eggs may be flown together in Apollo.

Extremely interesting results were obtained in an experiment on the effects of radiation and 0 G on human white blood cells, which is conducted by Dr. Bender from the Oak Ridge National Laboratories:

Purpose:	Weightlessness and radiation relationship on white blood cells
Equipment:	Apparatus containing cells and radioactive source
Weight:	6 ounces
Volume:	0.03 cu ft
Procedure:	Actuate slide mechanism
Location:	Pressurized cabin

The experiment was more or less stimulated by Russian reports of chromosomal disruptions as a result of space flight. Dr. Bender's flight package is shown in figure 4. Since the experiment and its results are published in the "Manned Space Flight Experiments Symposium

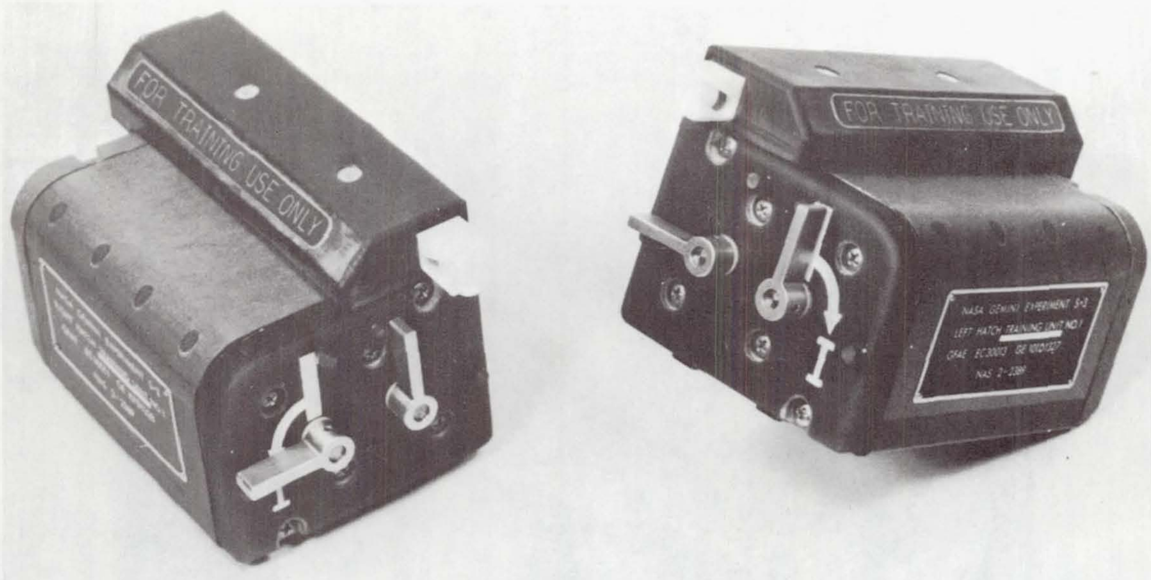

Figure 3.—Flight units.

Figure 4.—Flight package.

Gemini Missions Nos. 3 and 4," I will show only two of Dr. Bender's tables. Table II shows the increase of chromosome aberration with increasing radiation dose and, furthermore, the persistent increase of chromosome deletions in the flight samples. A synergism between radiation and some flight parameter—apparently weightlessness—seems to exist for human-chromosome single breaks in white blood cells. That the space flight by itself—one thinks in particular of acceleration, vibration, and pure oxygen—induces these aberrations is ruled out by the nonradiated flight samples and also by the preflight and postflight blood samples obtained from the flight crew (see table III). I am sorry that Dr. Bender is not with us to interpret the slight increase noticeable at the bottom of the table.

An experiment, which is not in a sense basic biologic in nature but was assigned to this Office, is being conducted by Dr. Duntley and Dr. John Taylor from the Visibility Laboratory, Scripps Institution of Oceanography, University of California, to measure visual functions in flight and visual acuity from orbital altitudes:

Purpose:	Investigate astronaut's visual performance in seeing objects on Earth's surface
Equipment:	Vision tester and photometer
Weight:	5 lb + D-6
Volume:	0.02 cu ft + D-6

Procedure: Preflight: Laboratory experiments and plane flight over target area
In-flight: Use vision tester, view, and photograph targets
Postflight: Visual acuity test
Location: Pressurized cabin

Table II.—Results of Experiment S-4 Chromosome Aberration Analyses

Subject	Sample	Cells scored	Estimated dose (rad)	Chromatid deletions	Chromosome deletions	Ring and dicentric chromosomes
Crew						
Grissom	Preflight	100	—	3	0	0
	Postflight	200	—	2	0	0
Young	Preflight	100	—	0	1	[a]1
	Postflight	200	—	0	1	[a]1
Experiment						
	Ground	400	2	3	3	1
	Flight	400	2	1	3	0
	Ground	400	47	1	6	5
	Flight	400	47	3	14	1
	Ground	400	94	5	13	13
	Flight	400	94	6	28	16
	Ground	400	138	6	32	43
	Flight	400	138	6	48	34
	Ground	400	189	6	45	36
	Flight	400	189	2	88	48

[a]These 2 dicentric chromosomes appear identical; both lacked acentric fragments.

The GT-5 astronauts used an in-flight vision tester once a day in order to determine the effects of space flight—in particular, weightlessness—on near-vision acuity. (See fig. 5.) Moreover, the astronauts tried to identify bright rectangles, which were placed on dark squares as background, which were laid out like a big eye chart at the Gates Ranch near Laredo, Tex. Figure 6 shows the orientation of the Gemini spacecraft over the observation site, which actually consisted of three rows of four markings each. An in-flight photometer was used to measure the brightness of light scattered by the Gemini window, as shown in figure 7. The values obtained varied very markedly during the GT-5 overflights. Due to the difficulties with the fuel cells during the first part of the flight, and due to shortage of control fuel at the end, the experiment had to be shortened and the markings were ascertained only

Table III.—GT-5 Astronaut Chromosome Analysis

Preflight	Cells scored	Chromosome-type aberrations				
		Chromatid deletions	Chromatid exchanges	Deletions	Dicentric	Exchanges
T-11:						
Cooper	300	7	0	7	1	1
Conrad	225	10	0	2	0	0
T-8:						
Cooper:						
[a]1	150	2	0	1	0	0
[b]2	150	5	0	1	0	1
Conrad:						
[a]1	49	0	0	1	0	0
[b]2	150	3	0	1	0	0
T-4:						
Cooper	150	3	0	0	0	0
Conrad	150	0	0	1	0	0
Postflight						
Cooper	150	5	0	5	0	3
Conrad	150	6	0	2	1	2

[a]After 125 I RISA injection.

[b]After Cr^{51} and RISA injection.

two times. Figure 8 shows the observation site photographed from orbit. The results of the GT-5 mission indicate that the visual performance of the astronauts was not degraded during the 8-day flight, and that the ground observations were within the predicted statistical probability. However, the individual identifications of the test markings were not reliable enough, and the experiment will be repeated—using a modified pattern as shown in figure 9—during the GT-7 flight.

Finally, the micrometeorite experiment (S-12) is as follows:

Purpose: Collect and study nature of interplanetary dust
Equipment: Collection apparatus with isolated compartments
Weight: 8 pounds
Volume: 0.045 cu ft
Procedure: Position collection apparatus on outside of spacecraft, open and close apparatus remotely, recover apparatus and stow
Location: Pressurized cabin and outside spacecraft

Hemenway's experiment has three objectives, of which the first is successful sampling of nanometeorites, and estimation of the percentage of these which originate by ablation from meteorites. Second, the flux will be measured from examination of the density of holes which

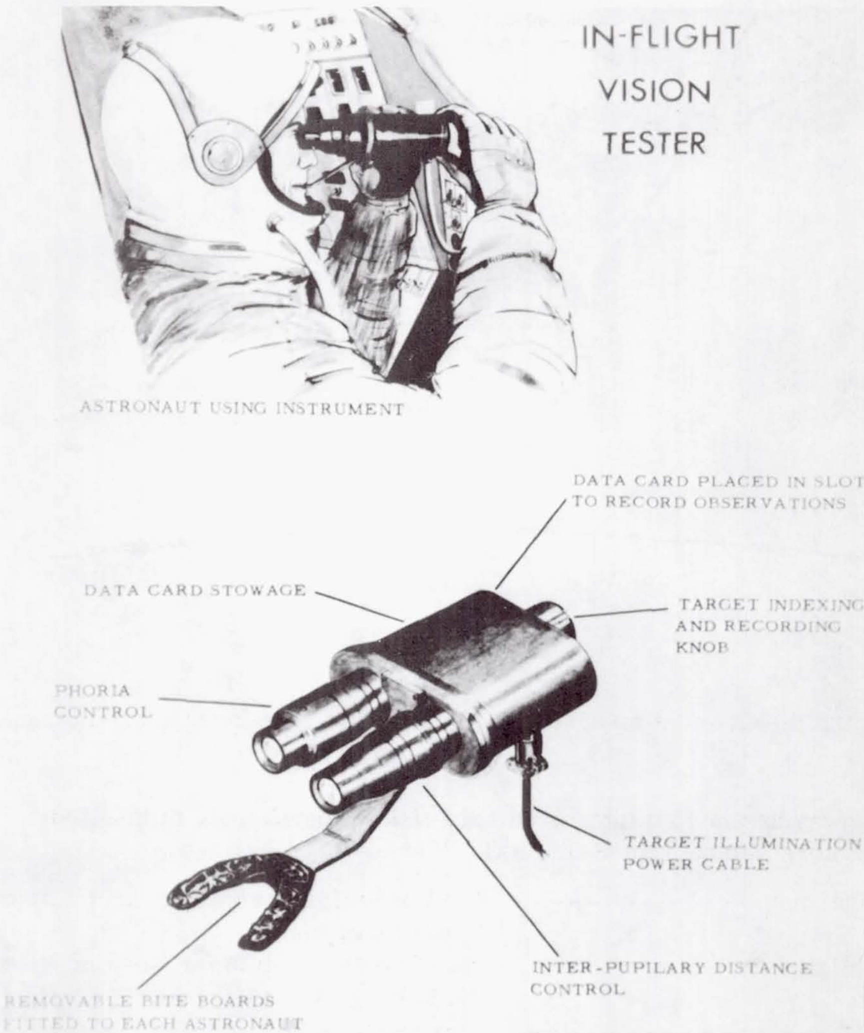

Figure 5.—In-flight vision tester.

occur in a series of thin films. Following Mercury flights, a study of the outer surfaces of the windows and periscope lenses used during those missions has already indicated such impact sites.

And finally, for biological purposes, sterile collection surfaces will be located within a discrete sterile compartment included to find out whether micro-organisms are present or absent in the space environment. An attempt to answer the further question of survival of micro-organisms will be made through incorporation of a nonsterile compartment (fig. 10) which will house various micro-organisms including bacteria, molds, spores, and viruses to be exposed to the space environment. After flight, the survival rate of these micro-organisms will be assayed. Also, the microbiological collection surfaces will be treated to a wide variety of culture techniques, including those to be used in search for extraterrestrial life. The equipment to be used is shown in figures 10 and 11.

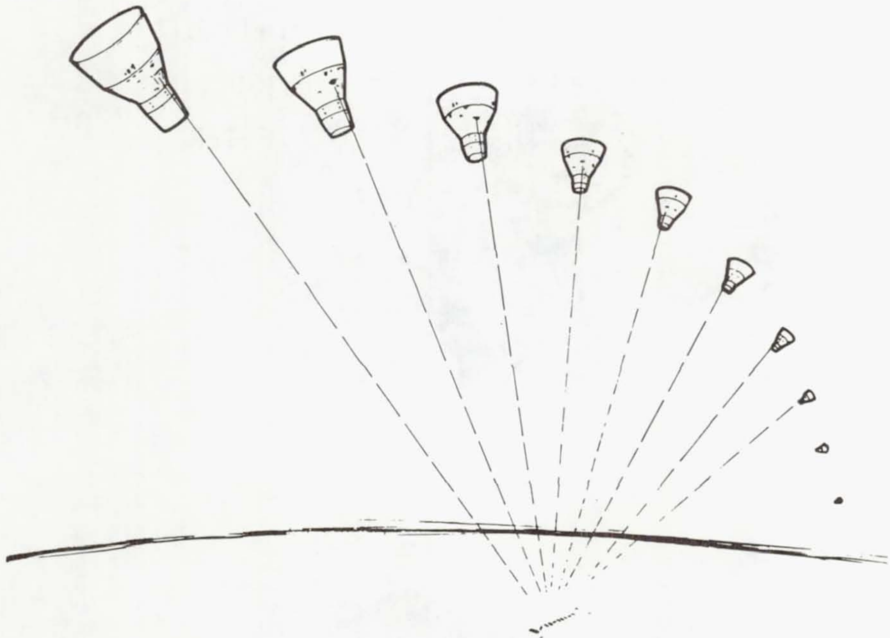

Figure 6.—Orientation of Gemini capsule over prepared ground targets.

Dr. Hemenway has invited interested scientists to participate in his study. For example, guest experimenters selected for S-12 on GT-9 are:

Robert Soberman	Air Force Cambridge Research Laboratories Cambridge, Mass.
Hugo Fechtig	Max Planck Institute for Nuclear Physics Heidelberg, West Germany
Uri Shafrir	University of Tel Aviv Tel Aviv, Israel
Michael Carr	U.S. Geological Survey Menlo Park, Calif.
Donald Gault	Ames Research Laboratory NASA-Moffett Field, Calif.
Paige Burbank	Meteoroid Technology Branch NASA-MSC, Houston, Tex.
Otto Berg	Goddard Space Flight Center Greenbelt, Md.

This is one of the first attempts where an experimenter has opened the door to let other scientists in as coinvestigators. I am pointing this out because this approach may be applicable to experiments under consideration for the Apollo Applications Program.

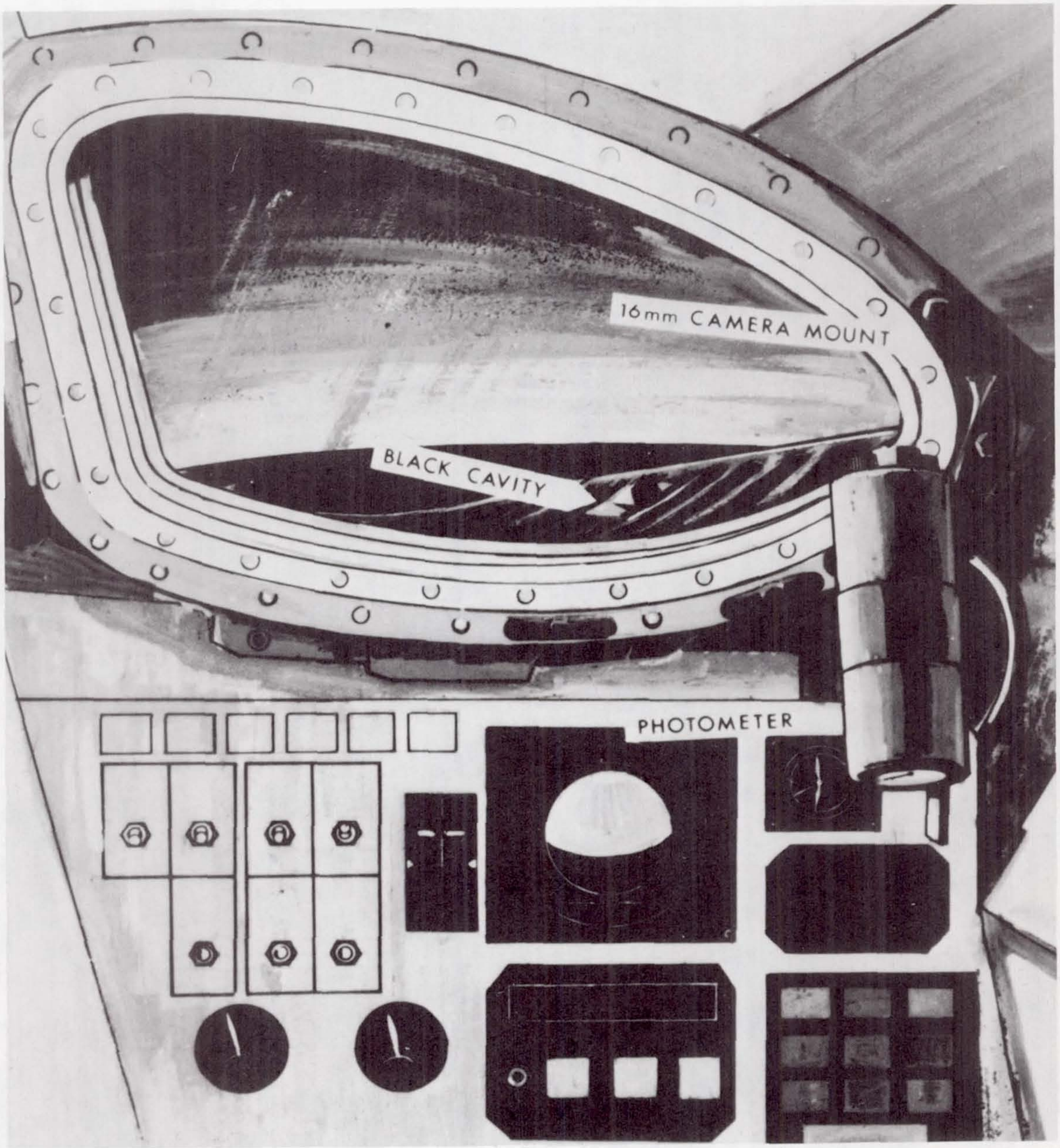

Figure 7.—In-flight photometer.

Figure 8.—Observation site photographed from orbit.

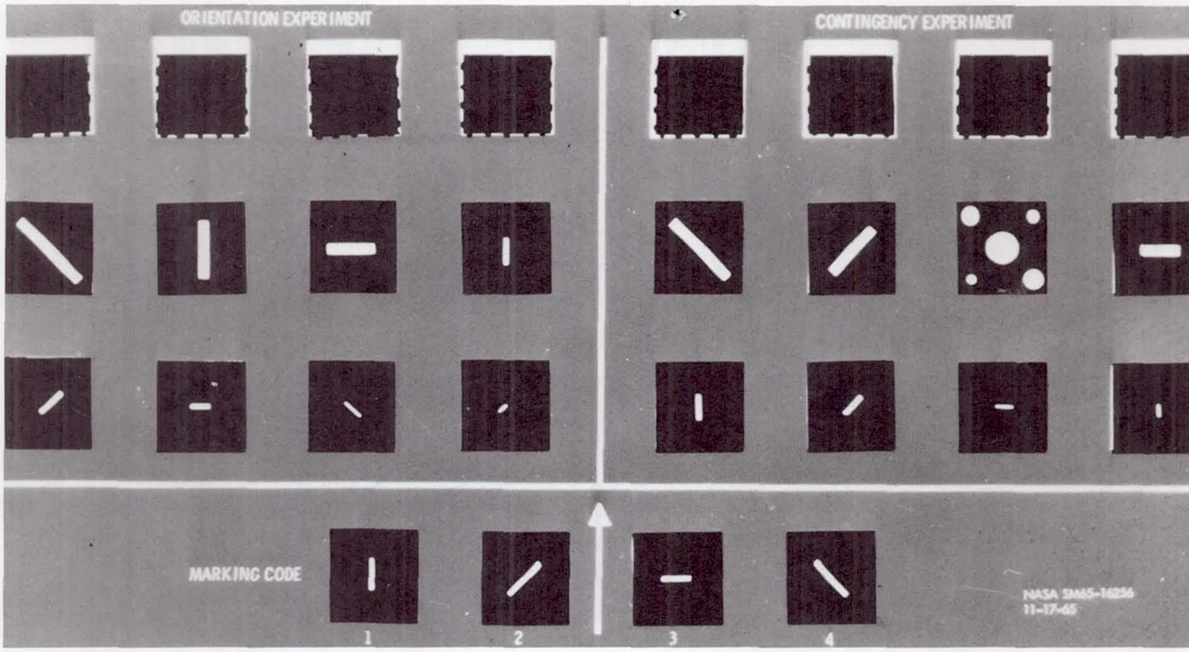

Figure 9.—Ground markings at Laredo.

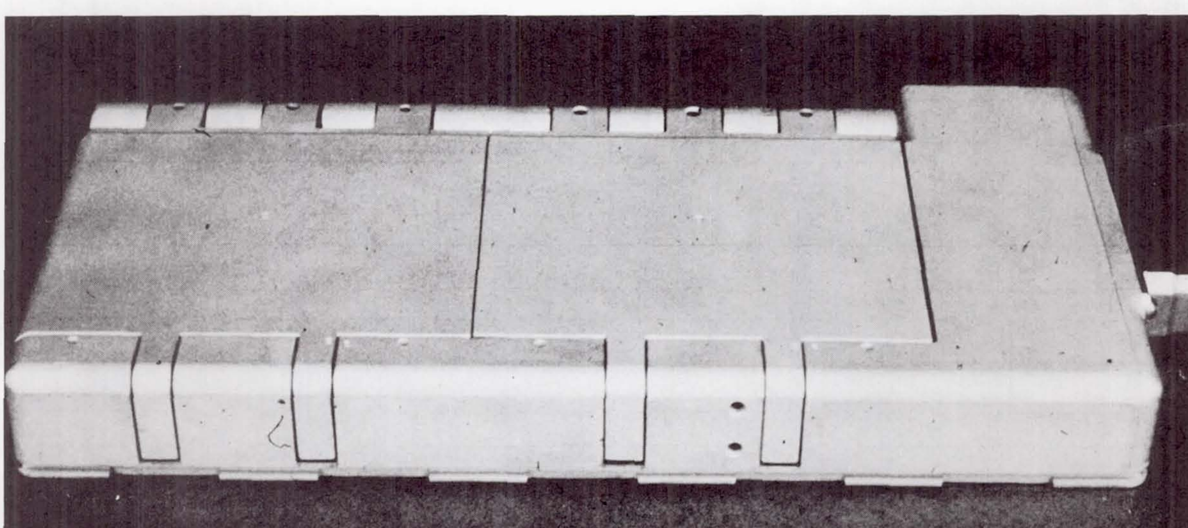

Figure 10.—Apparatus for microorganism survival experiment (closed).

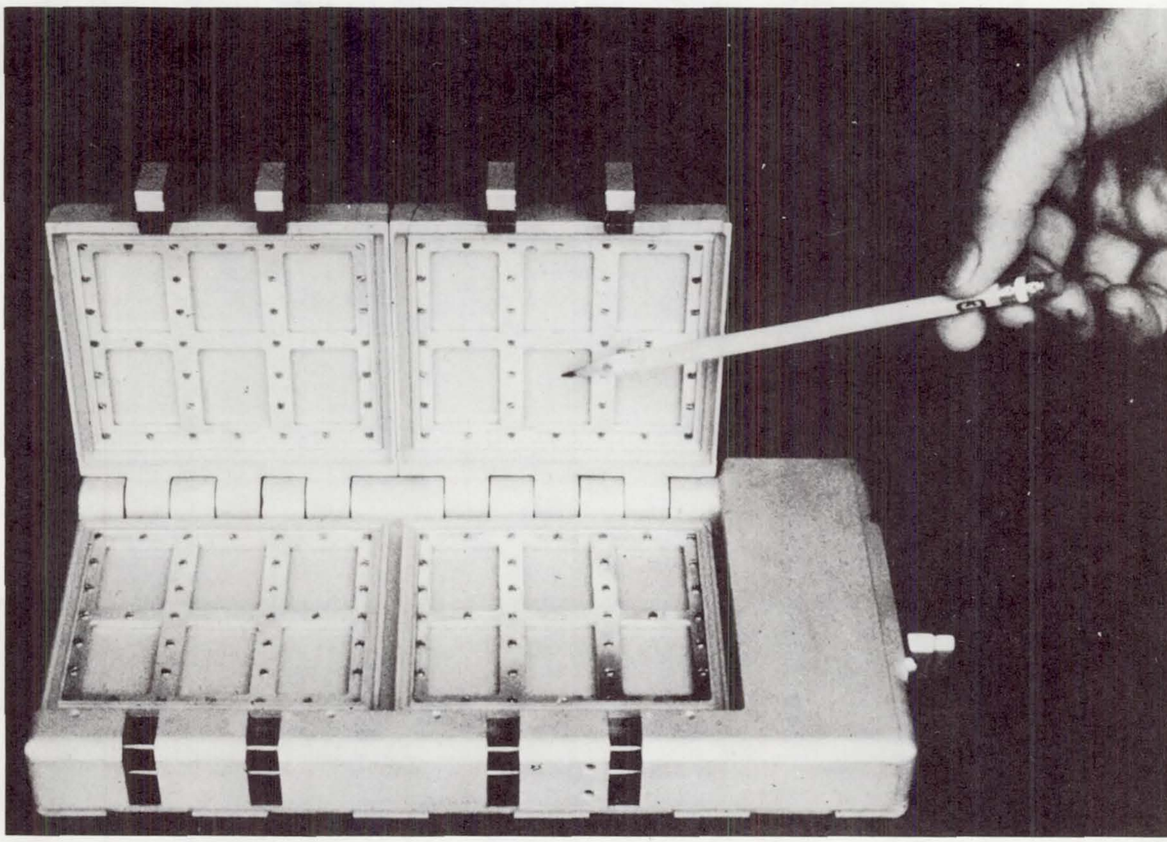

Figure 11. —Apparatus for microorganism survival experiment (open).

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2. STATUS REPORT ON THE BIOSATELLITE

DALE JENKINS
Chief, Environmental Biology, Bioscience Programs
Office of Space Science and Applications, NASA

GERATHEWOHL: Now I would like to ask Dr. Dale Jenkins to tell about the biosatellite project. He has been instrumental in organizing the biosatellite, in the early stages, has followed it, and will give us a picture of its present status and background.

JENKINS: The best way to give a status report of the biosatellite program would be to ask each of the various experimenters here to tell us the latest status of his experiment. A film will show you the status of the various experiments in the biosatellite program.

I would like to review the philosophy and the rationale of our biological program in space, to point out the rationale and philosophy of the Russian program to compare the two, and to point out why we are going the way we are. I shall summarize by pointing out what we are planning to do in the future, particularly the way the biosatellite program fits into the Apollo Applications Program.

In the environmental biology program, we are interested in all of the environmental factors of space. These can be studied better on the ground, with the exceptions of decreased gravity, radiation combined with weightlessness, and biorhythms in relation to changed periodicities with regard to the Earth's rotation.

We can study weightlessness, but not zero gravity. There is the gravity of the Earth and of the Sun. At about 200 nautical miles in orbit around the Earth, there is still 95 percent of the Earth's gravity. What we are studying in the spacecraft is weightlessness, or free fall caused by the velocity of the spacecraft traveling at a speed that equals the gravitational pull of the Earth.

We can duplicate the radiation in space with the exception of some of the high-energy, heavy-particle cosmic radiation. We can probably study the biological effects better in ballons in northern latitudes. We are interested in whether there is any synergism or antagonism between weightlessness and radiation. Since radiation effects are affected by oxygen, temperature, and other factors, there is a possibility, but no good rationale or hypothesis, that we would expect effects of combined weightlessness and radiation.

We are interested in the effects of weightlessness on a single cell, especially the physical processes, sedimentation within the cell, and lack of convection, which may or may not have any effect within or outside of the cell. We are interested in transportation of fluids, both in plants and in animals. Every organism on Earth is accustomed to an unvarying 1 G. If gravity is completely removed and we have a weightless state, it is possible that we may find extremely interesting changes in basic processes in biology. So far, however, nothing very exciting has appeared.

Plants are of interest because they are very sensitive to gravity. However, the response time is slow. It is possible to use a clinostat to rotate the plant to nullify the effects of gravity before the time threshold of response has been reached. The threshold of gravitational effects is probably about 10^{-6} G so that spacecraft movement must not cause gravitational effects during orbit that would confuse understanding the effects on these plants. Animals are probably not as susceptible as plants to very low gravity, but they respond rapidly, and have an effective adaptation system.

A number of experiments on the biosatellite will be designed to study the effects of weightlessness on plants and animals, from the single cell to the primate.

The Russians have sent up a large quantity of biological materials. About sixty different species of plants and animals have been orbited in nine flights. There were four Russian ballistic suborbital flights during the period 1950 to 1958. In some flights biological experiments were the major component of the payloads, and in others, particularly some of the recent ones, they have been carried along with the astronauts.

The philosophy of the Soviet program is very different from the NASA program. They are attempting to study the effects of ambient space radiation on a variety of biological organisms. They have used parts of organisms, skin, fibroblasts, enzymes, amniotic tissue, a series of different types of eggs of animals, a number of species of insects and mammals, viruses, bacteria, yeast, various molds, algae, and a large number of different types of plants, including seeds.

In summary the results indicate that the vibration and acceleration involved in launching are very important and cause biological effects. They sent up a large number of experiments which had a relatively high threshold of radiation effects, but the maximum radiation that any experiments received was the 5-day flight, which gave about 60 millirad. These organisms did not receive sufficient radiation to obtain really significant radiation results. Some Russian scientists have claimed that some of their experiments do show significant results. For example, they claim that Tradescantia microspores do show certain mitotic aberrations correlated with time of weightlessness. Dr. Antipov was asked whether these results, correlated with time of flight, could be merely the amount of time following vibration. He did not think so. I recently suggested to Dr. Gazenko that they try a critical experiment. Instead of only fixing plants at intervals during flight, that they also leave some plants alive for periods of time after recovery to determine whether there is a continuation of the increased number of mitotic aberrations in 1 G after recovery.

In discussions with Dr. Gazenko and other Russians on irradiation experiments, they appear to view most of these experiments so far as baseline experiments to determine whether there are any special effects at very low levels, and also to determine the effects of vibration, acceleration, and other dynamic factors during launch and flight. The Russians sent up their experiments without having exposed the organisms to vibration and acceleration, and some of the other factors involved in flight. They found that there were a fairly large number of mutations and aberrations, and at first they blamed this on radiation. Now they are running a large number of experiments on detailed effects of vibration and acceleration, and particularly vibration. Dr. Antipov said that the major effects are caused in a range of about 80 to 100 cycles per second. They find that the vibration does cause effects simular to those observed from radiation.

In the NASA biosatellite program, we are exposing all experiments to the effects of vibration and acceleration, to work out the baseline information required before flight, so we will be able to interpret the data from the flights accurately. It is then possible to state in advance what is due to vibration and what is due to weightlessness.

The Russians are very interested in the experiments which they interpret as positive results either from radiation or weightlessness. These organisms are Tradescantia, bone marrow, and Drosophila which are the main organisms that they are interested in working with in the future.

Some of you know the NASA biosatellite program in detail. There are a number of published papers that give a summary of the philosophy and rationale of the program, as well as list all of the 19 experiments which are presently aboard the biosatellite. There were 187 experiments submitted to the biosatellite program, and about 40 of these were put in Category 1 recommended for flight. However, there were a very large number of excellent experiments, some of which could not go on the biosatellite program for some reason such as weight, and some of these have real potential for the Apollo Applications Program. These 187 experiments were considered for the Apollo Applications Program. Those experiments involving ambient radiation effects and engineering studies were deleted. About 116 of the 187 would be of interest with regard to the Apollo Applications Program. Some of these the various review groups have stated are very good, valid scientific experiments. A number of people, both those who have biosatellite experiments onboard and those who have submitted experiments which are not on this series of six biosatellites, will be contacted and asked to revise these experiments.

GERATHEWOHL: In the next session we will discuss some of the last subjects which Dr. Jenkins just mentioned; namely, the possibility of converting some of the biosatellite experiments or some of the proposed biosatellite experiments into the experimental battery or the experimental program for manned spacecraft.

The American Institute of Biological Sciences has a NASA contract for helping us to define an inflight program, a scientific program in biology which will be conducted or can be conducted in manned spacecraft. Particularly, I am thinking here of the Apollo spacecraft and, to use the new stereotype again, of the AAP, the Apollo Applications Program.

3-A. REPORT ON APPROVED BIOSCIENCE EXPERIMENTS FOR APOLLO: EFFECTS OF WEIGHTLESSNESS ON ISOLATED HUMAN CELLS

P. O'B. MONTGOMERY, JR.
Southwestern Medical School, University of Texas

GERATHEWOHL: The next part of our program deals with the report on approved bioscience experiments for Apollo. At the present time we have two experiments which have been approved, and which are in preparation for the Apollo flights. One is an experiment prepared by Dr. Montgomery, and the other one is an experiment being prepared by Dr. Gualtierotti.

The first speaker is Dr. Montgomery, from the Southwestern Medical School, University of Texas, who is involved in an experiment that will be flown in the biosatellite as well as in one of the later Apollo flights. Dr. Montgomery is a very well-known cytologist. I do not want to read the titles of all of his papers; they are very many. The list of his affiliations with scientific and medical societies is longer than most of the bibliographies that I have seen. Among the latest papers that he has published is "Flying Television Microscopy," "Gravity, Radiation and Growth," "Ultrastructural Alterations Induced in E. coli B by Gravity," and "The Relationship Between Growth and Gravity in Bacteria."

He is at the present time conducting experiments with increased gravity, using a centrifuge, and he uses this more or less as a tryout to get baseline data for the experiments that he wants to fly at 0 G.

He has submitted just recently his latest report on the influence of zero gravity on single living human cells, the report from the Apollo Monthly Progress Report, and he says as Point No. 7: "The major problem appears to be the intense pressure of the schedule necessary to carry out the proper flight hardware production and testing program." In other words, he is scientifically all right, but he is under pressure to get the hardware prepared and ready for the flight.

I would like to turn it over to Dr. Montgomery to give you his presentation of his experiment, which I think is one of the unique experiments we are planning to do, and one of the very important experiments that we propose to fly.

MONTGOMERY: I would like to begin by reviewing for the moment some thoughts about gravity. Gravity has been with us always, and like most things that are with us always, we tend to devote little time and attention to it. Gravity literally rules the universe. It holds the Sun in its position. It keeps the Earth in its orbit about the Sun. It maintains the orbits of the planets, of the galaxies and, as far as we know, is a major force throughout the entire universe.

The earliest experiment with gravity that I can find in the literature is the mythological flight of Daedalus and his son Icarus. Icarus, disobeying the orders of the gods, flew too close to heaven, whereupon the wax on his wings melted, and he fell to Earth under the influence of gravity. We hope that not all of our experiments turn out as badly as this, but it does illustrate for you that people have at least been considering the possibility of gravity for some time.

Aristotle made some comments about gravity. Aristotle said that a stone falls because its place is on Earth. Thus everything has a place, and everything should remain in its place, a distinctly nonexperimental approach to the space environment.

Serious thoughts of gravity began with Isaac Newton. Among them many fundamental contributions which Newton made were contained in the publication of the Principia. The Principia was published about the time the Pilgrims came to our shores. Newton observed that bodies were attracted to each other by their mass, and Newton therefore considered that gravity was a force. Newton considered that centrifugal force and gravity were the same thing, and was the first person, at least the first recorded in scientific literature, to express the view that artificial satellites of the Earth were possible. In the Principia there is a drawing of a cannon firing a cannon ball at escape velocity, and showing that it would orbit the Earth under these conditions.

These rather staggering intellectual triumphs moved Pope to write a very famous couplet about Newton:

> Nature and Nature's law lay hid in night—
> God said, 'Let Newton be,' and all was light.

The biological and the medical people, however, were not very rapid to understand the potential possibility of the influence of gravity. The first recorded experiments that I can find in the literature were published in 1806 by Knight. Knight used water-driven centrifuges to demonstrate that it is the direction of the gravitational vector which orients the growth of plants. One of the experiments on the biosatellite is the effect of the absence of gravity, or weightlessness, on the growth of plants.

In 1894, Pflueger performed his classic experiments showing that inversion of the frog egg resulted in malformations of a variety of types in the larvae of the frog. I understand that these experiments have been repeated and confirmed.

In 1891, Anderson was the first person to make any observations related to the effect of gravity on the structure of the human body. Anderson noted that the human rib sags and rotates under the influence of gravity, while the rib of the dog, whose rib cage is oriented in the opposite axis, does not show such bending.

In 1897, Crooks remarked that the forms as well as the actions of our bodies are entirely conditioned by the strength of gravity on this globe.

In 1897, Morgan published his now famous monograph on the development of the frog's egg. He cited Pflueger's experiments, and in addition to that performed a number of experiments involving the centrifugation of eggs, and noted the abnormalities which occurred following centrifugation of frog's eggs.

In about 1850 or 1856, Virchow, the famous German pathologist, realized the enormous importance of the cellular nature of man's structure. This followed upon the invention of the microscope by Leeuwenhoek, which was some 100 or 200 years earlier, and upon the discovery by Schleiden and Schwann and Hook that all organisms are made up of cells. I would like to remind you at this point of the basis of modern medicine, which is really the recognition that disease in human beings is caused by alterations in cells. This started modern medicine on its present course, and these observations were based entirely on the simple observation of cells and patterns of cell behavior through the microscope. So that looking at cells and looking at the patterns and the ways in which cells behave is today one of the most valuable tools which modern medicine has.

In 1917, a brilliant Englishmen, Sir D'Arcy Thompson, published a monograph, which is still available, in two volumes, on the form and function of various biological structures. He said:

> Were the force of gravity to be doubled, our bipedal form would be a failure, and the majority of terrestrial animals would resemble short-legged saurians or else serpents. Birds and insects would suffer likewise, though with some compensation in the increased density of the air. On the other hand, if gravity were halved, we should get a lighter, slenderer, more active type, needing less energy, less heat, less heart, less lungs and less blood. Gravity not only controls the action but influences the forms of all save the least of organisms. The tree under its burden of leaves or fruit has changed its every curve and outline since its boughs were bare, and a mantle of snow will alter its configuration again. Sagging wrinkles, hanging breasts and many another sign of age are part of gravitation's slow, relentless handiwork.

It has been, therefore, recognized for some time that gravity has a profound influence on the structure and function of organisms. Up until approximately a hundred years ago, electricity, magnetism, and gravity were thought to be the three separate forces which shaped and controlled our universe. Then the experiments of Oersted and Faraday demonstrated that the first two of these forces, electricity and magnetism, were in fact the same force, and save for gravity displaced virtually all other types of forces of which we are aware in the realm of the electromagnetic spectrum. These forces include such commonly measured ones as chemical forces, which hold atoms together to form molecules, and molecules together to form more complex structures. Cohesive forces, such as those which enable a cell to stick to the surface or to another cell, frictional forces, elastic forces which help structures such as the aorta to maintain its size and shape, all of these forces involve the interplay of matter which is composed of atoms, which are in turn composed of electrical particles.

Einstein addressed himself to the problem of providing us with an understanding of the relationship between these forces. His first attempt was published in 1929 as the unified field theory. Later he rejected this theory as inadequate, and in 1949, he conceived a new theory, which was far more ambitious in its scope. Unlike Newton's concept of gravity, Einstein's law of gravitation contains nothing about force. Einstein defined the movements of the stars and the planets through a gravitational field, and hence his laws describe the field properties of the space-time continuum.

These thoughts moved Squirer to write a parody on Pope's couplet, which goes:

It did not last. The Devil howling, "Ho,
Let Einstein be," restored the status quo.

This introduction is designed to acquaint you in a brief way with some of the physical properties of gravity, and to point out a background for our interest in the study of gravity, particularly at the single-cell level. I am a pathologist, as I pointed out before. Pathologists deal with that branch of medical science which involves the study of the patterns of the cellular reaction to disease. This is done classically through the light microscope, but has now been extended to the electron microscope in the study of ultrastructure. But I want to emphasize to you that this is not really a numbers game. There are no numbers involved in the tissue diagnosis of a malignant tumor. There are no numbers involved in the ultrastructural changes in the mitochondria in hyperthyroidism. Therefore, our beginning approach in this problem is not one of a numbers game. Rather it is a game of observation, to see what we can learn, under the restraints placed upon the experiment by the satellite, of the form and function of human cells as they exist in the environment of zero gravity.

I would like to begin by describing briefly for you the way in which the biosatellite experiment will work, because the biosatellite experiment is a little less complicated, although not less sophisticated in terms of instrumentation than is the Apollo experiment.

In this experiment we propose to take time-lapse motion picture photographs of the phase-contrast images of living human cells in the space capsule in a state of weightlessness for a period of 21 days. Ordinarily, the equipment which we would use to take time-lapse motion pictures of the phase-contrast images of living cells weighs something like 25 pounds and occupies a space on the bench of perhaps 2 feet by 1 foot by 1 1/2 feet, and requires the constant attention of somebody to focus the microscope, adjust the light, pick out the cell field, feed the cells, and so forth. All of this to go into a biosatellite must be compressed so that in the space of a weight of 5.5 pounds (fig. 1), we have two time-lapse motion picture cameras, two microscopes, two chambers for holding the cells, and two media reservoirs which will automatically feed the cells on a predetermined schedule.

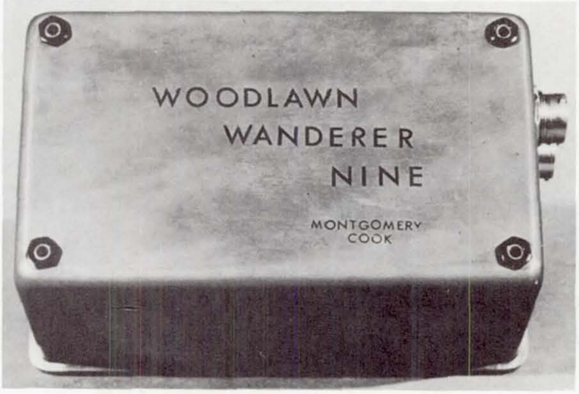

Figure 1. —The complete unit for the biosatellite experiment.

I would like mention why we elected to call this the Woodlawn Wanderer 9. It is named "Woodlawn" for the hospital in which our laboratory is located. It is named "Wanderer" for the fact that we expect it to wander around in space—and we hope come back. It is named "9" not for the fact that this is the 9th time we have tried this, because it is about the 199th time that we have tried it. It is named "9" because 9 is a very basic and mysterious number in human affairs in biology. For example, 9 is the human gestation period, and 9 is the length of the Venus cycle, which was known to the ancient Mayans, and is found in the numerology of all the Mayan temples. It is the number of heavens that there are in the Buddhist heaven, and if one goes to Bangkok, one will observe that there are 7 umbrellas for the king, but 9 for the Buddha, because no one can go higher than the Buddha.

Furthermore, 9 is also the basis of all biological movement systems; 9 little tubules in a circle, with a center exactly the size of the tubules, is the structure of the flagella.

It is also the numerologist's symbol for love, and we hope that with love and luck, this experiment will come back.

Figure 2 shows the inside of the capsule of Woodlawn Wanderer 9; there are two sets of film spools which represent two cameras, one above the other. There is a total of 100 feet of film, approximately 4000 frames, in the two cameras. Film will be pulled through each camera every day for a 90-minute period on a predetermined cycle; when the film is exactly in front of the gate, a light will be caused to flash, which will imprint the phase-contrast image of the cells in the culture on that particular frame. This will happen once every minute; 90 frames for 21 days for the two cameras ($90 \times 21 \times 2$) will just about use up the 4000 frames.

The two decks are two identical units, the one on top being identical to the one on the bottom. There are the two time-lapse motion picture cameras just described, two culture chambers, two microscopes, and two feeding chambers. All of these will be sealed in the cover in an atmosphere of 5 percent or 7 percent CO_2 in air; this atmosphere was chosen because it is approximately the mixture of gases which surround human cells and is the optimal mixture of gases for growing human tissue cultures.

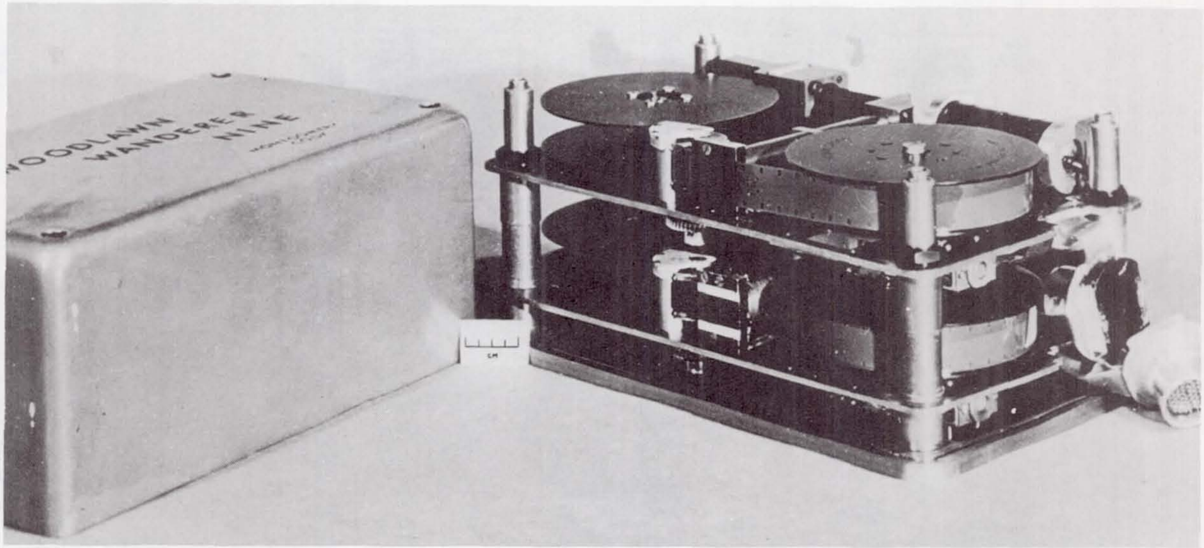

Figure 2. —The unit with cover removed showing the two identical units.

Figure 3 is a top view of the units showing the two film chambers of the one camera; the tissue culture chamber in which the cells will be maintained, and the condenser of the microscope. The optical system is the Cook-MacArthur miniaturized phase-contrast microscope designed by Dr. MacArthur in England. An image of the cells is projected against a mirror, which projects that image directly onto the film frame, as the film moves slowly through the gate. Once each minute at exactly the instant that one film frame is centered, a light will flash for a fraction of a millisecond, and that will in effect imprint a still image of the cells. When the film is returned, we will then have a 21-day record of the cells in time lapse.

The time-lapse feature is an extremely important part of studying living cells, and it has to be recognized that the microscope gives us resolution in space, but not necessarily resolution in time. Since all living things are related to resolution in time, it is extremely important to resolve events spatially as well as temporally.

Figure 4 shows another view, the tissue culture chamber. The feeding chamber has a piston in the center of it. The piston is backed up by a spring which is cocked into the position shown. It is then filled by means of a long, thin needle, and the excess fluid runs through the chamber all the way through the tissue culture chamber, and out the backside through another needle. One of the very difficult parts of this experiment, which was not at all obvious to us when we started, is the problem of filling this entire system without any bubbles. It is absolutely essential to have no bubbles in the system, because, if a bubble is pumped into the chamber, (1) the cells will die; and (2) the image will be an image of the bubble and not an image of the cells.

This is made even more complicated by the fact that in a state of weightlessness, there is no control over what will happen to this bubble. The bubble may float into any position which it sees fit, and, therefore, it is important to have a bubble-free system.

Figure 4 shows a gasket made of Silastic, a commonly used plastic for medical purposes which is known to be nontoxic to cells. It took us 6 months to find out that we were getting bubbles because the Silastic is porous to air. We filled the system up and left it for a day or two, and when everything was going along happily, we suddenly got bubbles in the chamber. The truth is that the bubbles were coming through the Silastic, so we had to change the

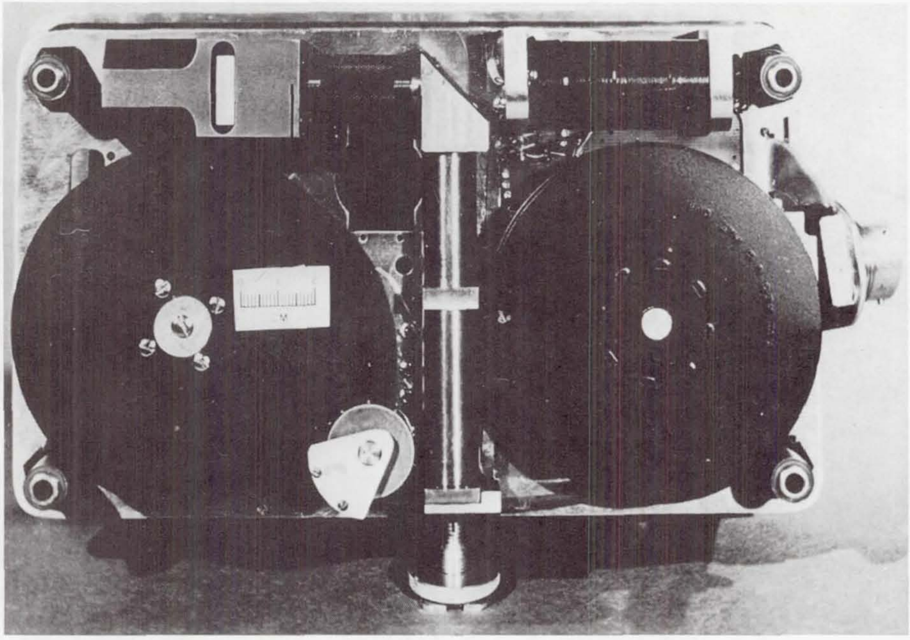

Figure 3. —Top view of the unit.

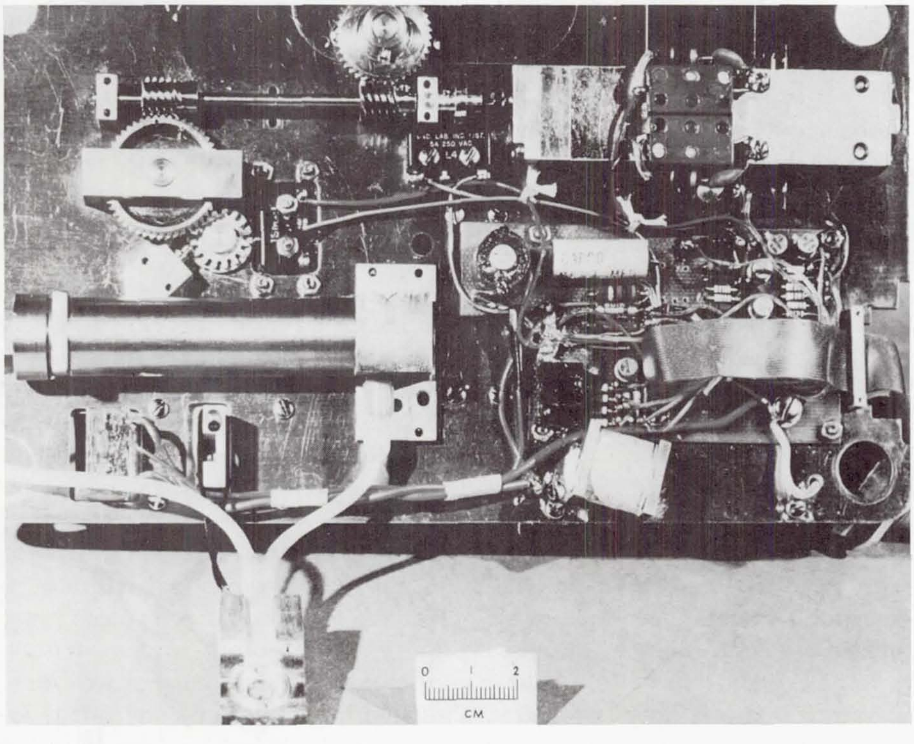

Figure 4. —View including the tissue culture chamber.

material we were making the gasket with, and now are making them out of a synthetic rubber, buta-nitrogen 19, which is also nontoxic.

Once the entire system is filled, the little chamber is filled with cells by inoculating them through a needle and allowing the excess fluid to come out through another needle. Every 24 hours the piston is caused to advance one notch, by means of a gear, and that is just enough liquid to replace all of the liquid in the tubing, and to feed the cells a fresh additional amount of medium.

We know that cells will live for 21 days in this environment if they are hand fed, and we hope that we are on the point of showing that they will live in this environment with the pump feeding them automatically at the present time.

The rest of the electronics, including a small motor, are necessary to control the activation of the gear mechanism, the flashing of the light, and the rotation of the film, and for the purpose of keeping the cells warm. Human cells, although they are somewhat poikilothermic, can live independent of their temperature environment, particularly if it goes down, but not if it goes up. We wish to have these cells maintained at body temperature, so that the rates of motion of the cell in such things as division—the rates at which the small droplets move in the cytoplasm that is an indication of the consistency of the cytoplasmic gel, and features of this kind—can be compared with known control information which we have accumulated over the past 10 or 15 years in our laboratories.

Figure 5 shows a mockup of the design of the experiment for Apollo. Before I leave the biosatellite, let me say that when the two cultures come down, we hope to fix one of these cultures for electron microscopy to study the ultrastructure of the cells after their 21-day flight. The other culture we hope to have loaded with a normal known strain of human diploid cells. This is the strain L lung cell which is known to be a diploid strain of cells, and upon this culture we hope to establish subcultures, and then do idiograms to determine whether or not there is any variation in the chromosome morphology or number.

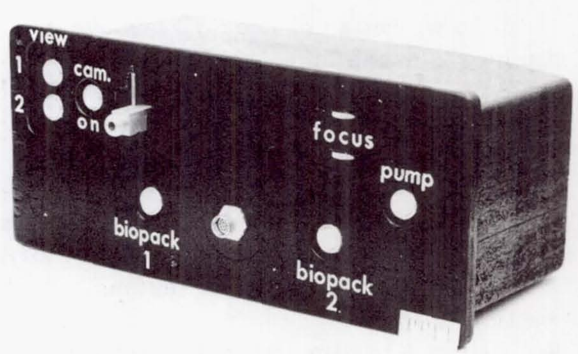

Figure 5. —Mockup of the unit for the Apollo experiment.

Now, in the manned satellite, we have the advantage of having the astronaut. In the biosatellite we must select a rather low magnification in the optics, because the optics must be locked into focus, and the depth of focus then becomes fairly critical. You can get away from the difficulty of depth of focus by not using too high a magnification, and therefore the vibration will not knock the system out of focus for you. However, in the manned satellite, we have the astronaut to look through the microscope, and therefore we can use a somewhat higher magnification, and in addition to this we can do a somewhat more sophisticated biological experiment.

Figure 5 shows the package for the manned satellite, which must weigh less than 13 pounds. It will be stowed under the seat of the astronaut on the right-hand side during takeoff and during reentry, but during flight it will be removed from this position, coated with this sticky tape, and set on a little table. The astronaut will then be asked to go through a daily series of observations on the cells.

This instrument, unlike the biosatellite instrument, will have two microscopes of different magnification. One will be of low power and the other of high power. Both will give phase-contrast images of the living cells in the cultures. The astronaut can use the eyepiece, and by punching the number one "view" button get a visual image of the cells under the microscope which he will then focus with the knob. The knob is designed so that there is no way he can break the microscope. It takes almost halfway through a residency in pathology after medical school to teach a medical student not to break slides, and we know very well that we do not have this much time to train an astronaut not to break a slide. So this is designed so that as he focuses down on the specimen, if he goes too far, the microscope simply travels back the other way. It is centered so that the gear ratio makes the focus come approximately in the middle of the screw, so that he can focus the microscope through the whole 14-day orbit and still not break our culture.

Then if he wishes to examine the other culture, to photograph it, he slides the eyepiece over. Then he pushes the number two "view" button, which turns the light on, and he focuses the microscope with the other knob.

The system is designed so that once he pushes a "view" button, the light will go on, but he has to hold the button in to make the light stay on. So he cannot push a "view" button, turn the light on, put the thing down, and ruin the photographs. It is also arranged so that if he pushes this button at a time when the camera happens to be photographing, the camera is shut off. Once he focuses both microscopes, he starts the camera by pushing the "camera-on" button. Once he pushes the button, the camera will automatically run at the rate of six frames a minute, rather than one frame a minute, and it will run for a predetermined length of time. This time, instead of having 100 feet of film, we have 200 feet of film, because we have more weight available to us. So when he pushes the button, the camera runs through one cycle. There is nothing he can do to stop the camera except to push the "view" button, and if he pushes that button and stops the camera, as soon as he lets it up, the camera will finish its cycle.

If he wishes to photograph two cycles, because he thinks, and we hope that we can teach him how to grasp this, that the observations which are presented to him visually are worth recording in more detail, he can push the "camera-on" button again and start the film cycle over. So, the astronaut has the ability to decide when to photograph and to decide whether to photograph one, two, or three times during a cycle.

The connecter pin supplies the 28-volt power to the pack from the spacecraft. The power is used for heating the cells, and on reentry for thermoelectric cooling of the cells, because the area in which they will be stored may reach a temperature as high as 160°.

There are two "biopack" buttons. Each button will cause one biopack to rotate one position.

Figure 6 is simply a side view to show the general configuration of the package.

Figure 7 shows the biopack when it is assembled. The biopack consists of two very carefully machined disks of epoxy. After we were sure that we had machined these disks so that they did not leak, and so that the cells would grow on this particular epoxy, somebody reminded us that we had better look to see if this epoxy was on the NASA-approved list of materials that could go into manned space flights. Sure enough, it turned out not to be. So now we have to select another epoxy, which we think we can do, and machine this in order to make the biopack.

The biopack consists of three chambers on each side, each chamber will be loaded with media, and then 2 or 3 days before the flight, filled with cells by injecting them through a Silastic gasket, which will enable the cells to have time in normal gravity to settle on the surface of a cover slip, and spread out as they ordinarily do. Then when the biopack rotates, the astronaut pushes the button, that rotates the biopack one position, so that each culture medium is moved to the next hole.

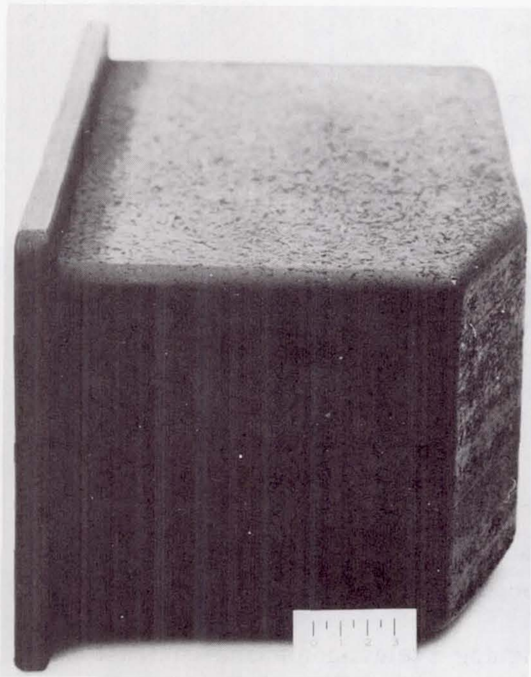

Figure 6. —Side view of mockup for the Apollo experiment.

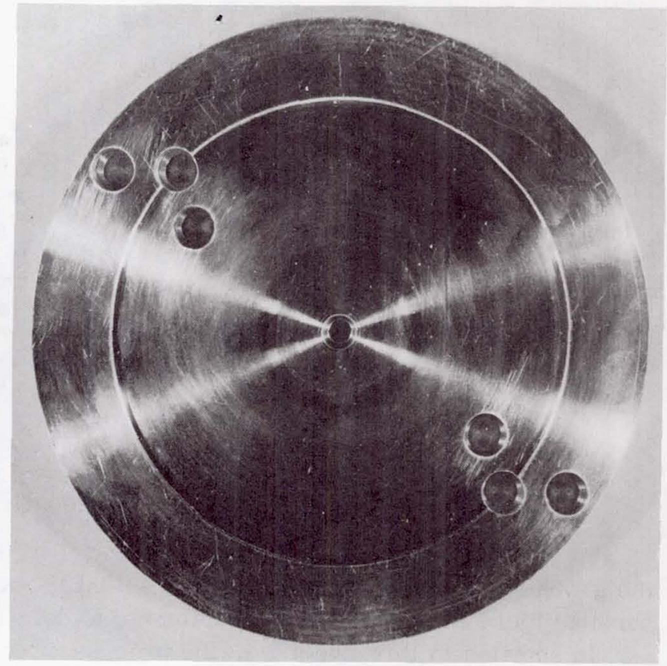

Figure 7. —The assembled biopack.

Figure 8 shows the disassembled biopack. There are a number of holes on the bottom disk through which the six holes which contain the cells will be rotated on the disk. This allows us to do some more difficult and sophisticated experiments. In the first place, we will have 4 such biopacks, which means that we will have 24 cultures of cells in addition to the 2 cultures which we are photographing, so that we can rotate these always in one direction, which gets us out of the problem of dragging, let us say, fixative into media, because the fixative will be the last thing in which the cells will be placed. So the disk is always going in one direction as far as the cells are concerned.

As the cells are rotated from disk to disk, if we wish, we can select to put one culture into fixative for electron microscopy, which would be glutaraldehyde. We can fill one well with tritiated thymidine, post-label the cells for 15 minutes, put the next one with some cold thymidine, rinse them—or chase them, as it is called—and then turn them into a fixative. Then when we get back, we can do radioautographs on these cells and study their uptake and distribution of thymidine and/or uridine or other radioactive materials which we might wish to select.

In addition to that, we have selected about six cytochemical procedures which can be employed on these cells, and the fixatives appropriate to those will be placed in the appropriate wells, so that at the time interval that the astronaut turns off the disk, the cells will be immersed in the proper fixative.

As I mentioned before, several of the cultures will be returned alive, both for the purpose of doing chromosome idiograms on them, and for the purpose of trying to use them to develop a strain which has been exposed to this environment, and study it further in our laboratories on the ground.

The control studies for these experiments will consist of using the identical equipment, by first passing it through the vibration profiles of flight, and performing the experiments on

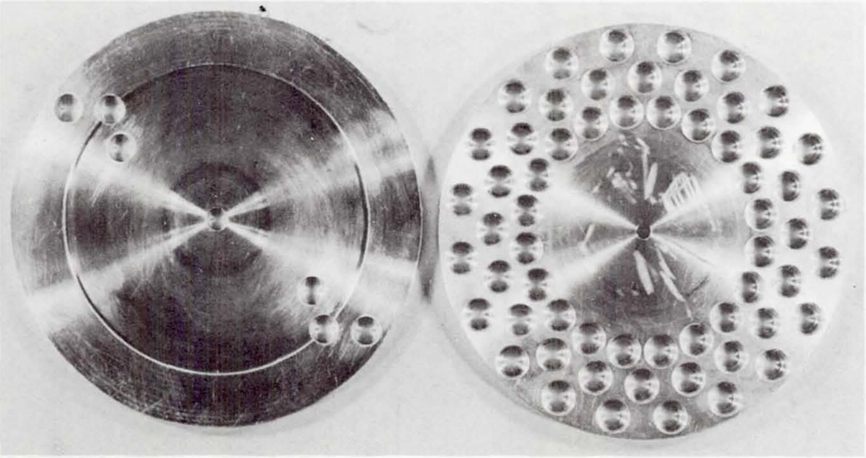

Figure 8. —The biopack disassembled.

the ground from now until the time the actual flight occurs, as well as after the flight occurs, because these are not simple experiments to do.

In addition to this, we are in the process of designing a television phase-contrast centrifuge microscope, which will allow us to observe cells for prolonged periods of time at anywhere up to 300 times gravity in the preliminary experiment. Most of the studies which have been done on cells and biological material in centrifuges has been devoted to the study of the viscosity of the cytoplasm and the density of the various particulate materials. The notable studies in this regard are those of Harvey and Loomis at Princeton, but they have not been devoted to the study of the influence of gravity on the growth, or of the form or the function of intact living cells, particularly as they are exposed to fairly low orders of gravity for relatively prolonged periods of time.

The Apollo flight will last for 14 days, if all goes as scheduled, and I would like to point out that this is a fairly short period of time as the history of biological things goes. It turns out that there are something like 10^{15} second of existence of the universe. Perhaps there has been living material here most of that time. But the numbers involved and the length of time to which living material has been exposed to the effects of gravity are very large numbers. I do not think that we should look for effects on single cells with very short periods of time. Nevertheless, I think the experiments are important to do. They teach us how to do experiments in the space biological environment. They set the stage for much more prolonged and extensive experiments in space biology, and I think that it is almost axiomatic that if human beings are affected by zero gravity, the effect is going to have to be a cellular effect. Therefore, it is of considerable importance to begin to study human cells in this environment, and to see what we can learn from the various possible experiments that are available to us with the restraints that are placed on doing an experiment in a spacecraft.

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3-B. DISCUSSION AND INTERPRETATION OF THE CHANGES PROVOKED BY ZERO GRAVITY ON THE OTOLITH UNIT OF FROGS

T. GUALTIEROTTI
Senior Research Associate, Neurobiology Branch,
Environmental Biology Division, Ames Research Center

GERATHEWOHL: The next speaker is Dr. T. Gualtierotti, who is a professor at the Medical School at the University of Milan, Italy. He has been affiliated with Dr. Margaria, who is the head of the neurophysiology department there. Dr. Gualtierotti has been instrumental in experiments on aviation and space medicine for quite a while. I knew his name from the literature before we met, after he came to this country. Every time I have to introduce him, I do not know what more I should say in order to tell about his competence and his qualifications. I would like to point out, however, that he is going to report an experiment which is also unique. Dr. Montgomery's experiment is unique, insofar as the Russians have not attempted a microscopic experiment in a satellite. This is one where we are going to have a first in the biological sciences.

The Russians also have not attempted as yet to do an experiment of the caliber that Dr. Gualtierotti is going to do; namely, record action potentials from the vestibular nerve of a living being. Dr. Gualtierotti has studied with Adrian in England, and he has been instrumental in some of the vestibular experiments that Adrian has been doing, and he has developed ultramicroelectrodes for actual insertion in single vestibular nerve cells to record action potentials.

Now, I do not have to point out that the vestibular organ as one of the gravity receptors has been thought to be instrumental in orientation in space, also, of course, for orientation under nongravity or weightless conditions. Dr. Gualtierotti is really the first one to prepare an experiment of this sort to be conducted in an Apollo spacecraft. He is at the present time senior research scientist at the Ames Research Center, where he is particularly involved in preparing this type of research.

GUALTIEROTTI: I would like first of all to thank you, Dr. Montgomery, because you spared me the necessity of speaking further about the importance of gravity. I do not think anyone can add anything, either historically or physically, to the particular problem.

I would like to thank Dr. Gerathewohl, because he spared me the necessity of defending the experiment so far as importance is concerned.

I would like to add only one point: that it is obvious that as soon as we left gravity, or we left weight, the otolith part of the inner ear, which is directly concerned in measuring gravity, is the obvious organ which has to be studied first. It is like trying to study a completely dark environment and forgetting about the eye. So I do not think it was a very brilliant idea to start with that.

Now, I would like to make some comments about the stages and the problems that such an experiment had. The first very difficult problem was technical. Whoever is accustomed to working with microelectrodes, and recording from single fibers or single cells in a living human being, and especially in an unanesthetized living being, knows that it is very difficult. It is very difficult even when you deal with perfect laboratory conditions in a shielded room with a perfectly nonvibratory support, and so forth. So we had to revise our technique to be able to record from single units after the vibration and high acceleration of the takeoff, and we had to find a way of maintaining the recording for a long time. We are planning to record for 3 days, which is also a major achievement. I do not think that anyone up to now has ever been able to record from a single unit more than 6 or 7 hours, or 10 hours at the most.

I have reported on this technique several times in the literature, so I would like only to make a very brief visual summary of how it works.

The main point is the electrodes we used (fig. 1). They are ordinary tungsten micro-electrodes, with a tip about or below 1 micron used according to the usual technique. It is fixed by a screw to a piece of polyethylene tubing, which contains enough air to assure buoyancy, and to bring the entire system to the same density as the nerve tissue. This is the main point, that it has the same density as the nerve tissue and the environment. It will not be displaced by vibration or acceleration. It has exactly the same density; even at very high acceleration on the order of 100 G or 1000 G, it will not move. But we have proximity enough to stand up to 14 G in acceleration, and up to about 8 G vibratory acceleration.

Another point is that it is counterbalanced by a weight which brings the center of gravity in the center of the mass, so that it does not have any torque or momentum during vibration.

Another problem was that the electrode has to be floating. If it is attached to something, it will start vibrating or the structure underneath will move out from it, so it has to be floating, and the point was how do we place and leave the electrode in place after it has been

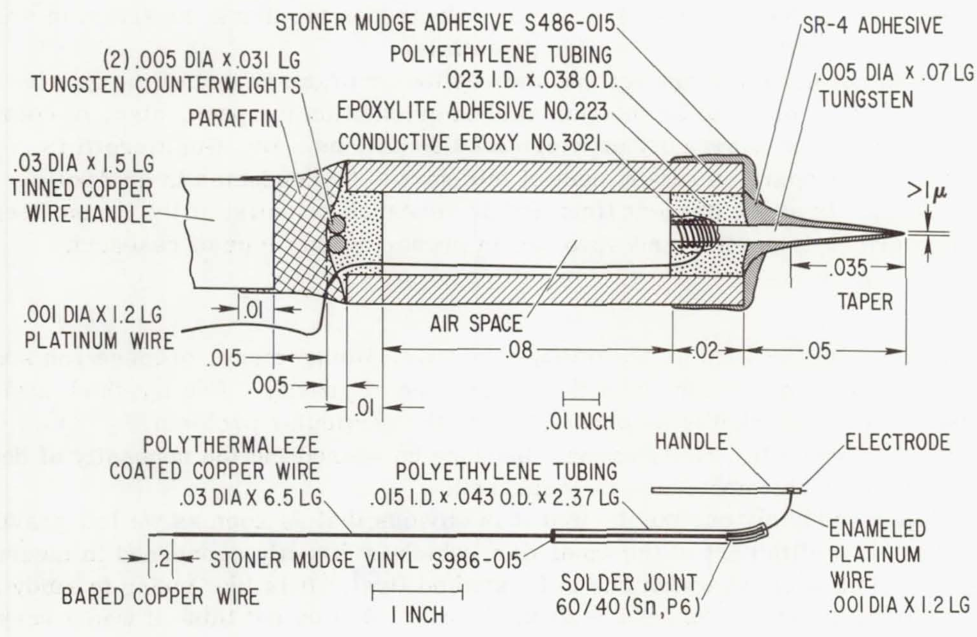

Figure 1. —Schematic of the electrode having the following characteristics: (1) same density as environment; (2) no vibration, the electrode being short and floating; (3) release from holder without displacement through dissolving the connecting paraffin drop.

stereotactically planted. How do we detach it from the stereotactic apparatus without moving it? We tried all kinds of different techniques, and finally found there was a very simple way. The main electrode is attached to the handle by a very small amount of paraffin. So when it is fixed in place, we just warm up the handle with a coil, without touching it, and the paraffin will dissolve, and the electrode will stay there without being displaced.

The electrical potential through the electrode is recorded through a very thin wire (about 1 mil) enameled platinum wire. It does not exert any practical pull or restraint on the electrode. So when the wire is in place, the electrode is completely floating in an environment of the same density.

Figure 2 gives an idea of the dimension of the electrode. We have to say also that there was another difficulty which I did not mention before when I made the previous presentation, but it is very important. The real reason why we could not get a long recording from a single unit, aside from injury or mechanical lesions, is that the actual current density on the tip of the electrode is very high, even with a very-low-current input in the high-input preamplifier that we use. For instance, we found out that a current of less than 10^{-13} ampere was enough to spoil our substrate after about 48 hours. So, of course, in a completely automated environment, we cannot adjust it as it is normally done in acute experimentation in the laboratory. We have to rely on something that has current just low enough to avoid this kind of destruction by current flow.

So we developed a solid-state preamplifier which has an input impedance of about 1000 megohms and has a current near to 10^{-15} ampere. Even in this case, the average duration of a preparation is about 3 or 4 days.

Figure 3 is the vestibular nerve of a frog; and it is very easy to get to it in the frog. We used the frog because it can stay in water, and immersion in water further damped vibration and helped the electrode to stay in place. It is very easy to reach the vestibular nerve, and we implant the electrode in the vestibular nerve to record single fiber activity.

Then we attach the frog to a tilting table (fig. 4), for otolith response, namely, response to tilting, to be sure that we are dealing with gravity receptors, gravity sensors. The gravity receptors in the otolith are divided into two groups. One group is more responsive to transient acceleration, and the other is sensitive to steady-state acceleration; namely, to the

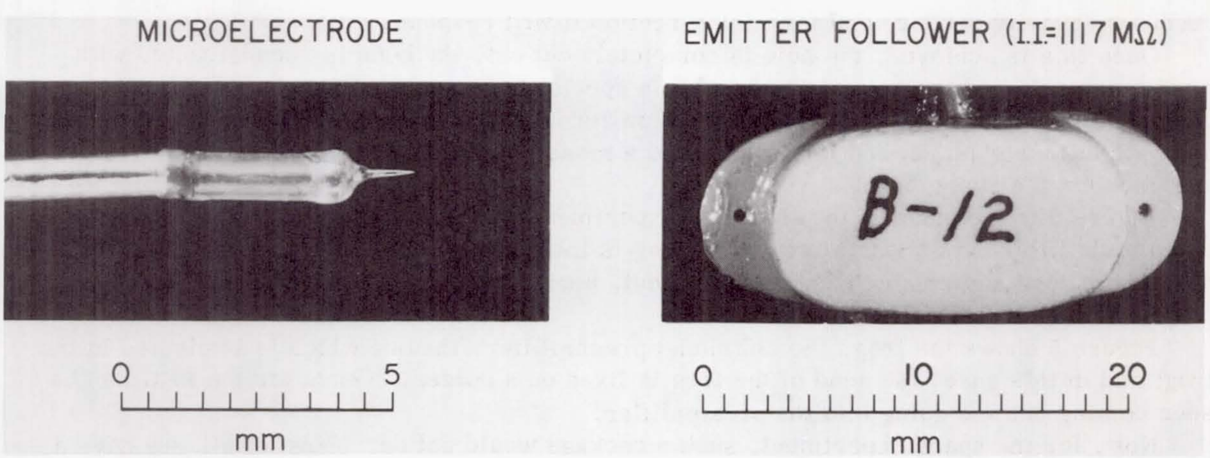

Figure 2. —The electrode and emitter-follower with the dimensions shown. The electrode is implanted stereotaxically in the vestibular nerve and tested for otolith-type response on a tilting and rotating table instrumented with three-directional accelerometers.

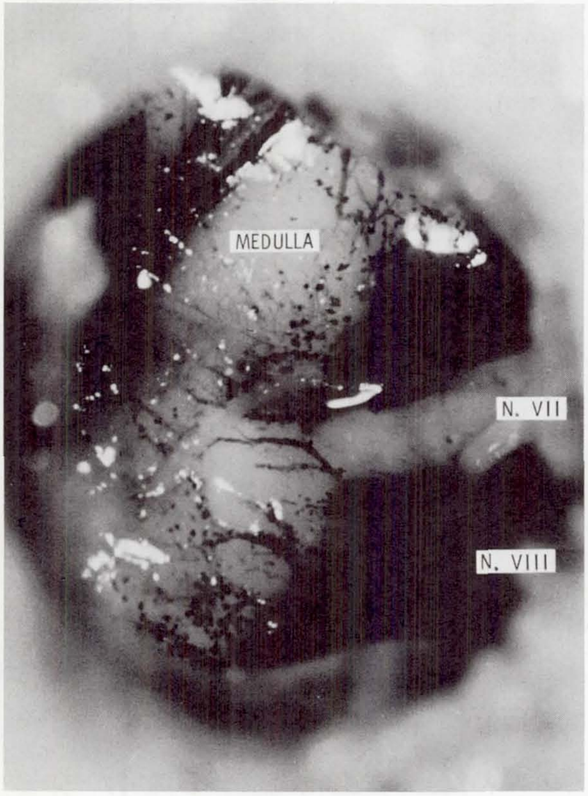

Figure 3. —Surgical preparation of the vestibular nerve in the frog.

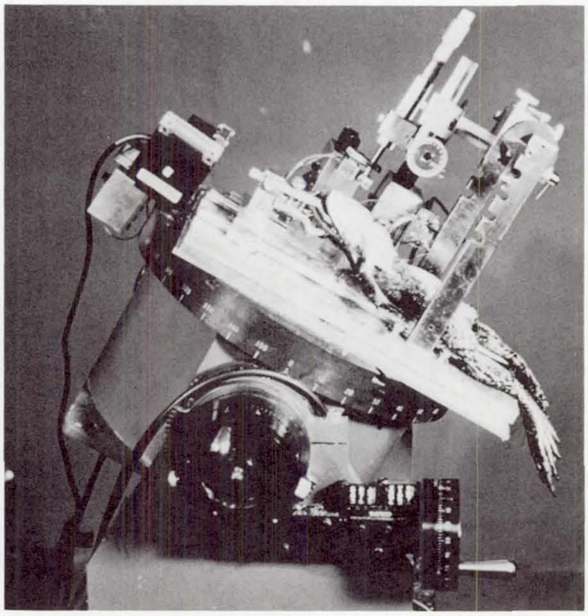

Figure 4. —The tilting table. Agar is poured in the hole, the microelectrode is released, the bone is reconstructed with dental cement, and wiring is connected to the emitter-follower fixed to the frog's jaw. The frog is then placed in a life-support system. The frog shown in figure 5, more simplified, was used for plane parabolic flight experiments.

gravity vector. So, I have been working mainly with these last ones. We will see an example of the two later on. In this way we can find out if we are dealing with an otolith gravity receptor, gravity sensor, and in which direction it will respond.

Once this is achieved, the hole is completely cut out, the bone is reconstructed with tensile cement, and the animal is placed in a special life-supporting system. Now, I have performed already a series of experiments on zero gravity or weightlessness during parabolic flight in a jet plane; and for that we had a more simple life-supporting system than the one used for the space flight.

Figure 5 is the package for the flight experiment, and for the experiment in aircraft it is completely filled with water in which the frog is immersed. We just supplied oxygen, flowing oxygen, without any means to take the CO_2 out, because the duration of the experiment was only about 2 or 3 hours.

Figure 5 shows the frog, the old model preamplifier, the one which is implanted in the frog; and in this case, the head of the frog is fixed on a holder. Leads for the EKG can be seen coming out and going into the preamplifier.

Now, for the space experiment, such a package would not do. First of all, we have a piggyback experiment and we are practically dealing with vacuum conditions. So we had to build a real life-supporting system more like a small satellite.

Then we find out that for the high acceleration and wide vibration range that we have on the liftoff, the fact that the head was fixed in a holder, fixed on the metal part of the life-supporting system, was not good enough. Then, the frog has to be really floating, although any angular displacement had to be avoided.

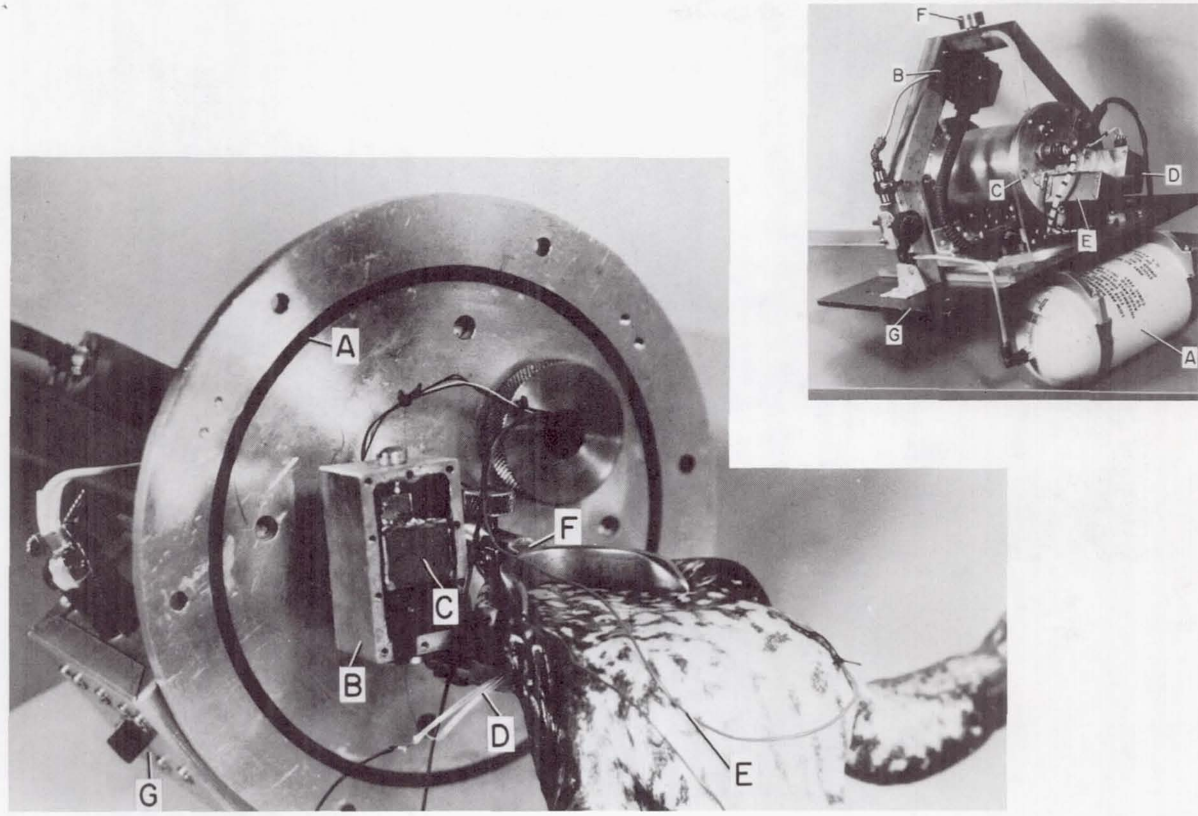

Figure 5. —Frog life-support system. For the experiment now in preparation, involving 3 days of space flight, a more elaborate package has been studied. Its main features are shown in figures 6-9.

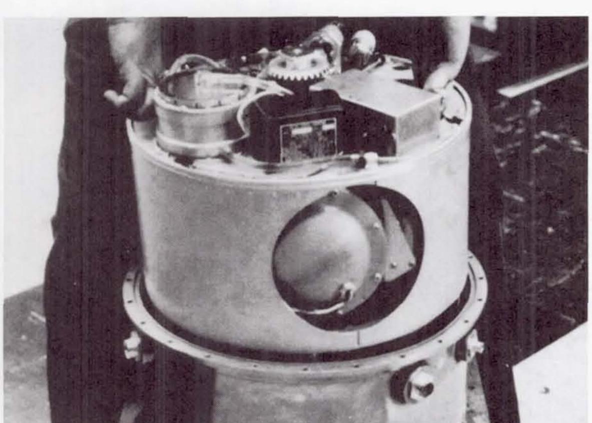

Figure 6. —Orbital otolith experiment package.

The package in figure 6 has been built by the Applied Physics Laboratory at Johns Hopkins University, and we have already completed the engineering model which is now undergoing tests.

Figure 6 is the outside or the outline of the engineering model. It weighed 86 pounds, and it is completely covered and self-contained.

We developed also a tester (fig. 7) for checking all of the parameters of this life-supporting system while it is already placed in the spacecraft. So with this, we can check one by one all of the different systems that will be illustrated later.

Figure 8 is the main schematic of the life-supporting system. We are planning to study not only the effect of weightlessness by itself on the spontaneous activity of the single unit of the otolith organ, but

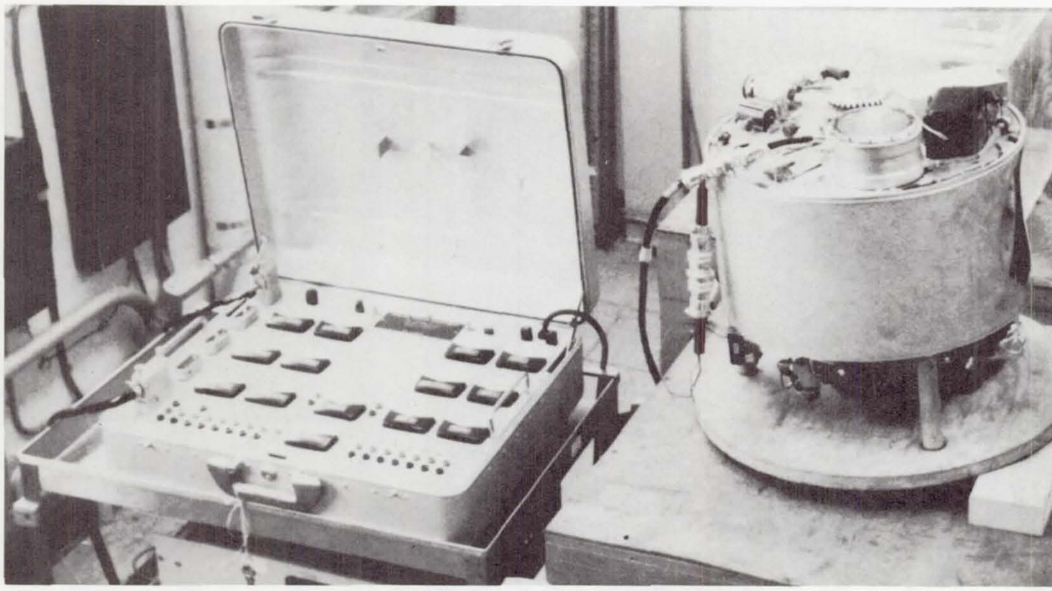

Figure 7.—Portable tester (left) and life-support system (right).

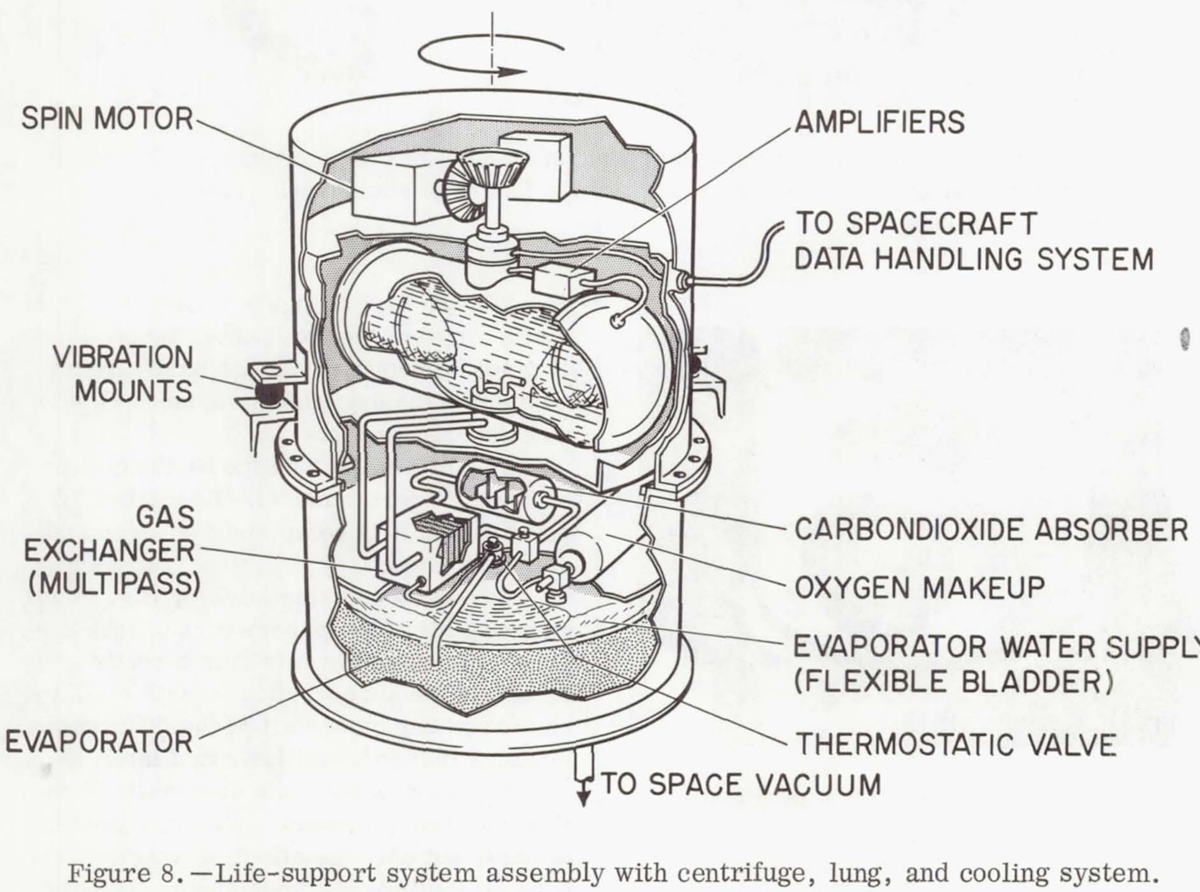

Figure 8.—Life-support system assembly with centrifuge, lung, and cooling system.

also how it responds to acceleration, both in the weightless state and as a result of the high acceleration during takeoff, and whatever further acceleration and vibration would be applied during maneuvers in orbit.

Therefore the package has a centrifuge-like device which is operated by the mechanism which allows a maximum acceleration of about 0.5 G, which is, for a single unit, just outside the maximum range. The content is shown in figure 9. It is filled with water, and a net sac which will contain two frogs. The electronics, the support for the main amplifier, is also shown in figure 9.

The water is kept oxygenated by means of an artificial lung which has been developed by GE. It consists of a very large number of very thin layers of silicon rubber which is permeable, selectively to CO_2 especially, and to O_2, and it is a very good device. It absorbs oxygen from the air phase, the gas phase, and takes CO_2 out of the water phase. It was tested a number of times, and it seems to work very well.

The water is pumped through the system, and then the CO_2 is absorbed by the CO_2 absorber, and then is sent again into the chamber.

Temperature control was very important, not so much for survival, but to keep the response steady. A frog can survive at a proper partial pressure of oxygen at a temperature between 50° and 100° F. Since the frog is sensitive to temperature and acquires the same temperature as the environment, we get a change in the response of the nerve, or any mechanism in the body, as a function of the temperature. To keep the response steady, we had to keep the system at a fixed temperature, with a maximum range of plus or minus 3° or 4° F.

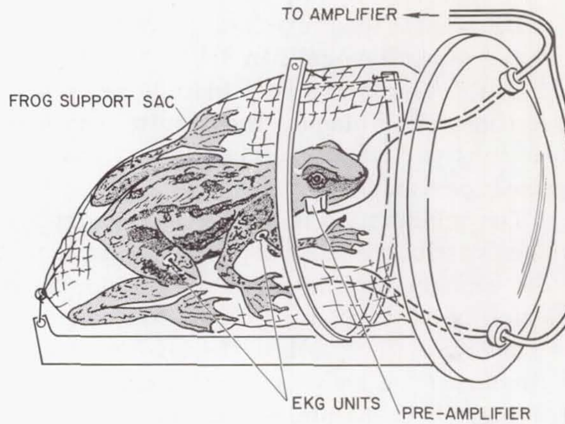

Figure 9. —Frog in net in proper position inside centrifuge.

We found that the main problem was not so much the heating, but the cooling. So we have a cooling device which works on evaporation, with a store of water which is evaporated in vacuum. We had quite a problem before we developed the chamber, because in vacuum the water tended to become ice and clog the output. So now we have a chamber which assures pressure a little higher than the vacuum, the outside one, and then the vapor is discharged.

The entire device is mounted on shock mountings because there is a critical range in vibration between 250 and 400 per second, which probably is the resonance frequency of the electrode, which has to be avoided. So the shock mount is not there to absorb the acceleration as such, but to absorb that particular range of vibratory acceleration.

Figure 9 shows how the frog is placed in the container, floating completely free. The net is shown for illustration purposes only, but it is really all around the frog, and is attached at several points, so that it can move sideways, and it is fixed on the frog, too. The frog is eventually likely to rotate on his own axis, which does not matter much, because the otolith units are responding only to acceleration in this direction, and rotation would not change things much, but even that we tried to avoid as much as possible.

Figure 9 also shows the preamplifier, the input stage, fixed directly on the jaw of the frog, and on both sides we are planning to implant two microelectrodes each in one nerve, for each frog, so we will have four units just for safety purposes, and possibly for comparison, if we are lucky enough to have all four working.

The electrodes go to the main amplifier, and we have EKG leads for the control.

This solved nearly all of our technical problems, but we still had more problems. First of all, the physiology of the labyrinth is not very well known. This means we had to do basic biological work to find out what we have to look for as the response of the unit. By the way, I want to mention the fact that we had to deal with a single unit because it allowed us to play with numbers. I believe in numbers. So we can really elaborate the response as an equational function, or something like that, because in dealing with a single unit, we are really having a numerical output.

But what is the important, significant information of this output is still under discussion, so we have worked more than 400 of these units to find out just that.

I will summarize very briefly the basework under laboratory conditions, and then if we have time, I can discuss the results obtained during 25 plane flights, each of which had several 25-second periods of weightlessness, and see how they compare as baseline work for the space experiment.

The information in figure 10 has already been shown a number of times. It shows a typical vestibular unit response. This is what happens when the vestibular unit is not stimulated, namely, in a horizontal position, as far as the unit is concerned. Now, the horizontal position is only as far as the unit is concerned. The animal may not be horizontal at all, but the important thing is how the functional axis of the unit is directed. But as far as this unit is concerned, it shows continual activity, and then during tilting, there is an increased rate of firing. It is maintained for a certain period of time, although we do have some accommodation here.

There are two problems. First, as several other people have reported, in unrestrained, waking animals, as in this case, even in the vestibular nuclei, the discharge is very irregular. There is a certain irregularity. Therefore, the basic theory that the information may be some sort of frequency modulation system, or something like that, is really under discussion.

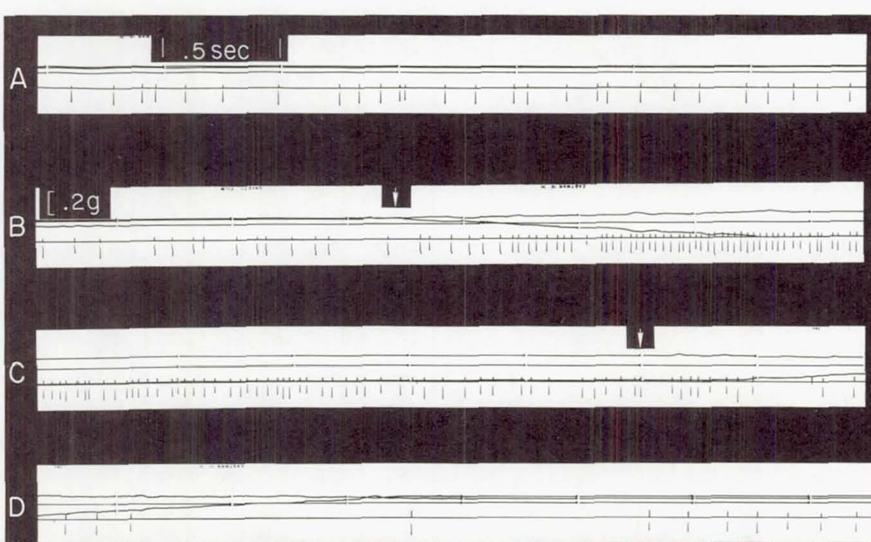

Figure 10.—Typical otolith response to tilting. Relevant information is time interval between consecutive pulses. Test of microelectrode stability indicates that preparation can be subjected to experimental routine shocks (plane flight or space flight).

By the way, the significant information in figure 10 is the interval between the different pulses. The pulses are all exactly the same in the same unit. So amplitude or duration of a pulse does not mean anything. The information is certainly provided by the time interval, by the duration of the interval between one pulse and the following one. Now, when these are as irregular as that, there is quite a problem, although it is obviously the kind of response that occurs.

Another problem is this. In this particular setup, we have quite a basic noise, which is provoked partially by the high impedance of contact, and partially by the fact that the electrode has a minute point. So the amplitude of the spike is not a good way to determine whether we are dealing with single units or more.

Another problem develops during a plane experiment. For instance, the entire half-hour flight would correspond to some 250 000 intervals, and 250 000 spikes, and I cannot go around looking for amplitude in each one of those, because I would still be here 10 years from now. But as I say, the amplitude is not a good index in this particular case, so we worked out a computer program.

Figure 11 is a vibration test, in an otolith unit. The vibration in this particular case is about 70 per second. We went all the way from 2 per second to 600 per second. But we did not have a shaker that could go high enough so that we could explore all of the vibration frequencies. But even at 4.5 G, in this particular case, we were actually able to record without too much noise and interference. At this high vibration level, even at this high frequency, this is valuable physiological information. We get a high response, and the unit is nearly sideways, although normally otolith units do not respond to vibration. But when you reach a particular high intensity of stimulation, you get quite a discharge from the unit.

After that we tested it again for 2 days, for normal response, and there was no alteration in the response as an aftereffect of this high-G vibration. To solve the first point, a histogram is made of a large number of events.

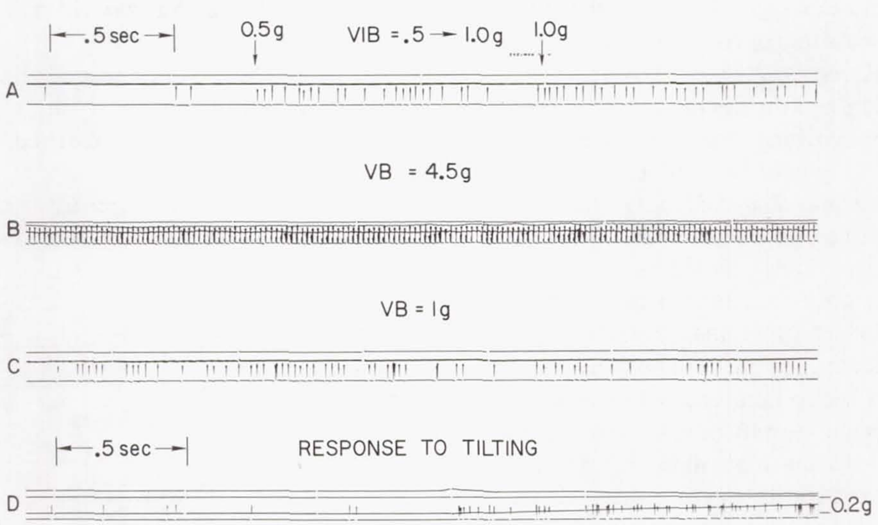

Figure 11.—Vibration tests. (1) It is not possible to use all the spike amplitude to determine whether a single unit is involved, owing to base noise artifact. (2) If a single unit is involved, discharge rate is very irregular. Sensory information cannot be conveyed through a pulse-interval modulation mechanism.

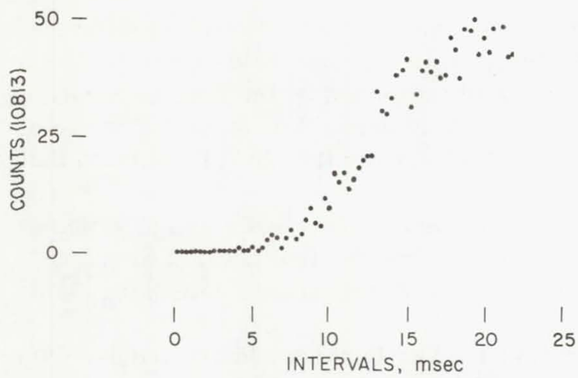

Figure 12.—If minimum interval is observed, a single unit is involved; even two units would cover all intervals from synchronization on.

The second point is a well-known factor in vestibular response. In alert animals, Bizzi, Pompeiano, et al. (Science, 145, 1964, 414-415), recording from the Deiters nuclei in the unrestrained, unanesthetized cat, found that the units discharged irregularly. Computer analysis of response confirms this fact. On the centrifuge, we have something similar. Up to 10 G there is a fully separated response.

Now, how do we know this is a single unit and not a number of units, two, three, or more?

Figure 12 provides data on a very short time base for nearly 11 000 intervals. We worked all the way in the entire experiment in sections. In this way the intervals were classified in groups, by their value, and the onset of the histogram itself can be seen. If we had any minimum interval with such a high count, we were sure that we were dealing with one single unit. Also, if you have two units, the data would go all the way in a large enough number of times from complete synchronization to complete asynchronization. So it was possible to run the 200 000 intervals of the entire series, and find out that we were dealing with a single unit.

If we see some noise here, we discard that part of the record which shows that there is either noise or an additional unit coming in. For instance, in this case, this particular count, which corresponds to about three parabolic paths, shows that we did not have any second unit coming in or noise coming in.

This, of course, is due to the refractory period or to the time constant of the single unit. A single unit needs a certain time to recover before it is ready to fire again, and therefore this is the equivalent time. It is about 5, 6, 7—it varies from 5 to 12 milliseconds which, of course, corresponds to what is known on the time base of the unit.

Next, we measured directly the intervals and the acceleration. The intervals in figure 13 are measured as consecutive intervals, as the distance between the zero baseline, and each one of the dots. So there is the same scattering of data that is shown in the records, and this is increased activity during the acceleration. What happens mainly is that there is more concentration of data and all of the longer intervals are eliminated. There is the maximum interval. The maximum duration interval comes down to this level, while during spontaneous activity it goes up to this level. You can see some accommodation; namely, at the steady-state acceleration for this particular unit, it tends to increase its frequency. This is accommodation only. It is slowly accommodating, not as fast as this, but it shows accommodation. Then when you go back, you obtain the same scattering.

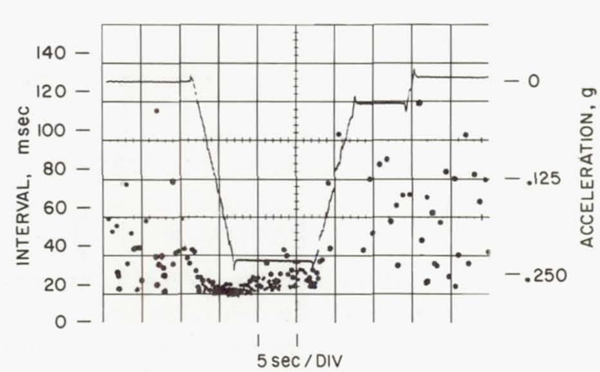

Figure 13.—Acceleration and time interval as function of time in a relatively fast accommodating otolith.

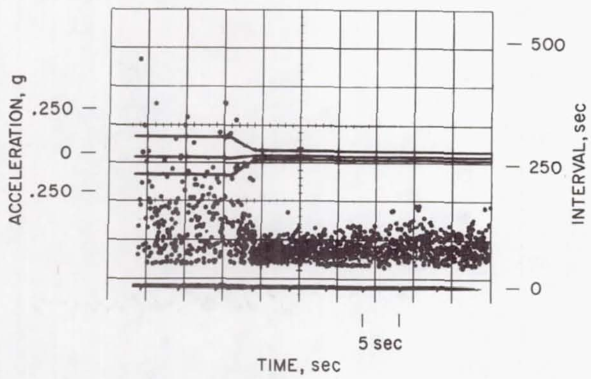

Figure 14. —Acceleration and time interval as a function of time in nonaccommodating otoliths.

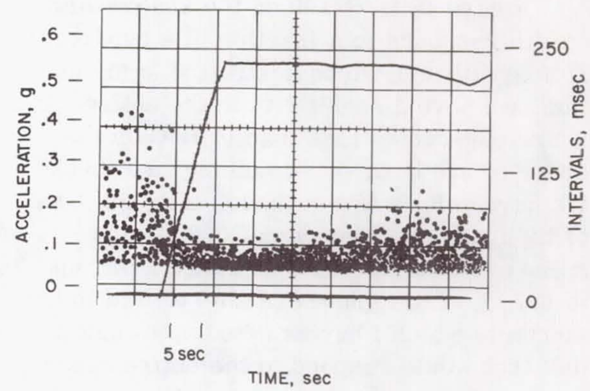

Figure 15. —Nonaccommodating otolith function sensitive to slight changes of acceleration.

Figure 14 shows three examples of a nonaccommodating unit, a unit that really responded. The unit in figure 14 responded to tilting in a direction which is midway between the two accelerometers. That is why there are two accelerometer changes, with a frequency of 5-second intervals. The frequencies tend to remain the same, or the change tends to remain the same all through the steady acceleration or gravity component that is supplied.

Figure 15 is a response to a different action of tilting with the same effect. It is sensitive. As soon as the acceleration changes slightly, immediately there is a corresponding variation in the character of the response.

UNIDENTIFIED: Is that interval plotted on your ordinate, as well as acceleration?

GUALTIEROTTI: Yes. Acceleration is here, and this is intervals. So this would respond to this curve, and this would correspond to this, to the intervals.

I think it is clear enough. Each one of the intervals corresponds to the distance from the baseline to each dot. We are dealing with a single unit, just by looking at this, because there is no firing below the line. When you have more than one unit, you have all sorts of intermediate intervals; except this is a limited number of intervals, even though there are quite a few.

At this point we can plot directly on the interval the changes provoked by the acceleration.

Figure 16 shows the relation between acceleration and interval. This is the range of spontaneous firing, and this is how it goes down during increased acceleration, until it reaches saturation roughly at this point. So this unit, for instance, has a range from zero to about 0.1, 0.15 G.

If we take the envelope of the two-dimensional figure, and we plot the curve, we have a nearly perfect biorhythmic relationship; namely, as far as the range is concerned, this unit seems to respond to this decrease of acceleration; i.e., it is in proportion to the amount of the stimulus. So it seems that the relevant information is more statistical than just based on a possible duration. Our theory now is that this unit works on a statistical basis by changing the range of the intervals that are present in the activity.

Now I would like to show that there are otoliths of different ranges. This one, for instance, I would say it is about 0.15 G. There are some units that are extremely sensitive.

Figure 17 is G/100 on the scale—this otolith responds to a fraction of a hundredth of a G; although we have still the same function, we have a sensitivity in the entire range covered by less than 0.01 G on the order of 0.005 G, or something like that. We have quite a few of those, although most of them are on the order of 0.2 G, and some are of a little longer range going up to 0.7 G. I have not been able to find in the 400 units which I have studied up to now a unit that would respond to the entire range from zero to 1 G, although there are some units which we have seen during the plane flight where they have responded above 1 G, from 1 G to 1.2, or 1.2 to 1.4. This sounds strange, but is probably not so strange because, after all, sometimes the impact of landing after a flight would cause it.

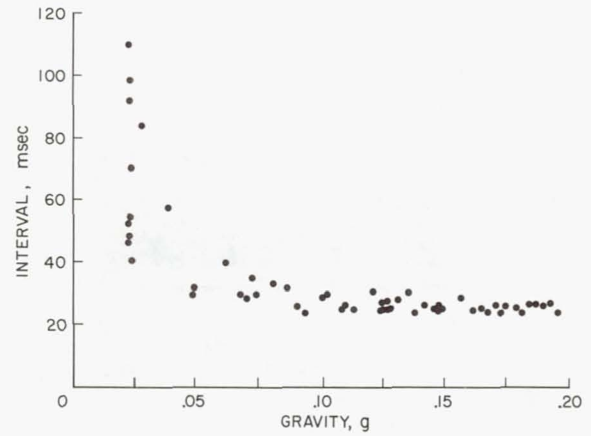

Figure 16. —Time interval as a function of acceleration in an otolith of average sensitivity indicates logarithmic function.

So this is the basic work that has been done for finding out how to treat the data, and what is the basic information.

All of this has been made for transients or change in acceleration. We did similar work for steady-state acceleration. Figure 18 shows this.

During steady-state acceleration, there is a steady change, an alteration that remains at the different levels of excitation. To study that, we make histograms of a sufficiently large number of data at each different level of excitation. For instance, figure 18 shows the accelerometer output, the main change in this one. Figure 19 shows the histograms during no excitation, with a very large pattern. There is also an intermediate value of excitation, and a maximum or supramaximum value of excitation.

Now, there are two main changes. First of all, the tail of the curve disappears. There are no intervals above this point. Included are interval duration, interval time, and the number of events. I have chosen roughly the same number so that we can compare it directly with the histograms. The change at steady state is a change in the tails; namely, the longer

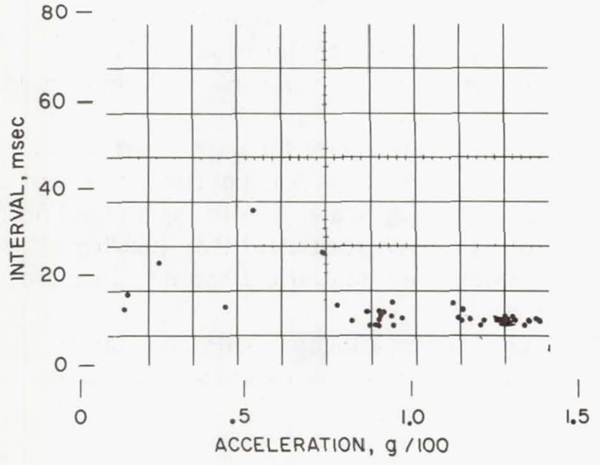

Figure 17. —Time interval as a function of acceleration in an ultrasensitive otolith. Given marked irregularity, the response consists of a progressive elimination of the longer intervals. The envelope in figure 16 and this graph indicates a logarithmic response to stimulus. Function according to the Weber-Fechner law. The otoliths which show nearly no accommodation are to be considered true gravitoceptors, namely, they respond to steady-state acceleration. For study purposes, histograms at different levels of excitation may be used.

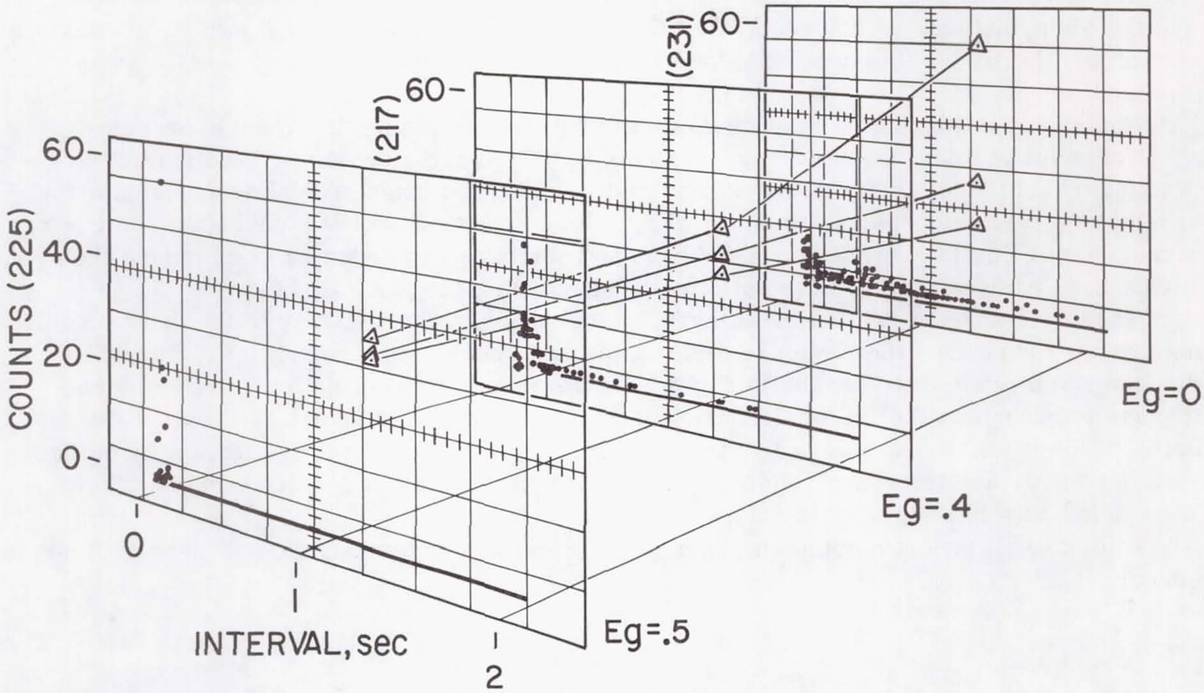

Figure 18. —Accelerometer output at steady-state acceleration. The results shown permit a discussion about which is the information as far as the centers are concerned.

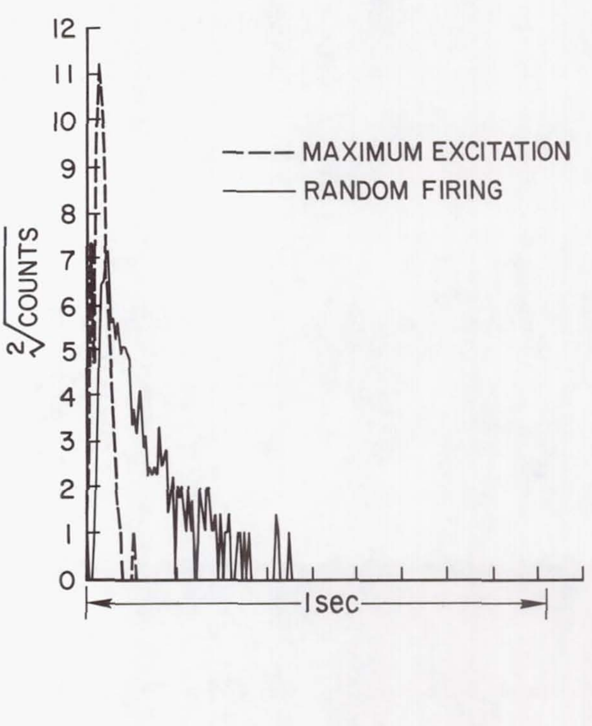

Figure 19. —Two extremes of steady state: no excitation (spontaneous firing) and maximum excitation. Two characters only have evidently changed significantly, as can be seen from the shortening of the tails and the concentration of data, indicating that the organ seems to work in a statistical fashion.

interval disappears. Second, we have a high concentration later. In this case, for instance, most of the data, nearly 60 percent, or more than 55 percent of the data, are at this particular value, whereas in this case, for the same number of counts, you have a more even distribution.

Now, we are working on what kind of distribution it is. We still do not know yet.

The point is this: I wanted to go into detail at this particular point, because that is really the basic study that was necessary for preparing the space experiment. So now we have developed the technique, we know what to look for, we are still studying on some particular points of this interpretation, and I have no time to tell you what happens during the plane flight, but I can say that we have definite changes during the plane flight.

There are at least two major changes. First of all, the sensitivity of the same unit is higher. We compared the response to the same test acceleration during level flight as we did immediately after the parabolic flight. We have some sort of inhibitory effect during 0 G that lasts throughout the 0 G period. Of course, we have to distinguish two main different units. The one that responds at 90° from gravity, which is not directly affected from the lack of weight, and the other which, on the contrary, responds in the direction of gravity. We studied both in a significant manner.

I think I will report a complete discussion of this at the seminar we will have at Ames in January.

DISCUSSION

GERATHEWOHL: Are there any questions in conjunction with the Gemini bioscience experiments?

LEVIN: In the experiment in which the bacteria or other life forms were exposed to the space environment to check survival, and so forth, what measures were taken to prevent these organisms from escaping into space? How could you expose them to space without risking contamination?

GERATHEWOHL: I am sorry I cannot answer this question, because I am not familiar with Dr. Hemenway's technique. The only thing that I can say is that Dr. Hemenway has already done similar experiments in conjunction with the Air Force program on high-altitude rockets, and he has published some of his results. I think, in his publication, he describes his technique, and this would answer your question. I do not know how he puts them in any kind of box and prevents them from escaping other than by either embedding them in a certain type of medium which carries them, or by putting something on top of it, perhaps Plexiglas. As a matter of fact, Dr. Hemenway and his associate who does the biological experiment have already published the results; and they found there were some micro-organisms which they had exposed which survived. Just to review his results very briefly, there were very few specimens of the micro-organisms or spores which survived. That is one result. The second is the most deadly means for killing any life under these conditions is ultraviolet light. They found this in the laboratory and also again under the conditions of space. I think you can find this in Dr. Hemenway's publication.

MARTON: Dr. Montgomery, I understand that the primary thing you are looking at is the effect of weightlessness on human cells' response, and if I understand the Apollo mission correctly, there will be extensive navigational midcourse correction as well as thrusting from the circumlunar to the other orbit, as well as the acceleration for rendezvous, and the accelerations for the three men moving around in their cabin, and this would probably create G-vectors that are not only of significant value, but of perhaps significant duration, so I wonder if you are taking any sort of procedures to at least assess when they occur, how frequently, and for how long, so that you can equate these to possible differentials in your analysis.

MONTGOMERY: I think it is evident that in any satellite flight you are not going to have exactly weightless conditions at all times during the flight. We expect to get flight-profile characteristics back as nearly as they can be provided for us, and these we can put into our control experiments on the ground. Other than that, since this is a piggyback experiment, there is not any way we have to control those features. But this Apollo mission is not oriented toward the Moon, and we hope to find out what 0 G does to human cells during an Earth-orbital flight.

LAWTON: Dr. Gualtierotti's data suggest that the most sensitive otolith single cells that he has identified are sensitive to about 5×10^{-2} G.

GUALTIEROTTI: Yes.

LAWTON: 0.05 G?

GUALTIEROTTI: Not 0.05; 5×10^{-3}.

LAWTON: 10^{-3}?

GUALTIEROTTI: Yes. There are very few of them, and they are being confused, I think, in the literature with in-and-out units. It has been described by Löwenstein and other people that there are two kinds of vestibular units, one that responds gradually to acceleration, and that is to respond as a function of the amount of displacement of the head, and the other one just responds to going in or out from the basic position. Now, I do not agree with that on the basis of my results, because the two units respond to the same characteristics. The only difference is the range. We have all the intermediate ranges, really, if you explore a large enough number of units in the same nerve. I have been able to explore up to 40 units in the same nerve, and have been able occasionally to find a unit responding to that high sensitivity, and a unit responding to intermediate value up to 0.2 G.

Another point is this: that all the experiments that were done up to now in biology have been done on acute preparations with anesthetized animals. Only recently they started using so-called chronic preparation, and really chronic preparation. They found out that it takes about 12 to 15 hours, and sometimes even 20 hours before you get a steady response. The response changes because the nerve first goes up, and then it becomes normal again, so there is some injury effect that disappears, provoking a constant response after about at least 15 hours.

So all of this, of course, shows that we might just have different values in the sensitivity of the system. We have to know that for our plane flight, because I am planning to use a long-range unit, and not a short-range unit, because as the sensitivity increases with 0 G, it would just become impossible to study it.

SEADAHL: Dr. Gualtierotti, I wonder if you would comment on the vestibular physiology as it relates to radiation and, more specifically, on changes possibly in all of its functions as a result of the radiation.

GUALTIEROTTI: There is some interesting work from which it seems that radiation might directly destroy part of the otolith receptors nearly specifically. I do not remember the authors, but it has been reported in several papers that that might be one of the effects. The otolith cells are sensitive to a number of things. For instance, they are partially destroyed even by antibiotics. They are destroyed by Aureomycin, and different things. So even a mild radiation might destroy selectively the cells before any other structure. We have had a problem in the Apollo mission, because we have been advised that very unluckily our package is near a tank which contains a radioactive component just for measuring the level of the liquid in the tank. So we had about 20 millicuries, and we had to make tests to find out if this would impair the frog. But we found out that the limit to get some alteration is about 500 millicuries, so we are very fortunate.

DUSEK: Dr. Montgomery, there are many controls in your experiments. How about the lighting effects. We know that light does affect various types of animal cells. Is this going to be a particular feature here, or will every time the astronaut decides to take an observation, is he going to flash a light on the cell population?

MONTGOMERY: Every time that he wants to focus the microscope, yes, he will have to illuminate. Six times a minute during the time the camera is operating, he will flash a light. It just happens that the intensity of the light which is falling on the specimen is not as great as the intensity of light which is used ordinarily in the laboratory for the time-lapse motion picture photography. If there is an effect of such light, over this length of time, it is not known to us. It is certainly true cells can be killed with visible light by taking time-lapse motion pictures at too high an intensity of light, but these intensities are not within that range. These cells also do not have any chromatophores in them. For example, they do not contain melanin. They are not pigmented cells. I think those effects would be minimal.

GUALTIEROTTI: I would like to ask one question myself, Dr. Montgomery. What happens to this culture during the 14-day period as a norm? Do they change much?

MONTGOMERY: It depends on the strain of cells that you use. We plan to use two strains of cells. One is Chang liver cells, which are a strain of fetal embryonic human liver, started by Dr. Chang, which are now widely available and used in a great many laboratories. The reason for using those is that they were started from a normal strain of cells, although I doubt that they are perfectly normal cells any more. There are a great deal of data available on their behavior, both in our laboratory and others. They are hardy. They are not contaminated by PPLO organisms as are Chang liver cells, or as far as we know, ambient viruses and other things that wander through your tissue cultures.

The second strain that we hope to use is the normal diploid strain of L human embryonic lung cells, which cannot be maintained indefinitely in tissue culture for the reason that they are diploid cells. Normal diploid cells will not grow indefinitely in tissue culture. The diploid cells will form a monolayer, and stay as a monolayer during this period of time; but the Chang liver cells, once they form a monolayer, will then begin to form small cellular aggregates. They will not exceed, however, in some way the capacity of the chamber to contain the number of cells, so that after they reach a certain number of cells in a given amount of media, apparently their growth rates begin to slow down over this 21-day period.

GUALTIEROTTI: They grow, of course, so you will have a different kind of cells during this space experiment. How long does one cell last?

MONTGOMERY: Well, one cell lasts until it divides, and in Chang liver cells, this takes about 45 to 60 minutes, and occurs roughly somewhere between the neighborhood of 9 to 12 hours.

GUALTIEROTTI: There you are studying the effects of zero gravity on a changing population.

MONTGOMERY: That is right. These cells will grow, divide, and will not be the original cells you started out with.

PRESTON: I have two questions. You mentioned that you anticipated exposing the film for a fraction of a millisecond. I am interested in the kind of film that you use.

The second question is, do you know when during the life cycle of this cell DNA synthesis occurs, since you have indicated you plan to use tritiated thymadine, which is not a precursor?

MONTGOMERY: Well, DNA synthesis occurs in the same period in the life cycle of these cells as it does in any other. There is a period when it has got to synthesize DNA before it can divide. It has got to synthesize DNA in the S-phase. Now, if you are asking me if I can tell by looking at a cell what phase the cell is in, the answer, of course, is no. The only way you can do that is to have synchronous cultures, and producing synchronous cultures is a fairly technical stunt. It is not a complication that we hope to get into. Really, this is where numbers will come into it. If you have a reasonable population of cells on which you have ground-control data, unless the variation in the uptake of the label is very large, it probably will not mean anything. It is still something that I think is worth doing as a beginning experiment. The number of experiments you can do on cells in satellites is at the moment remarkably small. I would be the first to admit that they are not the kind of experiments that I would design sitting in my laboratory, but I am not going to be sitting in my laboratory.

I am sorry, I missed the first question.

PRESTON: What is the type of sensitive film that you plan to use?

MONTGOMERY: The film that we use is the same film that they use to photograph football games, and the reason for that is that you can get it developed in about 2 hours on any single day that you want it under very highly controlled conditions. It is Eastman Kodak. I think it is S-100, but I will have to look that up and tell you. It is not an unusually sensitive film. It is film that is readily commercially available.

PITTS: As a layman, I am still a little bit worried about the possibility of light sensitivity of your cells. You may feel quite comfortable about this, but from my standpoint of ignorance, I would ask whether or not you are going to have a record of the duration and time pattern of lighting of that culture, so that you can reproduce this on your ground-based controls?

MONTGOMERY: Well, in the biosatellite, of course, we will have a very exact record, because the film will have a little marker on it which tells us exactly what day and at what time of the day, and on which day the camera either photographed or did not photograph, so on the biosatellite we will have a very standardized and reproducible thing.

In the Apollo flight, we will have to depend on the log that the astronaut prepares, saying that he turned the light on at this and that time. Again, as a practical matter, in 15 years of looking at cells, this does not seem to be a very big factor. I am not saying that light is not important, because light is important, but under the conditions that it is used in tissue culture laboratories all over the world, I do not think it is a major factor.

SESSION II

Afternoon, November 22, 1965

1. AAP CONCEPT (ENGINEERING)

WILLIAM B. TAYLOR
Director, Apollo Applications Office
Office of Manned Space Flight, NASA

GILL: I would like to call your attention to a reference which was given by Dr. Gerathewohl: "Survival of Micro-organisms in Space," by Drs. Hotchin, Laurentz, and Hemenway from the Dudley Observatory, published in Nature magazine, May 1, 1965.

You are going to learn about the possibilities for biological experiments to be carried on manned vehicles in the near future, the nature of the capability of those vehicles for carrying out your experiments, and for men to carry out your experiments, and then you will learn some of the hard facts which will be related to making your experimental dream come true. Finally, there are three speakers this afternoon to give you the three aspects of the program. Also, there will be a chance to ask questions of the various speakers.

With that, I think we will begin with the first speaker, Mr. William Taylor, who comes from the Apollo Applications Office, and he will review the general problem for you, the general possibility.

TAYLOR: I am not quite sure I know what "review the general problem" means, but what I would like to do this afternoon is to spend a little time giving you our current thinking on what the objectives of the Apollo Applications Program are, and this will be very brief: Some time scale or reference schedule type of information to set in context the time scale you should be thinking of in the possibility of flying bioscientific experiments on the Apollo and post-Apollo missions; a brief summary of some of the configurations that we are talking about for the follow-on capability or the follow-on missions to Apollo; and then I thought it might be interesting for me to run through the results of some of our feasibility studies, particularly as they apply to a bioscientific mission, or a mission whose primary objective was the acquisition of bioscientific data, and show you some of the things that we ran across in doing this feasibility study, the capabilities and constraints that this type of mission both provides and imposes.

I will try to cover these items, and I will be available for the question-and-answer session. I will try to leave a little time right now for questions, so if I say something that does not make sense, or that you would like to nail me on, please do not hesitate to do so.

The current definition of the objectives of the proposed Apollo Applications Program is summarized as follows:

- Acquire scientific, technological, and operational data and experience:
  - In Earth orbit, lunar orbit, and on the lunar surface
  - By the early 1970's
  - To lead to capabilities during the 1970-80's for ...
    - Space stations in Earth orbit
    - Lunar observatories
    - Manned planetary exploration
  - Through use of Saturn/Apollo hardware, production capability, and operational experience

The primary objective is to acquire data and experience in the lunar region of space, near Earth, lunar orbit, and the lunar surface, in the time frame of between now and the early 1970's—1971, 1972, and 1973—and as a sort of leading edge or steppingstone or bridge to the follow-on, or the next generation of spacecraft or space vehicles, such as permanent space stations in Earth orbit, manned lunar observatories of a temporary or permanent nature, and ultimately possibly a manned planetary exploration—all of this through the use of the hardware and the capabilities, both ground and flight hardware capabilities, which the Nation is developing for the Apollo program.

So in summary, our objective is to acquire data selectively from areas of primary interest to the scientific community, the technological community, or what is in the best interests of the Nation. These areas are summarized in the following list:

Major Areas of Interest: Space operations and technology
Meteorology
Communications
Earth resources
Astronomy and physical sciences
Bioscience
Lunar exploration

A later speaker, Mr. George, will discuss in some more detail the types of experiments and the numbers of experiments in these major areas which we are looking at, which have been identified, and which we feel are within the capabilities of our system.

This is not supposed to be in any priority order.

We feel that timewise the capabilities to conduct space operations and develop the technology are the first on our list of things that we must do if we are going to do any of the remaining ones. In the basic Apollo program, the space operations capability to live for 2 weeks in space, to land on an extraterrestrial body and return, this is really the objective of the Apollo program. To extend these capabilities to stay longer, to rendezvous for extended durations, and that sort of thing, we class as a major area of experimental interest for the Apollo Applications Program.

Similarly in meteorology, communications, Earth resources, these types of areas of interest really are an extension of the current activities that are going on in NASA's program and in the U.S. program generally, and we look on the Apollo Applications Program as a system which can take the results, for example, in meteorology of a Tiros or Nimbus satellite, and communications from the Early Bird or the Syncom, and Earth resources or lunar resources from a lunar orbiter. For example, we can take what we learn from those and apply that equipment and technology to manned flights in the Saturn-Apollo Applications Program which could then lead to either improved performance in manned systems or intermittently manned systems, or permanently manned systems thereafter. So we do not look on these as an end in themselves, but rather as a steppingstone in the technology.

In astronomy and physical science, in the bioscience areas, we feel particularly in the bioscience area that we may now have the capability for long-duration flights attended and in-flight monitored by man in the spacecraft, so it is long-duration zero gravity or space environment that we look to in the bioscience area.

In the lunar exploration area, again back to our basic objectives, the lunar exploration, of course, is one of the primary goals of the Apollo program, and extending that appears to be well within the capability of the Apollo system to get the data necessary to determine whether you are going to really establish permanent bases there.

All of these then, to some degree or another, can lead to the next generation of space vehicles for space exploration in the 1970's.

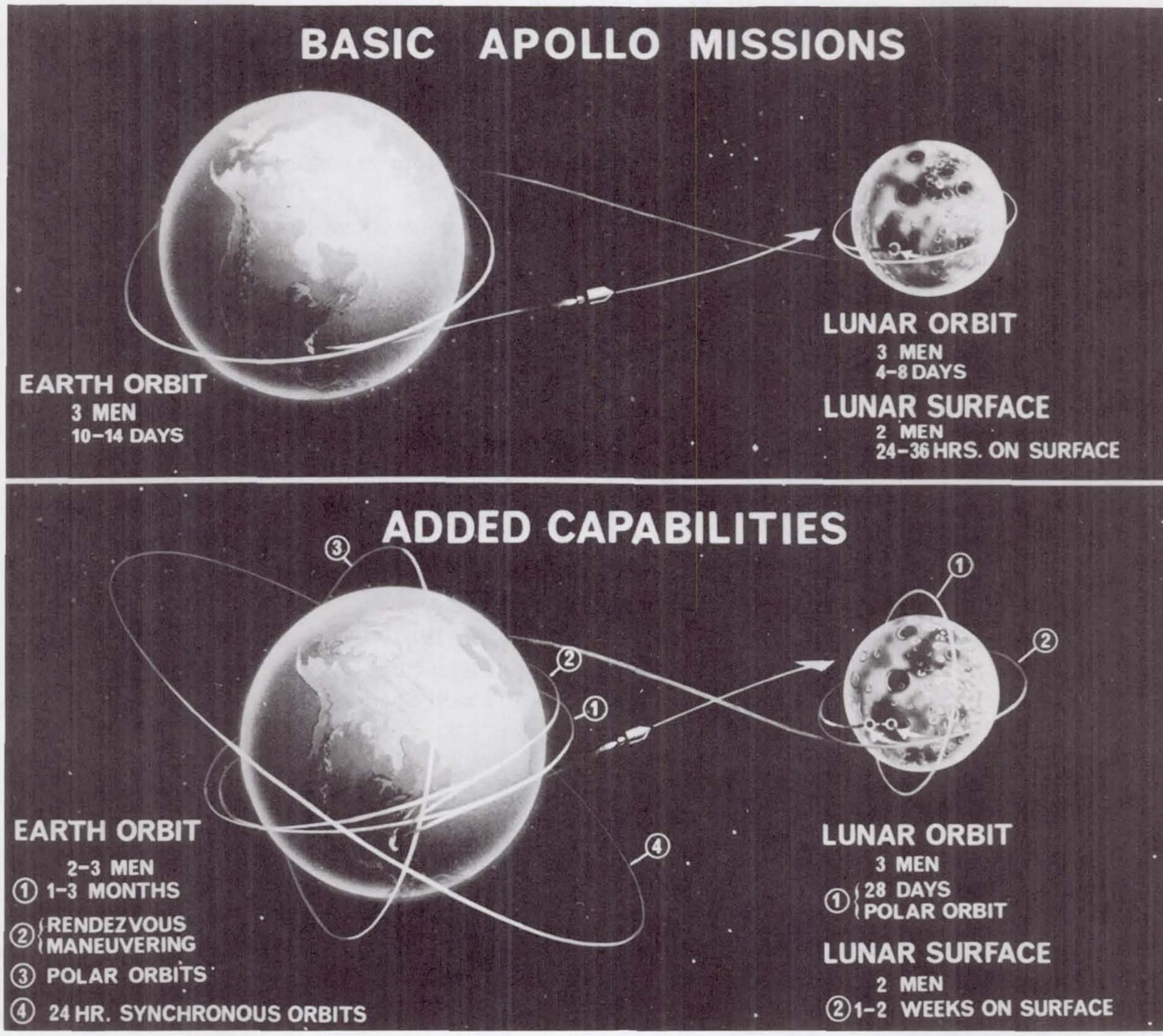

Figure 1.—Basic Apollo missions and added capabilities.

Figure 1 summarizes in a somewhat oversimplified form the capabilities that we are talking about, space-vehicle-wise. As I think you may be aware, the basic Apollo system with the Saturn IB launch vehicle, Saturn V launch vehicle, and the command and service module, and the lunar excursion module, has the performance requirements indicated in the top half of figure 1. In Earth orbit, a three-man crew for the order of 2 weeks, generally in a low inclination near equatorial orbit, since that is all that is required for the qualification for the prime objective of the lunar mission. The capabilities in lunar orbit are up to 8 days if there is not a landing, and the lunar landing has a design capability of 1 to 1-1/2 days for two men on the surface. That, then, forms the design goal of the basic Apollo program, and our studies over the past 2 or 3 years have indicated without any significant changes in even the launch vehicle spacecraft, we can achieve these kinds of capabilities indicated in the lower half of figure 1.

You can operate the spacecraft with a two-man crew as well as a three-man crew. It appears you can add expendables to the spacecraft and redundant subsystems, if necessary, to run the life of the spacecraft up to the order of 6 weeks on a single mission, and by combining two missions by rendezvous, you can get up to 3 or even 4 months, if there are particular experiments or areas of interest to be covered.

It is possible to go into polar orbits with the basic system or into a 24-hour synchronous orbit over either the Equator or a part of the Equator.

In the lunar area, capabilities with this long-duration spacecraft with the added expendables, you could probably get on the order of a month in lunar orbit, which in a lunar polar orbit would permit the complete observation of the lunar surface. On the lunar surface, if we are smart enough, we can get up to 2 weeks' duration for a two-man crew on the lunar surface by various combinations of the operating techniques planned for the basic program.

These, then, are sort of an envelope of the capabilities we see for the basic Saturn-Apollo system.

In figure 2 at the top, the two large black lines indicate the current plans for flight activity of the Saturn IB and Saturn V launch vehicles with the Apollo spacecraft in accomplishing the currently approved lunar landing mission. It shows that the Saturn IB flights will start in 1966, and this is on schedule. Figure 2 also shows they will run through 1968, or about 3 years of Saturn IB flights' activity, the last 2 years being manned, the first year being qualification flights.

Figure 2 also shows the Saturn V activity starting in 1967, unmanned; manned flights in possibly late 1967 or early 1968 in Earth orbit for qualification; and the possibility of the lunar mission occurring in 1969. It is conceivable it could occur earlier than 1969. So the flight activity there in some 15 launches extends from 1967 through 1969, possibly into early 1970.

So that is our basic frame of reference, and in planning the Apollo Applications flights (fig. 2), we then have worked from the technology to be developed and demonstrated there. We have split it down into generally three phases of flight activity.

The first phase indicated in figure 2 as 14-day orbital mission would be those flights which might be flown as alternates to the primary objective lunar missions during the 1968-69 time frame. It may be possible, either by variations of the mission priorities or because the lunar mission program is going better than anticipated, to have a number of launch vehicles and spacecraft from the initial or basic program at the top of figure 2 made available for flying alternate missions in Earth orbit or lunar orbit during 1968-69. I will talk more about those in a moment with some configuration drawings, but the principal point here is: there may be as many as six or eight missions that we can fly on Saturn-Apollo hardware in 1968-69 that are not directly oriented toward the lunar mission. This would require that these missions use the basic lunar hardware, since we will not know until quite late in the game whether or not these flights could be flown to meet the alternate objectives.

The next phase of activity in figure 2 is the follow-on missions, both long-duration orbital missions and long-duration lunar surface missions. The long-duration orbital missions are something on the order of 45 days in Earth orbit, or 28 days in lunar orbit, and the lunar surface mission is something on the order of 14 days on the lunar surface, using a combination of the launch vehicles and spacecraft under the lunar program.

In figure 2 there are a couple of shaded areas in the bar graphs that I would like to discuss, in talking about the alternate mission phase here, which indicates that the first possible alternate mission might be possible as early as 1968. This indicates there is some degree of time dependency on our actions right now. For example, experiments to be identified, defined, and developed in time to fly on missions in 1968 or 1969, 14-day missions in Earth orbit, should be in the reasonable state of definition and approval cycles at

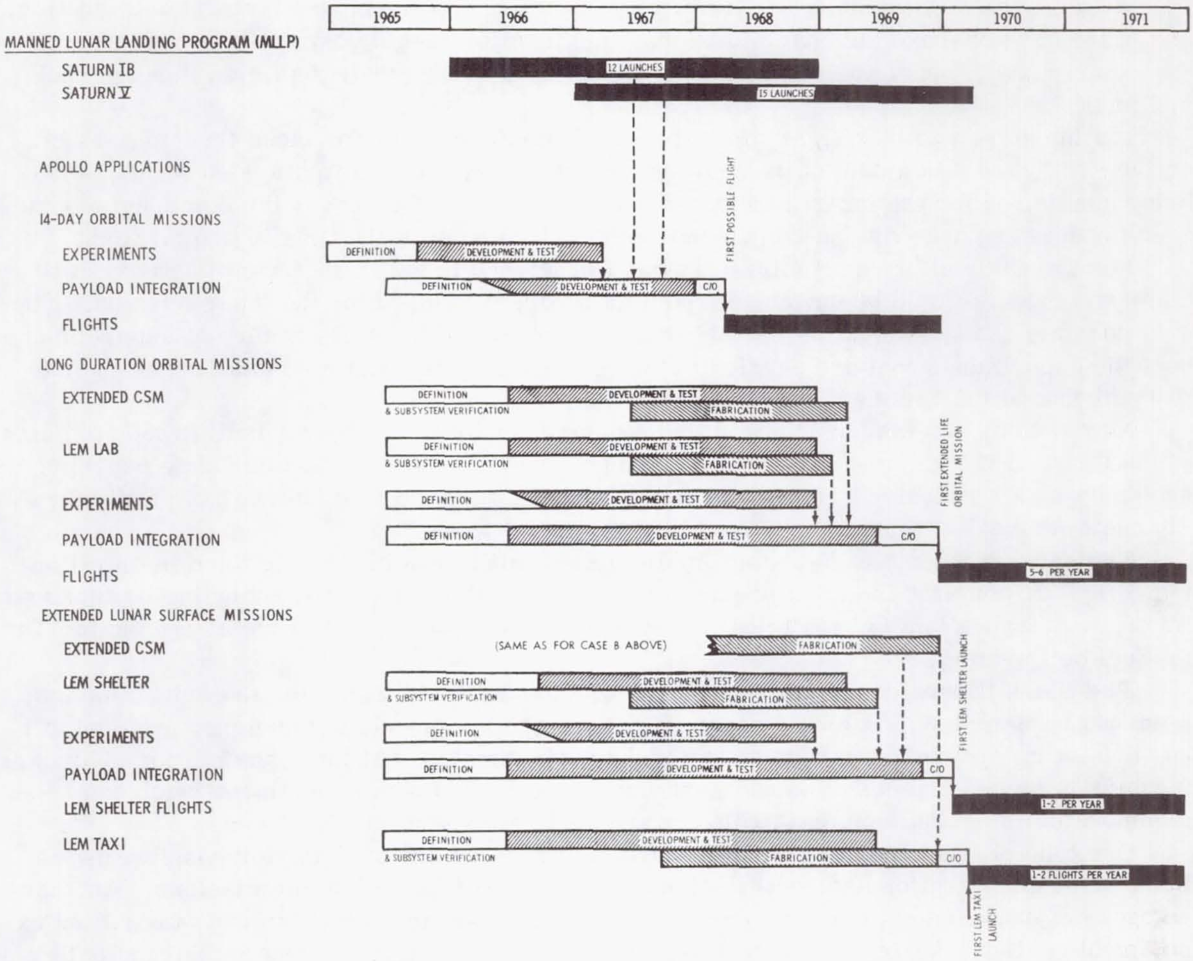

Figure 2.—Apollo applications planning schedules.

this point in time. We have identified a number of experiments. We do not have hard approvals on many experiments at this point in time, and I believe, Dr. Gill, this is one purpose of the discussion today, to let you know what our capabilities are, and what the time frame is. So experiments for these early flights, we feel, should be identified in the very near future.

There is another thing that figure 2 shows, and that is a payload integration function which I can elaborate on during the discussion session, if you will.

By payload integration, we mean the software activity, which is the design and the specification writing, the qualification testing, and that sort of thing, as well as the hardware activity, building prototypes of flight hardware, assembling it and bringing it together with the spacecraft into an integrated flight vehicle in the form of a payload. This activity is also a long lead activity, because between the spacecraft people and the experimenters, there has to be very early in the game a close correspondence, communication, and working back and forth. I think Mr. Small from Houston, who will talk later this afternoon, will talk about that.

We do feel that there is a fair leadtime associated with the payload integration function, and in the case of these alternate missions, this function should begin both on our part and on the experimenters' part some time during the calendar year 1966, the first interplay back and forth.

Let me go now to looking at some spacecraft configurations for these three phases of activity. Figure 3 is a sort of pseudo-engineering drawing of the Apollo spacecraft as it is being configured for the lunar mission. On the far right of figure 3 is the command module which houses the crew during launch and reentry, and most of the time in orbital flight.

For the early alternate Apollo missions I described in the first phase of activity, that command module would be unchanged from that being developed for the lunar mission. The only possible changes might be the addition of some expendables of a nature to supply or support the experiments that are carried in the command module and the installation of some experiments in the command module.

Now, I think you may have heard this morning, and you will hear this afternoon of some of the things that are being developed for the command modules to accommodate experiments, such as a small airlock. That kind of thing, of course, would also be available to fly the alternate Apollo flights.

The service module of the basic Apollo spacecraft shown in plan view and in elevation view (fig. 3), contains the main propulsion system for the spacecraft, including its tanks and its engines, as well as the electrical power system, the fuel cell, and the cryogenic fuel for the fuel cell system.

The Block II service module, as it is now being built and tested for the lunar mission, is shown in plan view. Below, on figure 3, there are six pie-shaped sectors, and sector 1 has been purposely left vacant to accommodate experiments. At the moment, our studies are focusing in on two classes of experiments or one major class of experiment which can be accommodated in sector 1 on the Apollo and the early alternate mission flights.

One type of experiment is a camera system which we are studying for possible use in lunar orbit for selection and certification of landing sites for follow-on missions. Another category of experiments would be those which could be accommodated in what we call an experiments pallet. Again, Mr. Small will discuss this later this afternoon. But the pallet shown at the top of figure 3 is really sort of an interface device or a glove that fits into the spacecraft and isolates the experiments from the interference, and so forth, of the spacecraft but marries the experiments to the spacecraft structurally and electric-power-wise, and things of this nature. I will not elaborate. Mr. Small will.

This, then, is the principal carrier of experiments, I believe, during the early alternate Apollo phase of Apollo Applications flights. That thing is big. It can accommodate something on the order of 3500 pounds of experiments, the total weight being about 5000 pounds. The dimensions of it are about the size of three tables put together, so it can accommodate a significant payload of experiments. The three-man crew riding in the command module can operate a significant number of experiments. We will go into this later.

Finally, in the early configuration, the LEM will be used, and we are planning its use as an orbital laboratory without landing gear and without some of the subsystems uniquely required for the lunar landing. It does provide an additional 250 cubic feet of pressurized volume for the crew to operate in, and subsystems to supplement the command module, and service the subsystems in orbital flight.

So during the period 1968 to 1969, and maybe early 1970, it is this type of spacecraft that we are talking about, the capability to carry experiments and crew for a nominal 14-day mission; we believe that this spacecraft itself can probably be extended by adding just expendables in a limited quantity for the order of 3 weeks or so during that time frame.

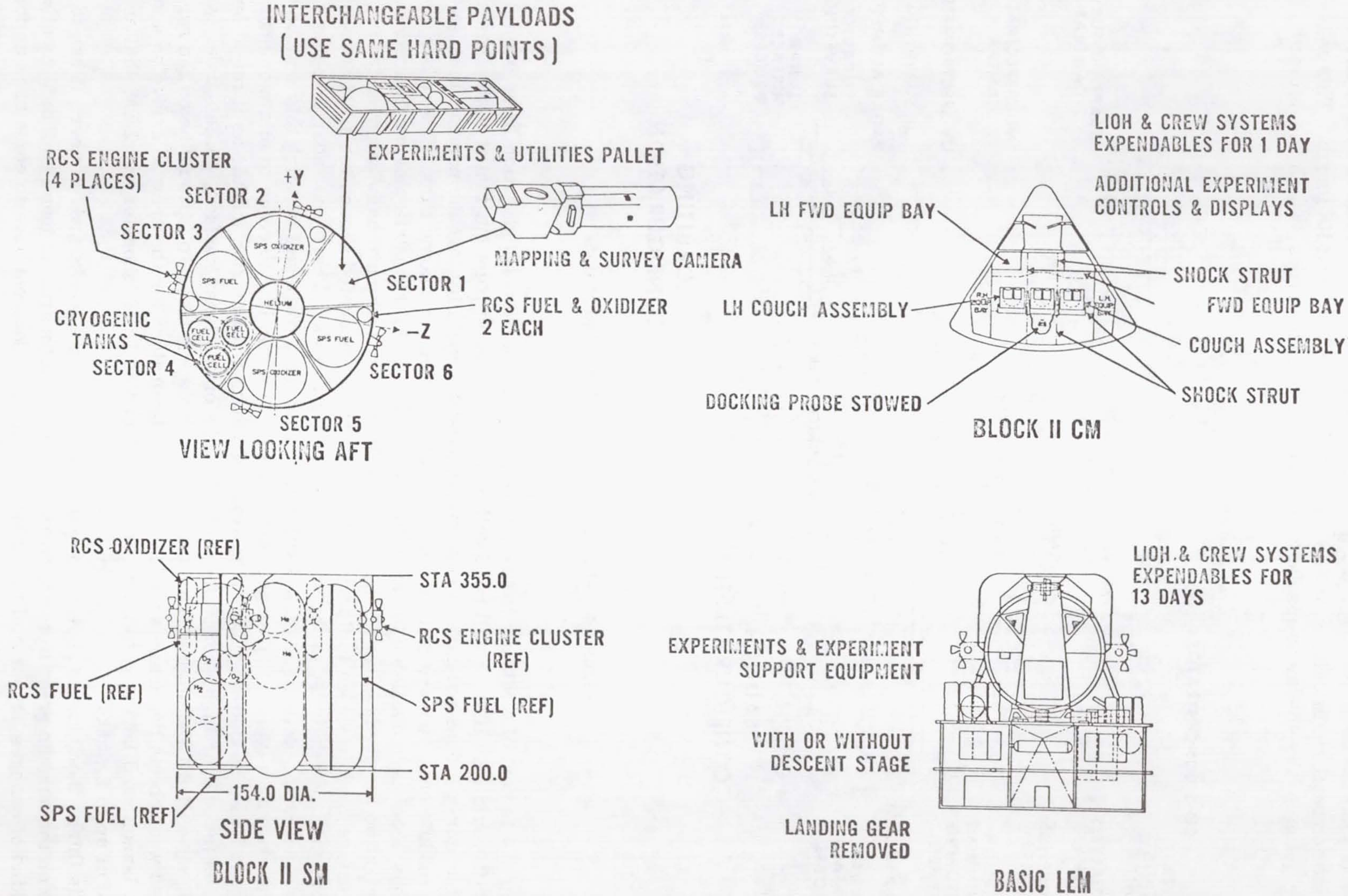

Figure 3. —Configuration for early flights.

Now, beyond the lunar landing, we feel then it would be possible and we should plan to make some minimal modifications to this spacecraft to really extend its length. This is where we get up to the 45-day or maybe 3 or 4 months by rendezvous, which I mentioned earlier.

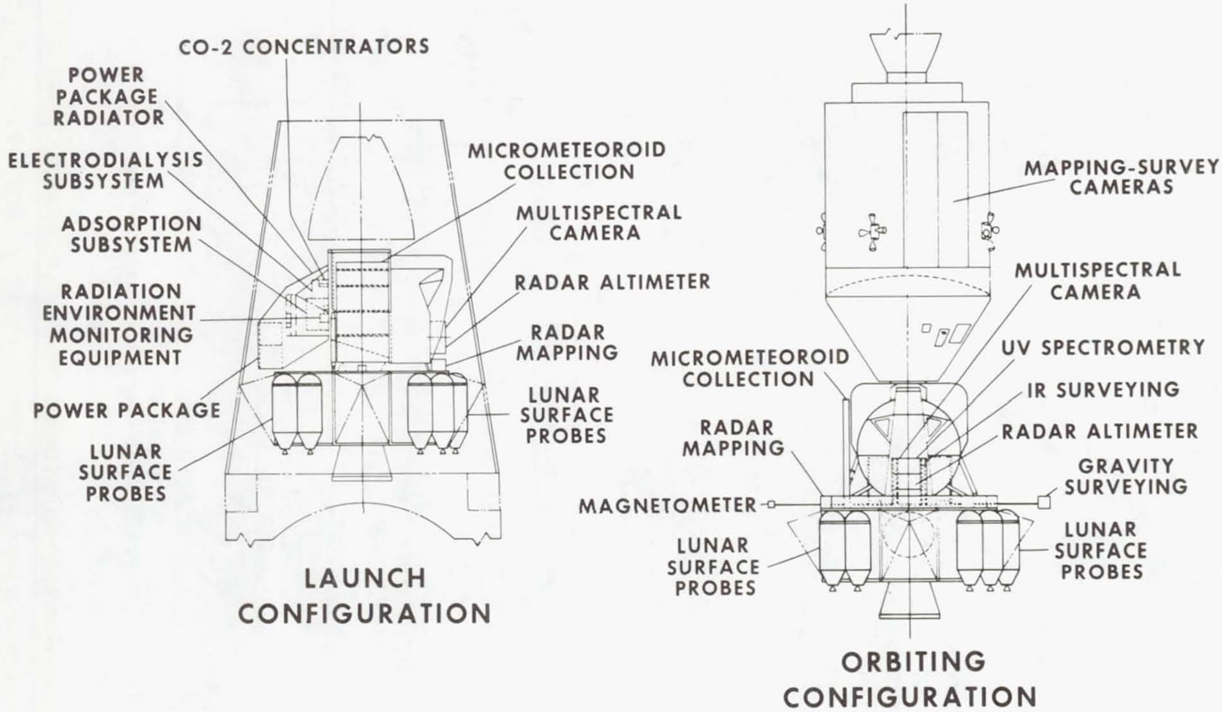

Figure 4. —Lunar orbiting LEM laboratory.

Figure 4 is sort of a Mickey Mouse drawing of what an extended-duration lunar orbital spacecraft would look like. I will not dwell on it other than to point out that it again uses a LEM laboratory; it does not have the ascent propulsion capability that the normal lunar excursion module has, because it does not land on the surface and come back. Therefore, weight has been made available for applying experiments. In this particular configuration, which might be the 28-day around-the-Moon configuration, there are cameras mounted back in the service module shown in figure 4; there are probes mounted around the LEM descent stage for unmanned delivery to the surface of sensing probes. There are radar mapping sensors, meteorite collection, etc. I will not go into this, because I do think this may be of less interest than a typical bioscience mission which I would like to come to in a moment.

Figure 5 is a pseudo-engineering drawing of the lunar excursion module as it might be configured for supporting the crew for up to 2 weeks on the lunar surface. In this case, we land this so-called LEM shelter unmanned on the lunar surface, so it would be on the surface, and would be in the nature of a shelter and a laboratory for the crew to arrive on a subsequent launch, and land next to it and operate out of this LEM laboratory or LEM shelter for a period of up to 2 weeks.

This thing, then, has to sustain life on the surface for 2 weeks and, further, it has to survive on the surface prior to the arrival of the crew for maybe as much as 2 or 3 months. So the kind of changes here are, first, since it lands and does not have to come back up for a

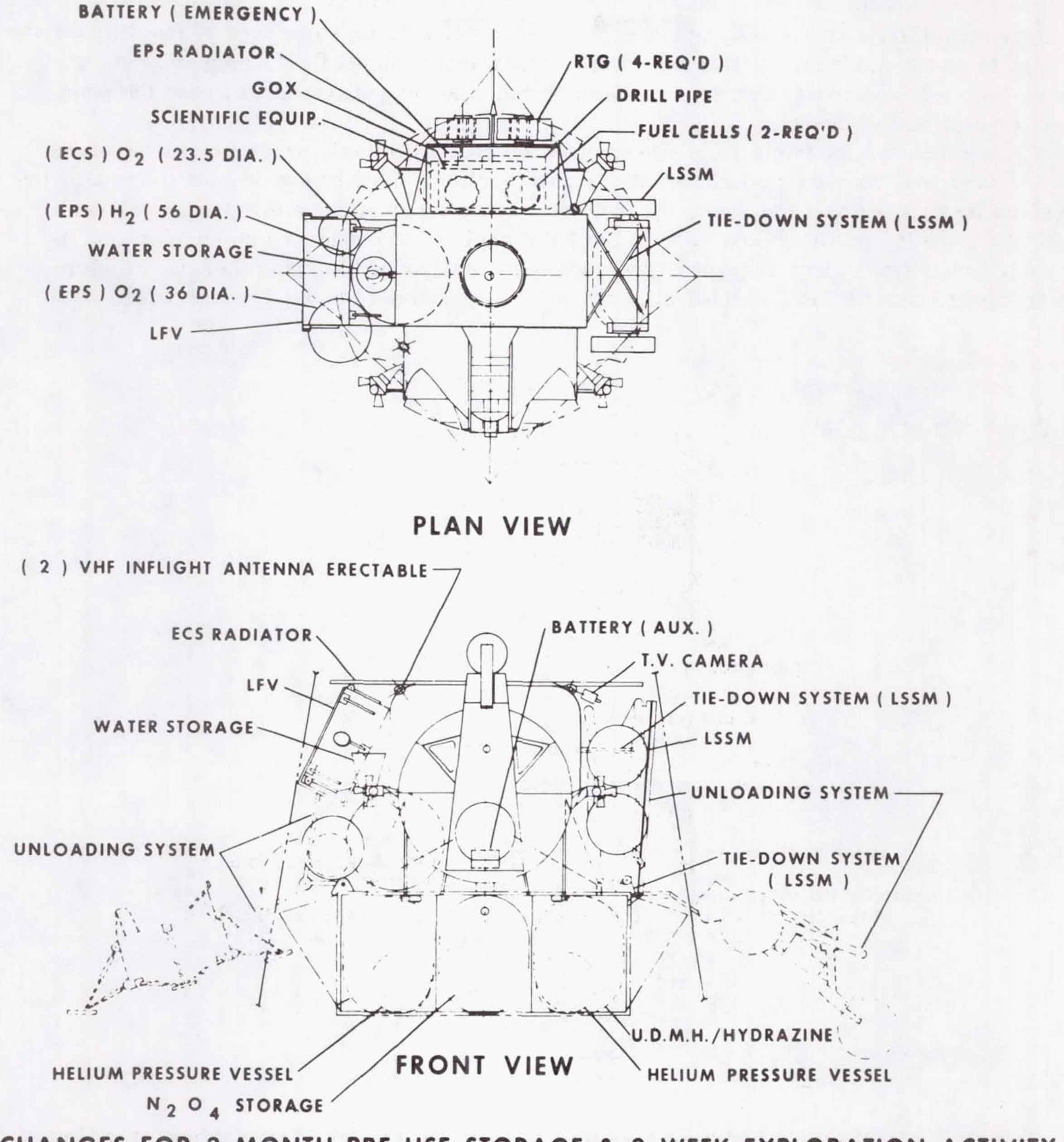

Figure 5. —LEM shelter.

return to Earth, you pick up some 6000 pounds in the propulsion system required normally for the ascent. Offsetting that, you have to add added protection for survival on the lunar environment over a period of a couple or 3 months, and that leaves something on the order of 3000 pounds of scientific payload for a lunar surface operation. This compares to about 250 pounds of scientific payload in the basic Apollo configuration which carries the crew down and brings the crew back. So we find it feasible by this means, then, to have an increase of an order of magnitude or so in the amount of payload, which means scientific payload or exploration payload, and which means you can then have an adequate weight margin to carry such things as a small roving vehicle, for example, or some type of mobility device to operate on the surface, as well as a drill, for example, which the lunar geologists at Woods Hole felt was most desirable, as well as the types of subsystems to keep the people alive for a period of 2 weeks.

Figure 6 shows the basic LEM now configured as a LEM taxi, which brings the crew down to land next door to the LEM shelter shown earlier. This has to do everything that the standard lunar mission LEM does, plus survive on the lunar surface for the 2-week period while the crew is operating next door in the LEM shelter. This means some additions in terms of protection, electric power, and radiators because of the lunar thermal problem, but it appears that this is feasible, although it is going to be a tough job weightwise.

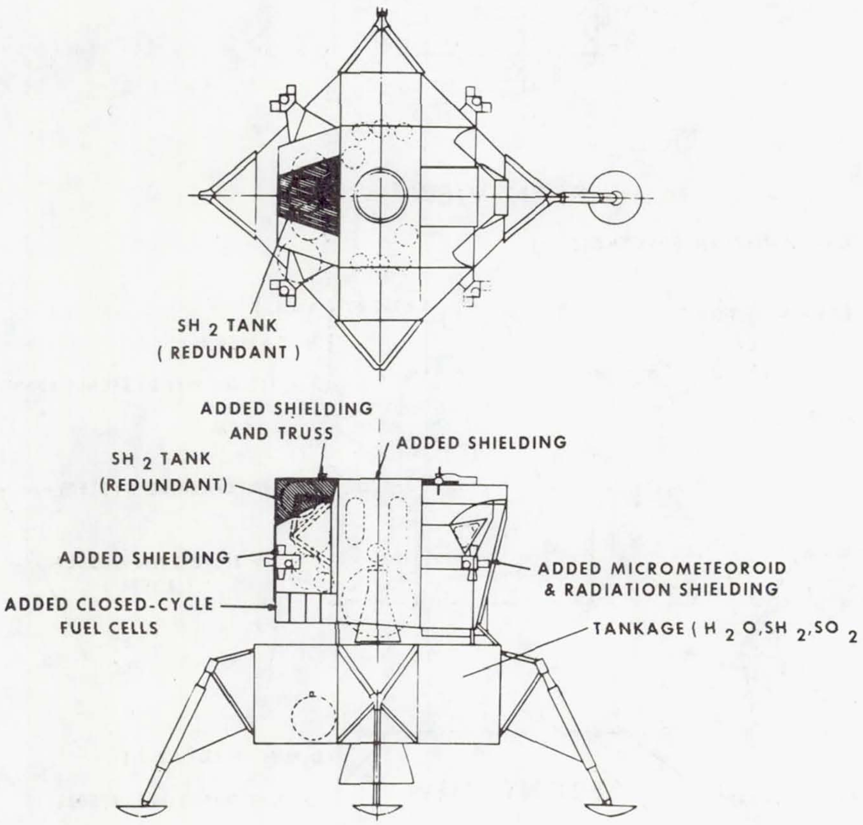

Figure 6.—LEM taxi. Additions required to LEM for 14-day lunar surface stay time.

So much for the general overview. I would like to discuss what we hope is representative of a bioscience mission that we studied earlier this year (tables I, II).

As we see the mission planning activity in Apollo Applications, each of the missions which we plan to fly will have a basic or a primary mission objective, in terms, for example, of astronomy, or bioscience or operations technology, and that sort of thing. This primary mission objective will determine the parameters of the mission, will determine what orbit it is in, what its duration is, what its attitude hold requirements are, and so forth. So in configuring the mission, we would give priority in the mission planning to those

Table I. —Space Operations/Bioscience Laboratory, NASA Mission 4, Outboard Profile

No.	Experiment	Name
1		Fuel cell assembly
2		H_2
3		O_2
4		O_2
5		Water tanks
6		
7		Tunnel and docking ring
8		Docking probe
9		LiOH
10		GOX
11		Safety line
12		Equipment radiator
13		Fuel cell radiator
14		Mission 3
15	0302	On-board centrifuge
16	0302	Centrifuge counterweight
17	0406	Spaceborne micro-organism cartridges (stowed)
18	0406	Spaceborne micro-organism cartridges (exposed)

things which are required by the primary mission objective. An astronomy mission, for example, might well require synchronous orbit and very fine attitude tolerance or attitude-holding capability on the part of the spacecraft.

In configuring this mission, if there were, after we had satisfied all of the requirements for the primary mission, additional capability in terms of either weight or electrical power or attitude-hold requirements, or more importantly—and one of the most important commodities which apparently comes out of this—is the availability of astronaut time to conduct the experiments, if there is a margin in all of these areas of mission capability, then secondary experiments can be added to the spacecraft, to the mission, as long as they do not degrade the objectives of the primary mission.

Figures 7 and 8 show how we have studied and configured a mission which would have its primary objective as the acquisition of bioscientific data. There are some secondary experiments conducted on this flight. I will touch on them briefly. But they are such that they do not, at least in our study, would not degrade the objectives of the primary bioscience experiments.

On the left of figure 7 is the launch configuration. Here is the launch vehicle, the Saturn IB. The command and service module is located above, and within the adapter area is located the LEM laboratory. On the right is the orbiting configuration, and in this particular mission, this was a rendezvous mission where the spacecraft here was put into the same orbit as the preceding spacecraft, shown below. The two rendezvoused then and came together to form a combined spacecraft with two LEM laboratories. In other words, by resupplying rendezvous, it will be possible to get a 90-day mission capability from the combined mission.

Now, in the spacecraft, in this particular spacecraft, its mission was primarily bioscience, and I will read you the experiments which were hypothesized and identified for us as a basis for doing this feasibility study. I want to make it really clear that these are not

Table II. —Space Operations/Bioscience Laboratory, NASA Mission 4, Inboard Profile

No.	Experiment	Name
1		ECS
2		Tunnel and docking ring
3		Film storage
4		GOX
5		Fuel cell assembly
6		H_2
7		LiOH
8		Mission 3 laboratory
9	401, 2, 3, 4, 5	Freezer
10	401	Lyophilization
11	401, 403, 404	Chemical and equipment storage
12	401, 402, 406	Incubators
13	401, 402, 406	Microscope
14	401, 402	Refrigerator (-15° C)
15	402	Refrigerator (-20° C)
16	402	Culture flasks
17	402, 403, 404	Supply cabinets (includes 35-mm camera)
18	402	Scintillation counter
19	402	Particle counter
20	402	Centrifuge
21	403	Chimpanzee container (pressurized)
22	403	Waste management (chimpanzee)
23	403	Food management system
24	403	Instrumentation for chimpanzee panel
25	404	Planaria and newts chamber (pressurized)
26	404	Refrigerator (-5° C)
27	405	Rat cages (pressurized)
28	405	Food storage
29	405	Waste storage
30	405	Quick freezer
31	406	Refrigerator (+5° C)
32	302	On-board centrifuge
33	302	Centrifuge counterweight

approved experiments, but are under design for the purpose of this study. Some of them may be, but these were identified for us so that we could exercise and determine the limits of the capability of our system for handling this type of thing.

The bioscience experiments that we used in this study included one on the genetic effects of 45 days of weightlessness on micro-organisms, particularly the recombination of DNA and mutation rates and phage production. The second experiment was the effect of 0 G on the morphology, the growth, the gas-liquid separation in micro-organisms and unicellular organisms, and in animal tissue cells. Neither one of those takes up an awful lot of weight and volume, but they do have some peculiar requirements which I will refer to shortly.

There were experiments on mammals, both rats and chimpanzees; experiments to determine the cardiovascular effects, the respiratory effects, hormone production, mineral and

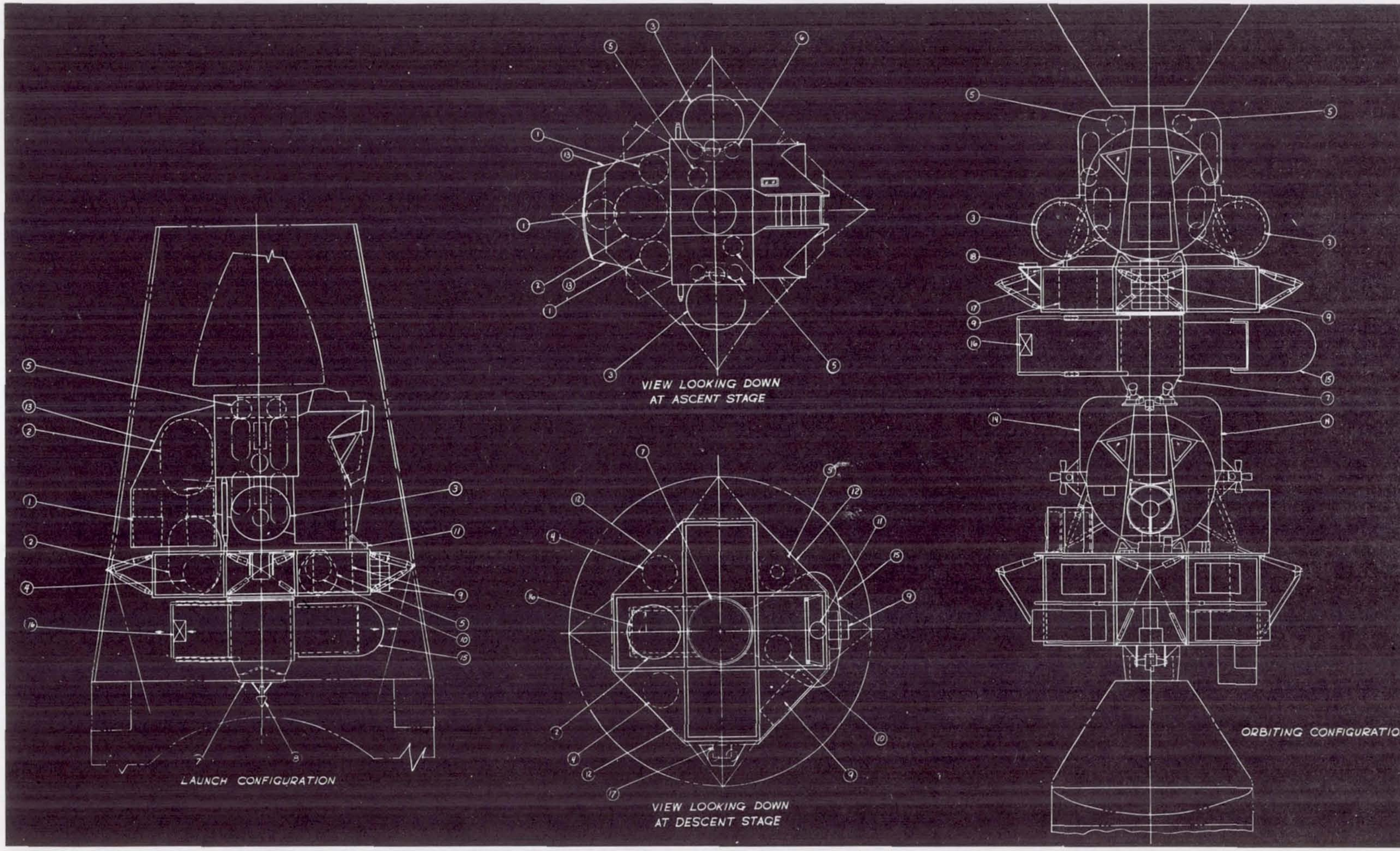

Figure 7.—Space operations/bioscience laboratory, outboard profile.

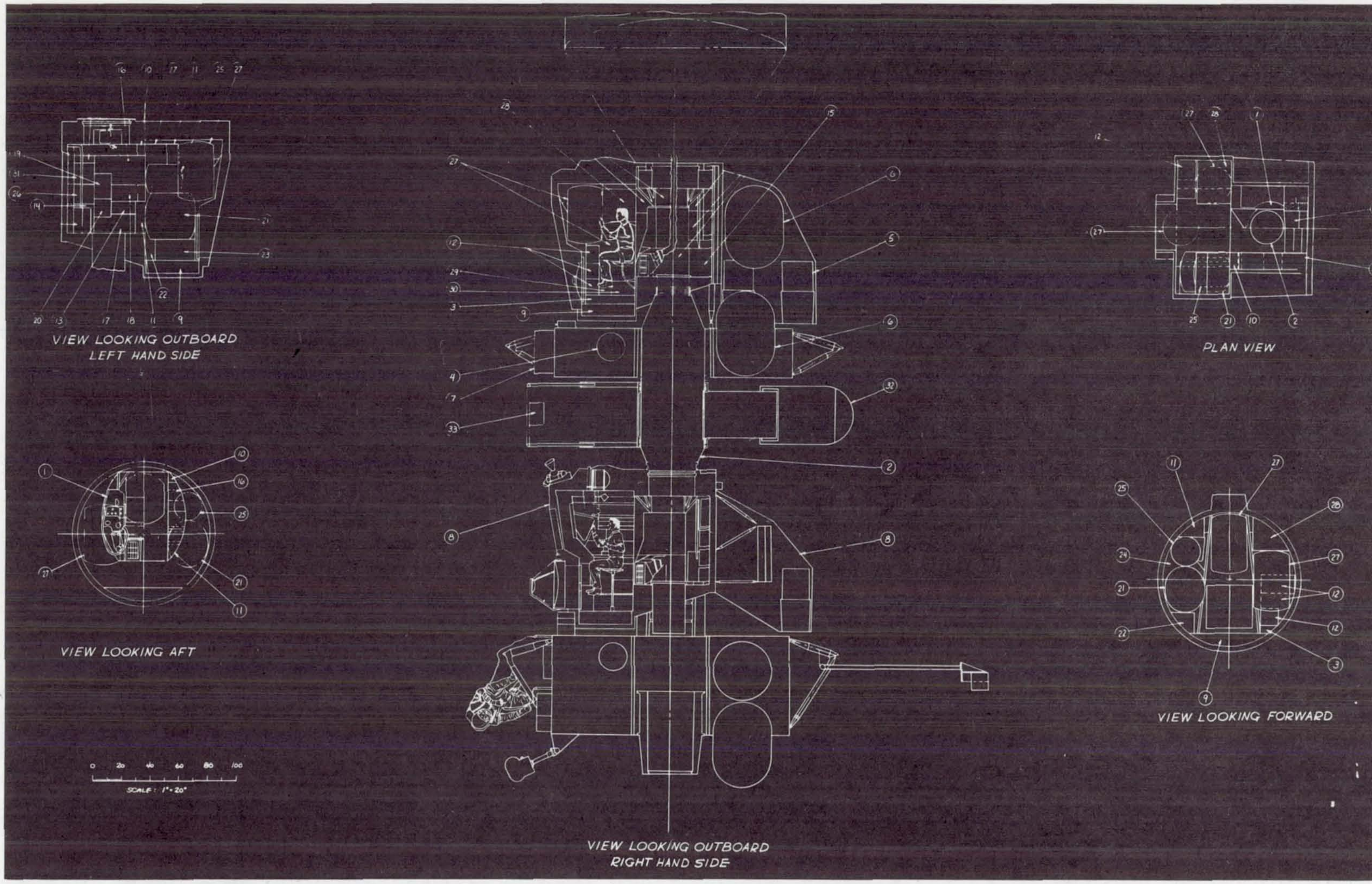

Figure 8. —Space operations/bioscience laboratory, inboard profile.

water metabolism, brain mechanisms, operant behavior and biorhythms, and the attendant engineering problems were significant for those experiments.

Another experiment was limb regeneration and wound healing, using newts and planaria. Another experiment was to determine the effects of drugs on mammalian behavior in 0 G, again using the chimpanzees and rats. An experiment on the soft capture, enumeration, and identification of spaceborne organisms, should they exist.

So these experiments, then, the acquisition of these data, form the primary objective for the purpose of this study for this particular mission. In addition to those particular experiments, there was the operational experiment, if you will, of rendezvousing and providing a 90-day mission by rendezvousing this flight with the preceding flight. Also in figure 7 you may notice that there is shown for the purpose of this study a small centrifuge located between the two spacecraft. Actually it is mounted, a one-man centrifuge offset for 0 G or artificial gravity conditioning, should that be required. What we went through was the engineering exercise associated with providing these things to determine if they could be done, and what would be the effects on the other experiments.

I would like to summarize some of the mission characteristics and some of the things that are important to us as a result of doing this and, we think, without degrading the mission objectives of the experiments that I have indicated.

First of all, the mission was studied for a 200-nautical-mile, low-inclination, 28-1/2° inclination orbit; two hundred miles, because for a 45- and 90-day mission, atmospheric drag will degrade the orbit severely and require orbit-keeping propellant if you try to maintain a lower orbit. It did not appear to us that the bioscience experiments required lower orbits, and were sort of insensitive to what the altitude was, so long as it was 0 G and essentially in a space environment.

Two hundred miles is probably as high as you want to go until you get considerably higher for this long duration because of the radiation belts and the effects primarily, of course, on the crew, but also on the experiments in this particular case.

This was a three-man crew. The launch vehicle was a Saturn IB. The total experiment weight of both the bioscience experiments and the operational experiments, the centrifuge, etc., was 3960 pounds. The total weight of the spacecraft and experiments was 32 910 pounds, which gave something like a thousand pounds' margin between the total spacecraft weight, including the experiments, and the launch vehicle capability.

I mentioned the importance of astronaut time availability in planning a mission like this. For three men, for 45 days, which is what this crew would be up there, the total is some 3240 man-hours available. Of this, some 70 percent, and the estimates vary from 50 to 70 or maybe 60 to 80, but something of the order of 1900 man-hours of the total of 3200, are required for the crew to eat and sleep and operate the spacecraft. Therefore, something on the order of 30 percent might be available or would be available, would be scheduled available for operating experiments, or some 1335 man-hours.

In running through the time lines on what the crew would have to perform to accomplish these experiments, it appeared that something of the order of 1200 man-hours would be required to accommodate this particular grouping of experiments. Of that 1200 hours, some 93 hours was extravehicular activity, either taking samples outside or I guess replenishing some of their spacecraft supplies that are carried externally.

I only dwell on this because we found, and I think the experience to date--you can bear me out, Dr. Gill--in the Gemini flights, this is a very critical parameter in your mission planning, the time of the crew, and we feel that we cannot necessarily load the spacecraft up with this to its weight limit and expect to have useful results from the experiments. Rather, a fairly detailed planning of what the astronaut has to do with the experiment, and how much time it takes him to do it, and some margin for setup and shutdown, and things not going perfectly is most important to us in planning these missions. So in the identification and definition of experiments, we would hope that the experimenters would give a fair amount of thought to what they want the astronaut to do, and how long it should take him to do it.

The other parameters turned out to be less important than that, but still important. On this particular flight, out of the total of some 600 cubic feet of pressurized volume in the command module and the LEM, the experiment payload shown in figure 8 required 75 cubic feet internally, and some 410 cubic feet mounted externally to the crew compartment. Figure 8 shows a lot of things mounted external to the LEM and down between the two LEMs.

The return weight of the data acquired during the mission, the estimated total from this mission analysis, was 48 pounds for this class of mission, assuming the return of samples and data on tape, and assuming that some of the observations are telemetered or communicated back to ground during the flight for real-time analysis on the ground, to tell the astronaut to change the conditions thus and so. But the actual weight of the return data in this mission was 48 pounds.

Now, obviously on an Earth-sensing mission or a lunar orbital survey mission the return data weight becomes a very important factor, on a lunar orbit mission, for example, there would be a lot of film. It does not appear to be, from this particular mission, that important. As a matter of fact, with the margin that we feel we have here, it would be possible to bring back maybe a complete chimpanzee which might be desirable after the mission.

The other parameters we looked at are electrical power, and from this grouping of experiments the average power was 350 watts, the peak power was some 750 watts. This compares to an average of some 1500 watts just to keep the spacecraft operating. The total energy consumed by the experiments during the 45-day mission is some 400 kilowatt-hours, which is well within the capability of the fuel cell system, and the fuel storage system of the spacecraft, since it is sized for something like 2600 kilowatt-hours.

Another factor we look at, not limiting in this particular mission, is the amount of attitude-control propellant required. In this particular mission, some 790 pounds of attitude-control propellant was required to hold the attitude to the tolerances specified by both the primary and secondary experimenters. This is well within the capability of the spacecraft, which for the extended spacecraft is sized for about 2500 pounds of attitude-control propellant.

This is just a brief summary of the types of things we have to do and we have to look for and design against and accommodate in planning a manned mission to accommodate a variety of experiments. I think I would like to leave just one thought, and we can get back to it later in the discussion. This is that on the Apollo mission and on the Gemini mission, these are primarily for developing spacecraft and space operations technology and capability. In the program that I am talking about, the Apollo Applications Program, which we hope to have defined in the next year, to the point where we can actually start into hardware development, roughly a year from now, the conduct of experiments is the principal reason for the program's existence, the conduct and acquisition of data or the use for the purpose of satisfying users' requirements in the bioscientific community, the astronomers, the political scientists, or what have you. The conduct of experiments is the primary objective, and the acquisition of data is the primary objective of this program. I think this reflects a maturing of the space capability that is being developed, or reflects the application of the use of the space capability that is being developed under the Gemini and Apollo programs. So we do, and I do appreciate the opportunity to talk to a group like this at this stage of our definition, which I think you can probably see is a relatively early stage of definition, and I think that a strong two-way flow of communication between our guys, the engineers who are trying to define the missions and define and build the equipment, and you as the potential users of the system is most important, and you cannot start too early, particularly in view of the fact that we may be able, roughly 2 years from now, to fly the first alternate mission on the Apollo system.

N66 31812

2. PLANNING OF SCIENTIFIC AND TECHNICAL EXPERIMENT PAYLOADS FOR AAP

T. A. GEORGE
General Engineer, Office of Manned Space Flight, NASA

GILL: We will now go into the second talk by Dr. T. A. George. Dr. George deals with experiments in the Earth orbital mission studies.

GEORGE: The purpose of this presentation is to cover the present status of our experiments program, including a discussion of how manned space-flight experimentation has evolved over the years, finally resulting into the concept of the Apollo Applications Program (AAP). Also, I propose to discuss some of the management problems which we face in organizing a major program of this type, together with some of the tentative solutions arrived at. I wish to emphasize the word "tentative," because in view of the formative stage which the AAP is in at present, none of our solutions are frozen. I will avoid engineering details of the Apollo hardware, which have already been covered by Mr. Taylor and, also, I will avoid the specific details of bioscience experiments under consideration by NASA, a subject which will be discussed by Dr. Gerathewohl in a later paper.

As you are all aware, the purpose of AAP is to conduct experiments in space. This is a broad statement which really does not convey a clear picture; consequently I would like to elaborate. The experiments which we visualize for AAP fall into three general categories: science, technology, and operations. The scientific experiments will be aimed at advancing our knowledge of the laws of nature, and the composition and history of the universe, with special emphasis on the Earth and our solar system. We visualize important byproducts resulting from this effort, including a better utilization of natural resources. Technological experiments will serve to obtain a quantitative understanding of the influence of the space environment on materials and functional components, and for testing advanced developments under actual space-flight conditions. Further, to develop through precursory experiments the space technology required in direct support of scientific experiments. Operational experiments will be aimed at building up the operational capability of the manned spacecraft complex in direct support of technological experiments. These are the general categories. Now let us go into the specific experiment areas.

The list below is a breakdown of the general categories into individual disciplines for which we are considering experiments. Also, NASA is always prepared to provide assistance to other agencies and departments. On the last line, a category for requests from the Department of Defense has been reserved.

Our present plans for conducting experiments in space as part of the Apollo Applications Program are strongly influenced by the capabilities of the AAP system to support such experiments, by our past experience in conducting experiments, and by the overall evolutionary processes in space exploration. First, let us examine how the capability has changed, since the days of Mercury, into the projected AAP system some 10 years later.

Space science and application:
- Astronomy/Astrophysics
- Bioscience
- Physical science
- Atmospheric science
- Communications and navigation
- Earth science and resources
- Lunar surface exploration
- Lunar orbit

Advanced research: Advanced technology and supporting research

Manned space flight:
- Biomedicine/behavior
- Extravehicular engineering
- Operations techniques
- Advanced subsystems

DOD: All types of supporting experiments

Table I includes some of the more important features which affect the spacecraft capability for conducting useful experiments. However, table I does not tell the complete story. For example, we might recall from Mr. Taylor's paper that with the help of the Apollo system it will be possible to place substantial payloads into polar and synchronous Earth orbits as well as into lunar orbits—and finally onto the lunar surface.

Briefly let us review what has been accomplished in the realm of experiments carried out by manned spacecraft. This is synonymous with describing our experience with manned space experimentation. However, first, I would like to give you a feel of our prediction as to how this effort will grow.

Table I. —Comparison of Spacecraft Capabilities for Conducting MSF Experiments

Program	Standard spacecraft payload (lb)	Volume: Pressurized, (ft^3)	Volume: Unpressurized, (ft^3)	Power, kw-hrs	Astronaut man-hours for experiments[4]	Maximum duration, days
Mercury	<100	<1	<1	16.5	25	3
Gemini	340	<1	~150	12.8	260	14
Apollo	3000-70 000	CM ---- 3 SM ---- 0 LEM --- 20 Total -- 23	0 210 17 227	[5]1000	390	14
Apollo application	3000-70 000	CM ----[1]50 SM ---- 0 LEM ---247 Total --297	0 210 1500 [2]1710	[5]3200	[3]1250	45

[1]With a crew of 2.

[2]May be as high as 5000 ft^3 if LEM is omitted.

[3]Based on crew of 3.

[4]Based on 40 percent of total time for experiments.

[5]Does not include 1500-W reserve fuel cell.

Table II is a statistical breakdown of past and future experiments. The Mercury experiments have, of course, been completed already. In the case of Gemini, some of the experiments have been completed while others are scheduled for future missions. In the case of Apollo, approximately one-half of the proposed experiments identified so far have received formal approval. As far as the AAP experiments are concerned, we must recognize that they are all still in the very early development phase. In fact, some have not progressed beyond the preliminary concept stage.

Table III includes a list of experiments completed during Mercury, and the degree of success attributed to each. Unfortunately, time will not allow me to go into more detail on these experiments. In fact, when we reach the AAP plan, it would not be meaningful to list all of the titles. However, you should be aware that detailed information about completed experiments has been published in most instances, and as far as the biological experiments planned for the future, these will be discussed by other speakers.

Table IV shows the experiments completed to date as part of the Gemini program. I should mention at this point that it is our intention to hold symposia covering the results of experiments as soon after each flight as possible. The first such symposium was held in October and covered the experiments on board GT-3 and -4. These papers were published in a single volume which is available to you upon request to NASA.[1]

Table V shows the experiments still scheduled for future Gemini flights.

[1]"Manned Space Flight Experiments Symposium, Gemini Missions III and IV," NASA. Held in Washington, D. C., Oct. 18-19, 1965; 236 pp.

Table II. —MSF Experiment Program by Area

Experiment area	Mercury	Gemini	Apollo	Apollo application
Astronomy/astrophysics	3	4	8	12
Bioscience	0	4	2	18
Physical science	2	9	4	26
Atmospheric science	1	2	1	14
Communications and navigation	0	3	0	9
Earth sciences and resources	3	1	1	24
Lunar surface explorations	0	0	16	65
Lunar orbit	0	0	0	20
Advanced technology and supporting research	4	2	0	38
Biomedicine/behavior	5	8	13	23
Extravehicular engineering	0	0	0	18
Operations techniques	0	0	1	12
Advanced subsystems	0	0	1	6
DOD support	0	15	2	0
Total	18	48	49	285

Table III. —NASA Mercury Experiments Program

Experiments	Flown on No.	Success	Astronaut man-hours required
Tethered balloon	7 and 9	partial	0.2
Flashing light	9	yes	0.7
Radiation level measurement	8 and 9	yes	1.6
Micrometeoroid study	9	yes	
Terrain photography	8 and 9	yes	2
Weather photography	7, 8, and 9	yes	2
Horizon definition photography	7 and 9	yes	3
Zodiacal light photography	9	no	3
Ablation materials	8	yes	
Zero-G water ball	7	yes	
Airglow green filter	6	yes	
UV photography	6	no	
Orbital speed reentry	6	yes	
Observation of ground lights	7, 8, and 9	yes on 1 flight	0.3
Xylose absorption test	6	yes	0.05
Calibrated exercise	6-9	yes	0.1
Tilt-table studies with flack test	9	yes	
Evaluation of hormonal output (steroids, catecholamines)	6-9	partial	

Following is a list of experiments approved by MSFEB for Apollo.

- Subcritical cryogenic storage
- Radiation in spacecraft
- Simple navigation
- Synoptic terrain photography
- Synoptic weather photography
- Frog otolith function
- Zero G—single human cells
- Trapped particles assymetry
- X-ray astronomy
- Micrometeorite collection
- UV stellar astronomy
- UV/X-ray solar photography
- In-flight nephelometer
- Cardiovascular conditioning
- In-flight phonocardiogram
- Bioassays body fluids
- Bone demineralization
- Calcium balance study
- Human otolith function
- Cytogenetic blood studies
- Exercise ergometer
- Metabolic rate measurement
- Pulmonary function
- Lower body negative pressure

As indicated previously, this represents only about one-half of those contemplated for the entire Apollo program.

Now to move on to the AAP. Instead of listing all the experiment titles, table VI shows a breakdown of the number of experiments being considered in each discipline, together with the present status of these experiments. What I hope this table will convey is that the AAP experiment program is still in the early stage of development. Relatively few of the experiments have reached the design phase. In fact, NASA would welcome any additional proposals or general ideas as to experiments which should be taken into consideration for future AAP space missions.

Now to delve into some of the management planning aspects of the AAP experiment program. First, I should state that it is our firm intention to treat each and every experiment as an independent entity. That means that each experiment will have a principal investigator

Table IV. —NASA Gemini Experiments Program (Conducted)

Experiment	Flown on No.	Success
Astronomy/astrophysics:		
2-color Earth's limbs photos	4	yes
Zodiacal light photography	5	yes
Bioscience:		
Sea urchin egg growth	3	no
Visual acuity	5	incomplete
Radiation zero G on blood	3	yes
Physical science:		
Electric charge	4 and 5	yes
Triaxis magnetometer	4	yes
Proton electron spectrometer	4	yes
Atmospheric science:		
Synoptic weather photography	4 and 5	yes
Cloud top spectrometer	5	incomplete
Earth sciences and resources:		
Synoptic terrain photography	4 and 5	yes
Communications and navigation:		
Reentry communication	3	yes
Biomedicine/behavior:		
Cardiovascular conditioning	5	partial
Bone demineralization	4 and 5	yes
Inflight exerciser	4 and 5	yes
Human otolith function	5	yes
Inflight phonocardiogram	4 and 5	yes
DOD support:		
8 DOD support experiments		

who will be in direct contact with all aspects of the experiment from its initiation through to completion. This approach is not contradictory to the concept of a centralized flight laboratory capable of serving the needs of several experimenters simultaneously. The objective of the experiment is to obtain data under carefully controlled conditions specified by the experimenter so that he and his associates can study these data and arrive at meaningful conclusions. But this requirement does not imply that the same instrument or set of instruments cannot secure data which would be equally useful to several independent investigators.

I will give an example of this situation which arose during the Gemini flights. Numerous photographs were taken which were of equal interest to oceanographers, geologists, and geographers. Obviously, a single camera was sufficient to satisfy these multiple requirements. It is NASA's responsibility to insure that all these interested groups receive the data which are relevant to their fields of research. At the same time we must insure efficient and economical management of the entire program. Early recognition of equipment commonality is an essential element to meet these objectives. To handle this problem and to prevent incompatibilities between experiments, a carefully planned integration process will be established as stated by Mr. Taylor. As part of this effort, it will be necessary to identify all equipment requirements for the various experiments as early as possible. This will allow prompt identification of equipment commonality and prevent unnecessary expenditures and redundant equipment development. Figure 1 is a dramatic example of how expenses can be

Table V. —NASA Gemini Experiments Program (Planned)

Experiment	To be flown on flight No.
Astronomy/astrophysics:	
Zodiacal light photography	8, 9, and 10
Airglow horizon photography	9, 11, and 12
UV astronomical camera	10, 11, and 12
Bioscience:	
Frog egg growth	8
Visual acuity	7
Physical science:	
Triaxis magnetometer	7, 8, and 12
Bremsstrahlung spectrometer	10 and 12
Micrometeorite collection	9 and 10
Proton electron spectrometer	7
Beta spectrometer	10 and 12
Nuclear emulsion	8 and 11
Ion wave measurement	9 and 10
Atmospheric science:	
Synoptic weather photography	6, 7, 10, and 12
Cloud-top spectrometer	8 and 12
Communication and navigation:	
Optical communication	7
Manual navigation sightings	12
Earth sciences and resources:	
Synoptic terrain photography	6, 7, 10, and 12
Advanced technology and supporting research:	
Color patch photography	10
Landmark contrast measurements	7 and 10
Biomedicine/behavior:	
Cardiovascular conditioning	7
Bioassays body fluids	7-12
Inflight sleep analysis	7 and 9
Inflight exerciser	7
Bone demineralization	7
Human otolith functions	7
Inflight human phonocardiogram	7
Calcium balance study	7

reduced. The number of experiments appear on the abscissa, while the corresponding weight of the integrated payload shows on the ordinate. There is a gross correlation between cost and weight of payload, and consequently the ordinate might equally well represent funding requirements. The importance of figure 1 is that the equipment commonality curve approaches asymptotically a maximum weight/cost figure, whereas the curve which disregards commonality continues to rise indefinitely as the number of experiments increases. Furthermore, the commonality curve indicates a lower funding requirement at all levels of experimentation, including those missions with only a few experiments on board.

Table VI. —Present Status of Apollo Application Experiments

Experiment area	Stage				Total
	Concept	Preliminary definition	Design and development	Operation	
Astronomy/astrophysics	2	8	2	0	12
Bioscience	0	15	2	1	18
Physical science	4	16	5	1	26
Atmospheric science	3	9	2	0	14
Communications and navigation	3	5	1	0	9
Earth sciences and resources	0	19	5	0	24
Lunar surface exploration	2	55	8	0	65
Lunar orbit	0	20	0	0	20
Advanced technology and supporting research	1	24	13	0	38
Biomedicine/behavior	4	10	5	4	23
Extravehicular engineering	3	12	3	0	18
Operations techniques	1	7	4	0	12
Advanced subsystems	0	4	2	0	6
Total	23	204	52	6	285

The experiment planning process followed internally within NASA is quite complex. However, there are a few points worth mentioning. We visualize all experiments going through a sequence of phases: first, conceptual; second, definition and feasibility; third, hardware development. The conceptual studies are generally of short duration and intended to establish the scientific/technical merit of the experiments. The second phase, definition and feasibility, will carry the experiment from concept to breadboarding, and may include simulation studies and special equipment development. The experiment definition study should result in an experiment program plan, including detailed equipment description, specifications, and hardware development. The third phase, hardware development, should cover design, mockup, prototype, flight hardware testing, and delivery of flight-rated equipment.

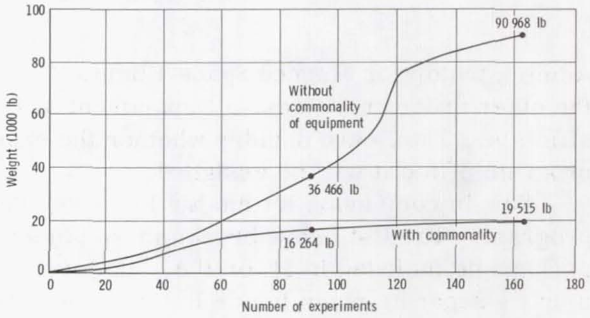

Figure 1. —Effect of equipment sharing.

Let us now briefly consider the experiment approval process. The idea for an experiment may originate at a university or at an industrial organization; it may be conceived by a member of the NASA staff, or some other Government technical agency. Irrespective of how the experiment originates, it will require a sponsor in one of the NASA program offices.

Each of the offices in figure 2 has an experiment review and approval process. After the experiment has cleared this step, it is ready to be funded through the conceptual, and definition and feasibility phases. If the experiment still shows promise after passing this stage of development, a decision must be made as to whether to proceed with hardware development and procurement. This decision is made by the Manned Space Flight Experiments Board, which is under the chairmanship of Dr. George E. Mueller, Associate

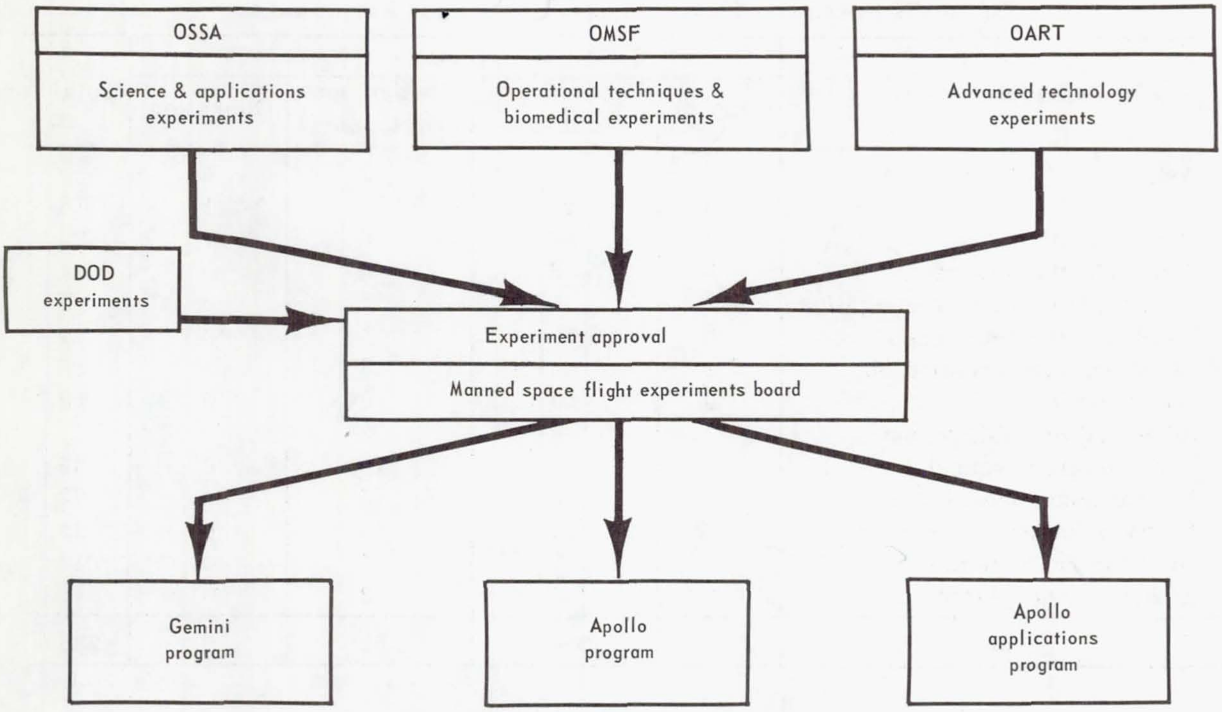

Figure 2. —MSF experiment program.

Administrator for Manned Space Flight. Other members of the Board include the heads of the other program offices, a Department of Defense representative, and several other NASA officials. The Board decides whether the experiment will be continued, and, if so, to which program office it will be assigned.

Now in conclusion let me try to convey the overall objectives of the manned space flight program. The list below breaks these objectives into four separate areas. Category 4 could perhaps be included in IE or IIA. However, in my opinion it is of sufficient importance to merit a separate place in our list of objectives.

I. Use of space:
   A. Improved communications capability
   B. Better weather forecasting
   C. Real-time Earth resource inventory
   D. Worldwide traffic monitoring
   E. Expanded scientific and technological capability
   F. Support DOD

II. Exploration of space:
   A. Expanded knowledge of the universe
   B. Improved space operations capability
   C. Increased international prestige

III. Operations through space:
   A. Improved long-range Earth transportation systems

IV. Life in space:
   A. Increased knowledge of life processes
   B. Improved understanding of behavioral processes

N66 31813

3. SPACECRAFT INTERFACE IN APOLLO, INCLUDING APOLLO EXPERIMENTAL PALLET

RAYMOND CLEMENCE
Planning and Management Office

GILL: Our third speaker will be Mr. Raymond Clemence, who is here instead of Mr. Jack Small, who was not able to make it today. Mr. Raymond Clemence represents the Experiments Office at the Manned Spacecraft Center, the Block II, Pallet, and so forth, and he will be discussing these problems of the real world in the experimental picture.

CLEMENCE: As Dr. Gill mentioned, Mr. John Small is unable to be here because of illness. I hope he and you will forgive me for seeing some irony in the fact that he was prevented from speaking to the American Institute of Biological Sciences by a virus.

I would like to talk this afternoon about the capability of the Apollo spacecraft to carry experiments, and the steps you, as prospective experimenters, might take to assure the successful flight of your experiments.

Let me begin by describing the spacecraft's capabilities.

Figure 1 shows the Apollo Block II command module and the sections of the command module available for experiment stowage. The total weight allotment for the experiments is 80 pounds. The allowable weights shown next to the various compartments are upper weight limits for those specific compartments. It is not possible to utilize the full weight capability of each compartment, since some of these compartment maximum weights exceed the total spacecraft allowable weight of 80 pounds.

Some other standard provisions for Block I and II experiments are as follows:

(1) Space for equipment storage
(2) Electrical power system (ac and dc)
(3) Electrical power and data handling/telemetry outlets
(4) Coolant circuit system (coldplates)
(5) CSM umbilical provision
(6) 80 pounds, gross weight allocation
(7) Data transmission system (real time and playback)

We have already talked about space allocation. There is also spacecraft power available for experiments, and I will discuss this a little more in detail shortly. Spacecraft systems are also able to provide support in areas of data handling and telemetry, thermal control. Provisions for utilizing the command and service module umbilical are also provided, and data transmission capability, both real time and playback, are also provided.

A more detailed description of the available electrical power follows:

Maximum energy: 10 kwh of dc
Source: Electrical power system serviced by nonessential buses A and B
AC power: 3 phase; 115 ± 2-V steady-state voltage
DC power: 27.5 ± 2.5-V steady-state voltage

Power profile: To be outlined for each spacecraft when specific mission requirements are defined. Operation or scientific equipment shall not cause main bus voltage to drop below 25 volts, dc

Other power: When scientific equipment requires special voltage levels, batteries, inverters, and converters will be provided as scientific equipment

A maximum energy of 10 kilowatt-hours of dc is available from the spacecraft electrical power buses A and B. Three-phase, 115-volt ac and 27.5-volt dc power is provided. The specific power profile for each spacecraft is developed just as soon as specific mission requirements are defined. Some power constraints are that operation of the spacecraft or the experiments must not cause main bus voltage to drop below 25 volts dc, and if experiment requirements of electrical power have characteristics different from those described, the additional power or the equipment to modify available spacecraft power must be provided as part of the experiment.

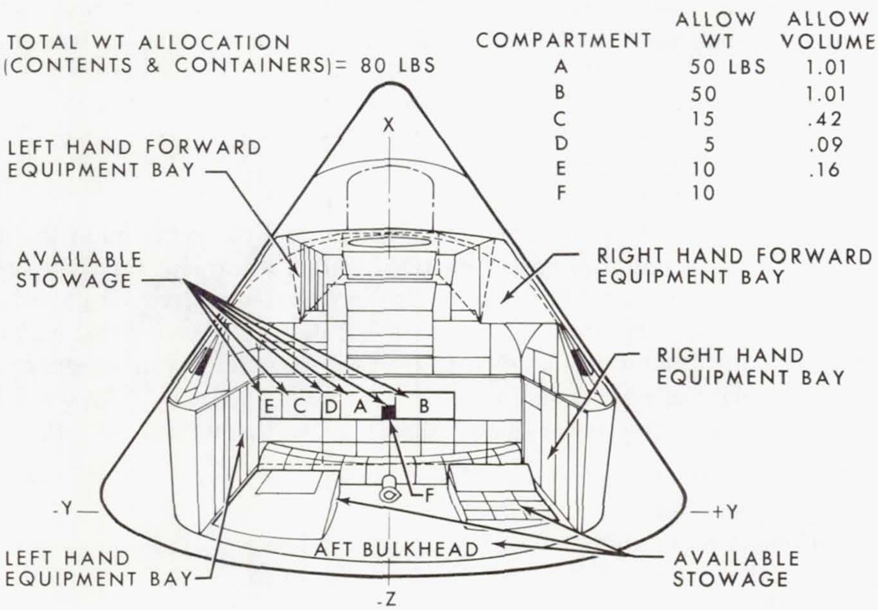

Figure 1. —Available stowage (Block II).

One of the jobs in the environmental control system (ECS) is cooling of spacecraft subsystems. Cooling by the ECS is also available, as shown in table I.

The base temperature range for all locations shown on this slide is 68° F minimum to 118° F maximum, with an average of about 92° F.

The cold-plate capacity for all locations is 1 watt/in.^{2} average, and 2 watts/in.^{2} local.

One interesting feature of the Block II spacecraft will be the experiments airlock shown in figure 2.

The purpose of the airlock is to allow exposure of certain experiments to the space environment without exposure of the entire cabin and crew. The airlock is shown in the deployed configuration in figure 2. Spacecraft hatches are shown in the stowed position.

Table I. —Cooling Provisions

Location	Volume, ft^3	Type of cooling	Coldplate area	Source	Capacity	Base temperature
Block I:						
Volume B lower bay	0.641	coldplate	171 $in.^2$	CSM ECS coolant loop	1 watt/$in.^2$ average 2 watt/$in.^2$ local	118° F maximum 68° F minimum 92° F average
Volume C lower bay	0.618	coldplate	147 $in.^2$	CSM ECS coolant loop	1 watt/$in.^2$ average 2 watt/$in.^2$ local	118° F maximum 68° F minimum 92° F average
Block II:						
Volume A* lower bay	1.01	coldplate		CSM ECS coolant loop	1 watt/$in.^2$ average 2 watt/$in.^2$ local	118° F maximum 68° F minimum 92° F average
Volume B* lower bay	1.01	coldplate		CSM ECS coolant loop	1 watt/$in.^2$ average 2 watt/$in.^2$ local	118° F maximum 68° F minimum 92° F average
Volume D lower bay	0.09	coldplate	56.8 $in.^2$	CSM ECS coolant loop	1 watt/$in.^2$ average 2 watt/$in.^2$ local	118° F maximum 68° F minimum 92° F average

*Note: Volumes A and B in Block II are coldplated for initial lunar landing mission.

Thus far we have looked at the capability of the Apollo Block II command module to accommodate experiments. Now let us consider some truly exciting capabilities and possibilities which the Block II service module affords.

Figure 3 shows the Block II command module attached to the service module, and the experiments pallet. The experiments pallet fits into Sector 1 of the Block II service module. This concept, the use of the pallet in the service module, permits a variety of experiments to be accommodated without changes to the spacecraft configuration and without the necessity for a development program for the integration of specific experiments with spacecraft subsystems. It is anticipated that this technique will enable an ambitious space experiments program to be accomplished at relatively modest program cost.

The capabilities of the pallet in comparison to the capabilities of earlier manned spacecraft to carry experiments is enormous. A single pallet can accommodate as much as 3600 pounds of experiments. This 1.8 tons of experiments is almost twice as much as the estimated weight of experiments to be carried by the entire Gemini program. It has 3600 watt-hours of electric power for exclusive use of experiments, and a volume of about 170 cubic feet. Coincidentally, this volume is identical to the volume of a nine-passenger Volkswagen bus.

About 60 percent of the total volume is for experiments. A typical pallet load of experiments is shown in figure 4. This is just intended for purposes of illustration, those particular experiments shown.

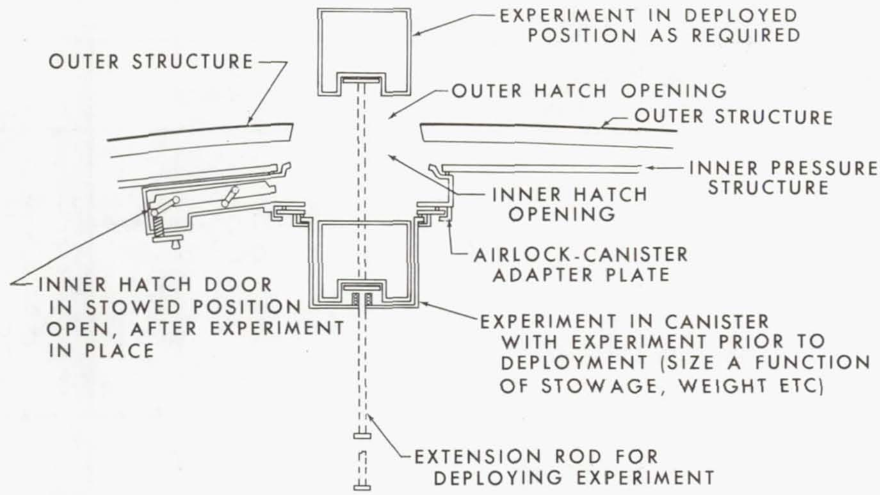

Figure 2. —Experiments airlock.

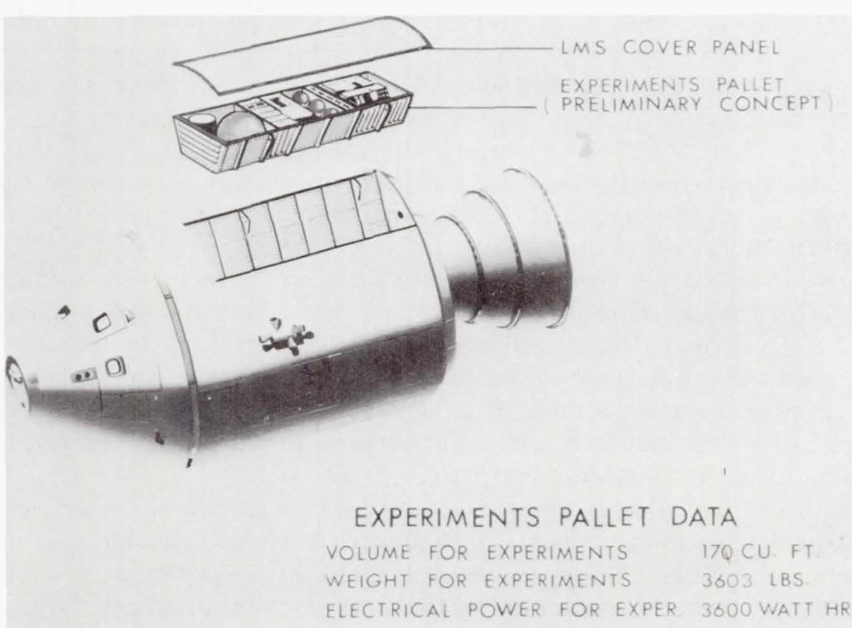

Figure 3. —Block II CSM showing experiments pallet.

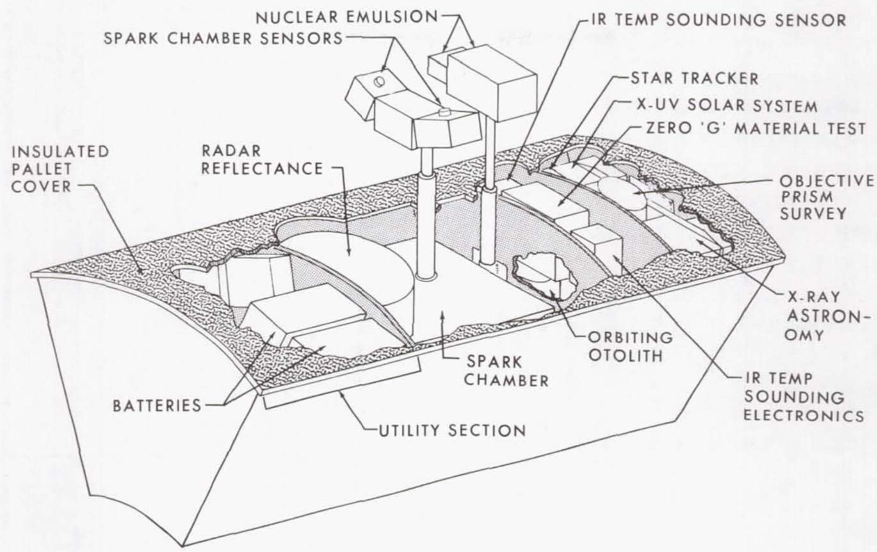

Figure 4. —Typical pallet load of experiments.

I should emphasize that the pallet carries its own utilities, and electrical power system, thermal control system, and data system, which are integral to the pallet. Stabilization and control are provided by the spacecraft, which can maintain an attitude of about plus or minus one-half a degree, and an attitude rate which will not exceed 2.4 arc-minutes per second.

I hope I have given you an accurate picture of the capabilities of the Block II Apollo spacecraft to carry out experiments. Further, I hope I have conveyed the notion that there is a lot of capability.

Now I would like to consider how you as prospective experimenters might exploit this capacity. I will not repeat what Mr. George has already covered with you; that is, the procedure established by NASA for submitting an experiment and having it considered for flight aboard a manned spacecraft. He has already discussed the operation of the Manned Space Flight Experiments Board (MSFEB), but I might bring to your attention the document you have received, NPC500-9, Apollo Experiments Guide, which is an excellent source of information to you prospective experimenters on the steps to be taken in having an experiment considered for manned space flight.

I would like to talk in a little bit more detail about what is done at the Manned Spacecraft Center after we have received an order from the Director of the Apollo program to implement an experiment on a particular flight.

Figure 5 shows the steps or milestones which an experiment goes through after the receipt of this implement order at the Manned Spacecraft Center.

The first, and one of the most important events after receipt of the implementing order, is the completion of a statement of work. A statement of work is just what its title suggests, a clear and explicit description of the work to be performed in implementation of a particular experiment. It generally consists of a performance specification that tells what the experiment will do. The NASA quality and reliability requirements are also spelled out. A delivery schedule, documentation requirements, and the NASA requirements for data reduction and publication of scientific information are other standard features of the statement of work.

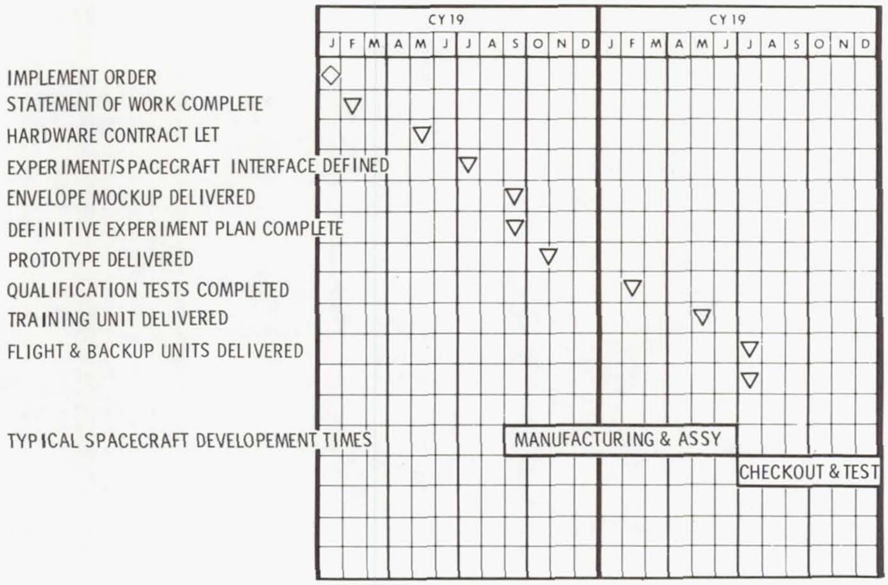

Figure 5. —Experiment implementation schedule.

A good statement of work is no guarantee of successful implementation of an experiment, but a bad statement of work is almost certainly a pretty serious impediment to successful implementation.

A statement of work is prepared by the Manned Spacecraft Center Experiments Program Office, with very close coordination and cooperation with the principal investigator. The statement of work forms the backbone of the contract which is the legal vehicle which joins the Government and the experimenter in an effort to fly a particular experiment.

In some cases the experimenter will agree to fabricate experiment hardware, or to subcontract directly for its fabrication. In such cases, his contract will generally state his intentions. Where an experimenter does not wish to fabricate flight hardware, nor to subcontract directly for its fabrication, the Experiments Program Office will take on the task of contracting for the fabrication of flight hardware.

The choice of which of these approaches to take is generally made by mutual agreement of the experimenter and the Experiments Program Office.

After the completion of the statement of work, the signing of an experimenter's contract and the completion of flight hardware contracts, an experiments spacecraft interface document must be completed. This interface document defines the physical, functional, and environmental interface between the experiment and the spacecraft. The interface document must be agreed to by the spacecraft contractor, the experimenter, and by the NASA.

The remainder of the milestones shown in figure 5, with one exception, deal with equipment deliveries. I would like to speak for a moment about that exception. This milestone is the completion of a definitive experiment plan.

What I said about the statement of work is even more true about the definitive experiment plan. A good one is almost a prerequisite to a successful experiment implementation.

A sample table of contents for this plan follows:

Title
Objective
Description
Prelaunch techniques
Operations requirements
  Crew-oriented requirements
  Flight operational requirements
Data requirements
Proposed suit modifications
Crew training plan
Detailed data processing plan
  Photographic criteria
  Data-processing requirements
  Control
Preflight, flight, and postflight plans
  Preflight, flight, and postflight plans
  In-flight requirements
  Postflight debriefing plan
In-flight consultation plan
Status report
Postlaunch report
Experiment supplement to the postlaunch report

This will be the authoritative reference on a particular experiment. It will be used by the spacecraft contractor, by the Manned Spacecraft Center, and by other elements of the NASA, such as the launch operations personnel at the Kennedy Space Flight Center.

The plan serves to notify the many organizational elements—and there are many involved in a manned space flight—of support that they may be required to give to an experiment. A good example of this is the S-4, 0 G, and radiation on blood during the Gemini 3; the requirement that blood samples be taken from the crew and from a preexamined subject; storage of these blood samples prior to flight; simultaneous conduct of the experiment on the ground, simultaneously with the experiment conducted in flight. These are the kinds of things that the definitive experiment plan should point out, and notify all of those elements, as I have stated, involved in a manned space flight of support which they may be required to give to an experiment.

Let us return for just a moment to figure 5 and talk about delivery of hardware. The numbers of units required and their types, that is, mockups, prototypes, qualification test units, flight hardware, spares, are specified in the contract. The units shown in figure 5 represent normal requirements. They may vary as a result of the number of missions to be flown by a given experiment, its complexity, and a number of other factors.

Two important points to note are that successful completion of qualification testing is prerequisite to flight, and delivery of flight hardware should occur at the beginning of the checkout and test of the spacecraft. This can be as much as 9 months prior to flight.

If I may, I would like to recap what I have covered thus far. We have looked at the capabilities of the Apollo Block II spacecraft to fly experiments, and we have reviewed the steps the prospective experimenter must take in order to fly his particular experiment. More specifically, we have seen how we in the Experiments Program Office of the Manned Spacecraft Center work with the experimenter in trying to assure the successful implementation of his experiment.

Before closing, I offer the following special considerations for manned space flight experiments.

Crew safety

Spacecraft/experiment compatibility
- Technical
- Schedule
- Quality control
- Reliability
- Mission

Crew training

First, of course, is crew safety. I think you as bioscientists are keenly aware of this requirement. In fact, much of your effort is devoted to just that objective.

Experiment spacecraft compatibility is also important, in each area shown, technically. For example, the experiment must be designed to survive the rigorous boost environment, as well as designed to function in orbit. I think Dr. Montgomery's and Dr. Gualtierotti's experiments are good examples. This morning the message came through loud and clear of some of the requirements placed on their experiments by the fact that they fly aboard a spacecraft which has to be launched and has to withstand the rigorously severe boost environment.

The experiment must be developed in sufficient time to support spacecraft schedules. The levels of quality and reliability must be commensurate with flight objectives. Finally, they must both be compatible with the design mission, and with a multitude of contingency or off-design missions. This sometimes is a major effort to build the experiment to survive the off-design missions. The design mission in some cases is relatively straightforward, and it is the contingency or off-design missions which consume a good deal of your effort.

Finally, if we are to make the maximum use of the man as a scientist observer, as an intelligent and discriminating operator, we must give adequate attention to crew training. Familiarization of the crew with the experiment objectives, the operation of the experiment equipment, and the part to be played by the crew in performing the experiment are all vital to making the crew what I call experiment oriented. Optimization of the man-machine, or in our vocabulary, man-experiment system, should be a prime objective.

I would like to say that I have just barely touched on the problem of data reduction, analysis, and dissemination of results. This is certainly not because this effort is unimportant or relatively straightforward. Quite the contrary. It results from the fact that this presentation sought to emphasize the spacecraft capabilities and steps leading up to successful flight. I personally feel that our increased payload capabilities present some rather interesting problems to the agency and to you as experimenters in the area of data reduction, analysis, and dissemination, if for no other reason than the sheer bulk of data generated by these large payloads.

In closing, I would like to say that we at the Manned Spacecraft Center feel that the Block II Apollo spacecraft offers attractive possibilities for carrying on experiments, and we do welcome your efforts toward putting the spacecraft capabilities to good use.

DISCUSSION

BRODERSON: Mr. George, what do you mean by the topic, extravehicular engineering?

GEORGE: That includes an area which results in one of the astronauts actually leaving the space vehicle itself to conduct certain experiments outside of the vehicle. I can give you an example of that. For example, the erection of the large communications antenna outside of the space vehicle itself, the man actually leaves through an airlock, goes into outer space, assembles the antenna, which has already been constructed, of course, and is inside the space vehicle. He actually assembles it outside, and then returns into the space vehicle. This would be an example of an extravehicular activity.

PINCE: Mr. Clemence, are those illustrations available anywhere, so that those of us who do not write as quickly as you talk can have the benefit of what you have just said?

CLEMENCE: I apologize for my quick talking. My wife warned me about that, but I did not heed her advice, it seems. Yes; I think we could make those available. They are not available any place else, but for the glass originals that I have with me. But I can, if you will give me your name and mailing address, get a packet of glossy prints to you, and I would be more than happy to mail you copies.

STAUB: On the temperature control system, could you give us the range of calories exchanged, and what method of cooling or heating is used?

CLEMENCE: In the command module itself?

STAUB: Right.

CLEMENCE: The spacecraft contractor has prepared a detailed performance and interface specification which specifies the operations which they will guarantee to the experiment. They are just as I indicated to you. The temperature range for the various locations shown in figure 1 are taken directly from that performance and interface specification. That range I have given was about 68^{o} F, I believe, to about 118, was the range, and the average temperature was about 92^{o} F. The heat rejection in those compartments, or the rate of cooling, was 1-watt-per-square-inch average, and 2-watt-per-square-inch local.

STAUB: So within the given module or compartment using electrical devices, further local cooling would be possible?

CLEMENCE: That is correct. What I said about electrical power is also true of cooling requirements. If the experiment requires capability beyond that provided by the spacecraft, you are perfectly free to provide that capability as part of the experiment, but it will penalize you with regard to your weight available. In the pallet, it is a little different situation. The cooling system in the pallet design itself is evolving, and we do not have firm capabilities to give you at this time for the pallet.

MARTON: I do not mean to take you to task for this, but Mr. Taylor brought up the point, too, and that is this pallet concept. I find that particularly dangerous, since what we are doing is taking a pallet and putting it external to the pressure area, and once the vehicle is spaceborne, the man has no access to it. How do we who are interested in manned space flight, and yourself, justify the inclusion of three men into what essentially is a package that they cannot modify or touch?

CLEMENCE: I would not, first of all, presume to defend the pallet concept for NASA, but I will give you my individual opinion. First of all, I do not believe that access to the pallet is completely out of the question.

MARTON: He would have to go extravehicular in order to get at it.

CLEMENCE: That is true.

SACKEY: Is it not possible that there are many experiments that could fit in the pallet in which there would be absolutely no reason for the astronaut to have any access to the pallet? I wanted to blow up a little controversy here.

CLEMENCE: There are a number of experiments that can be put in the pallet that the astronaut would not have to physically get in there and manipulate. I think, however, he does serve a very useful function, in that displays and controls can be provided in the command module which would monitor the observation of experiments which are in the pallet.

SACKEY: My own view is an expression of delight really over the fact that we might eventually have enough space on some of these vehicles to plan some rather detailed experiments, broader experiments.

CLEMENCE: I think I heard somebody say, when I talked and gave a little homely analogy about what sort of volume that is, like a nine-passenger Volkswagen bus, that we can now put up a nine-passenger Volkswagen bus. But it does. And it is encouraging, and frankly it is very exciting that we do have this kind of capability.

GUALTIEROTTI: One point to me is very critical, because of the experiments ahead. What about a data-processing system for this kind of large load of experiments? We are hard put to instrument our rather minute necessities in the mission. There are so many different experiments with so many different specifications as far as the system is concerned; how can that be managed? I would like to hear some thoughts on this.

CLEMENCE: The data handling of the amount of data generated by this kind of payload weight?

GUALTIEROTTI: Yes. There might be a number of different specifications where the different information has to be stored and printed. For instance, frequency response of the data-processing system, duration of the actual acquisition time. It may be continuous. That means on different channels. Now, a payload like that would mean an enormous amount of channels for the different specifications.

CLEMENCE: I think that the data problem is perhaps somewhat analogous to the thermal problem or the electrical power problem, in that you do have significant growth in the capabilities that these subsystems require, and they are being considered in the design of this pallet. There also is the capability of utilization of data storage and data transmission capability of the spacecraft itself. So I think the people who are responsible for the design of the pallet are considering these things, and are trying to provide and have a definite feeling that they must provide a data system that is compatible with that great volume of weight that you can have.

GUALTIEROTTI: That is a kind of reasoning that is very nice, but we had, for instance, a problem with our experiment, and we had to content ourselves with some halfway solution, instead of the best one, because we had to share channels, and therefore the frequency response was not exactly the same. There comes a certain point at which you make sort of a halfway provision like that, and your chances decrease.

CLEMENCE: I think one of the reasons for the evolution of the pallet concept is just the problem you ran into with your experiment, in that you had to rely on spacecraft subsystems for data reduction, for thermal control, and they had to provide all of the support of the experiment; whereas the pallet has its own utilities, its own electrical power, its own thermal control system, its own data system. It will free you from restraints that the spacecraft itself has placed on you previously.

GILL: I think Dr. Gualtierotti is worried about the fact that we might attempt to do too many different things at the same time, too many different kinds of experiments. I think we do not contemplate this. We intend to specialize as soon as we can. In other words, we might conceive of using the pallets, say, for life science experiments, or we might conceive of using it for astronomy experiments, or for things that went together.

GUALTIEROTTI: That is OK, but take the life science experiments, take any kind of recording of electrical activity in the system, you go from dc potential which has been found to have to be on the order of 5000 per second. That is an enormous range. If you have a number of experiments that are in that kind of payload, and you make one pallet, say, only for biological experiments, you might be in a more difficult situation. It might be easier to have, for instance, our experiment, and the data-handling system, together with the noise band, not to include biology, because we find out that the two same things were more compatible. That is quite a problem.

GILL: Well, compatibility is certainly a very great problem.

CLEMENCE: Dr. Gill, if I may, I would like to say that the pallet also enables you, because of its great payload capability, it is conceivable that you could design a data system as part of your experiment package, and supplement the existing capability, if your experiment package has rather unique data-handling or telemetry requirements.

GUALTIEROTTI: Yes; but there is still a limited type of telemetry.

CLEMENCE: That is true.

GILL: You are just getting into the problems. There is no question about it.

PITTS: Is there anywhere collected into a single document a list, preferably with abstracts, of the experiments that have been flown and are approved to be flown in a manned spacecraft? The point is that in the listing, I see several titles which suggest things which I might want to propose, you see, and I do not want to put a lot of effort into rediscovering the wheel.

CLEMENCE: Representing the Manned Spacecraft Center, we do have some involvement in this, but what I am going to do is try to pass the buck to somebody from headquarters involved in the experiments program, and perhaps they could better answer that question than I could.

GERATHEWOHL: I hope that I can cover this later.

DE VINN: I wonder if you could give us some idea of the demands we could place on the astronaut, and how much time would be available for training, how long a task might be performed in flight, and how complex a task might the astronaut do?

CLEMENCE: That is one I would like to pass on also to Dr. Gerathewohl. The requirements for utilization of the astronaut's time, to my knowledge, are nowhere generally described. There is no publication, and for a number of reasons. I think they are good ones. The mission-duration changes, and the required use of their time in performing operations that are directly connected to the flight itself, directly connected with checking or testing on-board subsystems, or performing a maneuver like rendezvous, which is essential to the overall mission objective of landing three men on the Moon, but could not be properly classed as a scientific experiment. So I cannot really give you the general answer about what demands you can place on the astronaut's time and how complex a task you can ask him to do, but I will give you a general comment, which is probably not what you want. I think as the emphasis is shifting from the development of manned space vehicles and their hardware in just proving that they will work, and that man can survive for 14 days, the emphasis will shift from that to utilizing this platform. I think some of the previous speakers touched on the fact that that emphasis will shift. As we more and more develop confidence in the spacecraft and its ability to support the crew, I think you will see a shift in emphasis in the crew's utilization more and more toward using them for experiments.

So all I can say is that I think the demands on the crew have utilized their time quite fully, and crammed the mission full of everything we could up to now, but I think you are going to see more of that, and I think you are going to see more of an emphasis on using spacecraft as an experiment platform. I think that the possibilities of your placing demands on the crew is why we are flying a manned spacecraft, and not an unmanned. I think we want to use them to the very maximum, but I cannot give you a specific answer.

THUROW: Back to this temperature control thing, I think some of this supplementary cooling could be dispensed with if we knew the exact duration of the extremes of temperature in the different locations of the spacecraft. In some instances you could substitute insulation where the particular organism would not be bothered by extremes of certain duration. This information has not always been made available.

CLEMENCE: I think if we would be to the point where we have a specific experiment and had been given an order to implement, we would sit the principal investigator down with the spacecraft contractor, and they would be able to provide you with a great deal of detailed information about temperature, vibration, environment, in a specific spacecraft location. But all they have agreed to provide right at the moment is a performance and interface specification which tells the general performance of the overall spacecraft. But when we reach the point of having a specific experiment, and having an order to implement, we would be able to provide that kind of detailed information.

GUALTIEROTTI: Is there any chance in this particular mission, or a future mission, as the flight develops as an experimental tool that some of the most difficult phases of flight can be reduced, like, for instance, acceleration vibration? Is any thought being given to having a vehicle which is smoother in flight, because whenever we look at a biological study, this high-acceleration vibration range especially is a very demanding initial factor, and may alter severely the success of the experiment, or the entire findings of the experiment?

CLEMENCE: Well, I think the approach here would be just as I mentioned for the data system. Rather than go into the development of a new vehicle, the increased payload capability would allow you to isolate your package, to give it the degree of isolation or the degree of isolation from vibration environment, or from noise or from special temperature environment in particular parts of the spacecraft. These increased payload capabilities will allow you to do that as an integral part of your experiment, to isolate it from the harsh launch environment, for instance, with a fairly brute-force-type vibration isolation system. Increased payload allows you to do this.

CRANDALL: Can you tell us what the guaranteed maximum G-levels will be in both the pallet and also in the AAP configuration?

CLEMENCE: I cannot guarantee the maximums in the pallet at this time, and I cannot recall from memory what they are for the command module, but I do have a performance and interface specification with me, and I will be more than happy to look at that. It does contain the vibration profile for the launch phase.

CRANDALL: I am not speaking of launch phase. I mean the actual orbital operation itself.

CLEMENCE: The maximum accelerations——

CRANDALL: 10^{-2} or 10^{-3}?

CLEMENCE: No; I could not specify those for you. They would be much higher than that, particularly if you had firing with your service module engine or your reaction control jets controlling the attitude of the spacecraft, I think, would give you accelerations that would exceed that, but I do not know. I think it would properly be in the interface specification just what impulse the reaction control motors give and during the normal operational mode what accelerations you would likely have.

WILLERS: Consistent with the requirements for crew safety, to what extent could not only the time of the astronauts be used, but the astronauts themselves be used as biological experimental material? I was thinking would it be possible, for example, with proper training, to draw blood specimens during flight for processing, rather than postflight blood specimens?

CLEMENCE: The use of the astronauts themselves is, of course, already happening. The Manned Spacecraft Center has quite an extensive medical program utilizing the astronauts. I am sure they have every intention to continue. The one thing that presents a bit of a problem is, of course, the fact that they have been required to have the full pressure suit on during flight. If some of the things you are considering are possible with the suit being worn by the astronaut, I am sure that those experiments would be considered by the NASA.

MARTON: Do I understand in the case of the pallet, this is nonrecoverable?

CLEMENCE: The total pallet? That is correct. It is nonrecoverable. The service module detaches from the command module just prior to reentry, but it may be possible through extravehicular activity, or even some sort of mechanical mechanism for withdrawing tapes or certain data, film packages, or whatever, from the pallet, and stowing them in the command module, and then returning to Earth with them.

WALLMAN: This is to Mr. George. He mentioned in the experimental program here of jumping from rats on up to chimps, and nothing was mentioned in between. There are some good baseline data on macaques, and I just wondered if this was considered. Certainly with a 48-pound return, you are not dealing with a mature chimp, and there are certainly some advantages to using a mature primate. Was that just used in a loose sense, that chimps included all primates?

GILL: Dr. Gerathewohl, would you answer that?

GERATHEWOHL: I may be able to give you the answer right now, although I will speak about this tomorrow morning. The two species that were used were rats and chimps, and only representative of what could be done.

WALLMAN: That is what I thought it was—representative.

GERATHEWOHL: They are representative. They are not experiments that have been accepted as just experiments for rats, but will cover the whole range of experimental animals.

DRYSDALE: The question is about what kind of skills are available? Are they life scientists trained in astronautics, or will they be astronauts tried on biological problems?

GILL: Dr. Gerathewohl, would you attempt to answer that?

GERATHEWOHL: The question was what kind of people will be available to do experiments in the AAP. Are these astronauts which have been trained a little bit on the sideline to know how to prepare a petri dish and to do some biology, or are these biologists who are being trained as astronauts?

This, again, is one of the subjects I am planning to cover tomorrow morning. You are stealing all of my thunder. But we have at the present time astronauts who are the technology types, the flying personnel types who are being trained to do the experiment just by performing some manual labor, so to speak. At the same time, you may have heard that the National Academy of Sciences and NASA have been selecting the first astronaut-scientists already, who are trained scientists, who are now being trained as astronauts. These are the first six scientists who are being called astronaut-scientists or scientist-astronauts, on whichever part you want to put the main emphasis. But these are actually scientists, people who know how to do experiments in the special discipline. It is very unfortunate, though, that none of the biologists who had volunteered for this program were selected. They did not classify according to the standards that are still being applied for astronauts. So at the present time we do not have the biologist in the astronaut-scientist training program. This has to be remedied. I think I can say with some assurance: when we need the biologists in orbit for the experimental work there, we will have biologists all right.

DRYSDALE: I have another question about the atmosphere available for bioscience experiments. Is it going to be the same atmosphere as is available for the astronaut, or is it going to be a normal atmosphere like we run our experiments in on Earth?

GILL: Well, I will attempt that. I may be talking out of turn. But in view of the amount of payload that is available, I suppose that you could construct your own atmosphere if you had to. If you wanted a special atmosphere for your experiment, you could construct it.

DRYSDALE: Well, in most of the biological experiments, we are going to compare the effect of weightlessness, and so forth, and we have to turn the factors so that the variable will be only weightlessness and not other different atmospheres that might be the results of different experiments. The astronaut will be living in an atmosphere with a different pressure and different composition than the experiment, where the experiment is performed, so how will we get access from one atmosphere to the other?

GILL: Well, that would be a problem, but I suppose there will be a solution, at least a first-order solution.

GUALTIEROTTI: I have a very naive question. What is the basic philosophy for the pallet business? Would it not be nice to have a second subcapsule for the same thing, which is fully instrumented initially just exactly like the capsule of the astronauts, and have a nice environment there very similar to a laboratory? With the same payload and the same complication, I think two satellites would be just as good.

GEORGE: I might say that NASA has given some considerable consideration to the point that you raise here. In fact, there has been a proposal that was made regarding the development of what we refer to as an experiment module. That is pretty much what you are describing here. However, the present philosophy of the Apollo Applications Program is that we will try to stay as close as possible to the basic Apollo hardware, and not go into any major modifications during at least the early phases of the AAP. Now, the experiment module, or canister, as it was referred to occasionally, would represent a fairly major deviation in terms of hardware, so that is probably going to be one of the restraining factors. However, your idea, I think, is a very good one, and is certainly going to be considered by NASA. Possibly Mr. Taylor has something else to add to that.

GILL: Perhaps you would restate the question. Will you repeat the question, and Mr. Taylor will answer it in his way.

GUALTIEROTTI: My question is given the amount of money and effort to build a separate pallet, and the amount of weight and space we have there, costing a lot of money because it has to have its own refrigerating system, its own atmosphere support. My question was what was the reason not to study to start with a second module system. Instead of having all these different pieces, each one of which has to take care of itself, build a satellite-like structure, why not build a second module with a space already serviced with air, power, temperature control, and everything?

TAYLOR: Well, we have done quite a bit of study on this, as a matter of fact, and have traded off various new configurations, as Mr. George suggested, of alternate spacecraft modules against what we already are building and spending a considerable amount of money to build and fly.

GUALTIEROTTI: Well, there is one more point that I would like to find out, if there would not be more advantage if the two modules were intercommunicating, so that if anything goes wrong, the astronaut can go in the second one and take care of whatever is not working properly. It would be an enormous advantage.

TAYLOR: Well, I think you should keep in perspective that the pallet is not the only capability for handling experiments in the Apollo Applications Program. As a matter of fact, in my discussion earlier, I discussed the use of the LEM system as a module as you are talking about. Now, it is not an optimum module, either, but it does sort of double or triple the pressurized volume available for shirtsleeves operation by the astronauts about 250 cubic feet. It is interconnected directly with the command module, and it does have life-support, power, and electrical communications subsystems to support experiments that do require the direct monitoring by the astronaut actually operating it. As a matter of fact, the bioscience mission which I described involves the astronaut directly in operations with the specimens or the animals which are carried on that particular mission. So we have traded off and done a number of engineering and programmatic analyses of developing new alternate spacecraft modules to substitute for the LEM. They have lots of attractiveness. However, in the kinds of studies which I indicated earlier, I showed you the one bioscience mission where we actually analyzed some 20 missions, and we have not had identified for us in our studies any experiments which require any more pressurized volume to perform the experiments than the LEM has. As you say, NASA is spending a lot of money, and spending it to man-rate and qualify spacecraft modules that are reliable and safe. We feel that before developing new and additional modules for other purposes, we should see what the capability is of the ones we are developing. So far, it appears that the use of the LEM system with the command and service modules is a very flexible orbiting-laboratory configuration. Possibly it is not optimal. Neither would a larger module with like a 45-day or 90-day lifetime limitation be optimal. I do not know whether that helps any.

SACKEY: When you speak of a pressurized volume, is this still 100 percent oxygen, or will you start thinking again of ambient atmosphere some time?

TAYLOR: The Apollo spacecraft as it is now being built in on a 5-psi, 100-percent oxygen atmosphere, or nominally 100 percent. There are traces. For the longer duration missions that we are considering, we are doing design studies on changing this environment system to a two-gas system. It will not be at one atmosphere, because this involves considerable structural problems, or structural redesign and weight, but it does appear that a 5-psi, or possibly a 7-psi, two-gas system is compatible with a relatively minimum change and a relatively early availability, so this is what is now being defined in our design study.

The early flights that I described that use the Apollo hardware precisely as it is being built for the lunar mission will be in 100 percent oxygen, 5-psi atmosphere. The later ones—1970, 1971, and beyond—may have a two-gas atmosphere, either oxygen and nitrogen, or possibly oxygen and helium. Oxygen and nitrogen look better to us.

OLCOTT: Will there be no more than 80 pounds of capability for return?

TAYLOR: No; that is the current specification on the Apollo lunar spacecraft, and it is based on not only the command module reentering capability, and the parachute hung weight. There is a lot of margin there. It is also based on the LEM's capability to launch from the lunar surface that amount of lunar samples. The design of the command module is geared also to this. So the basic specification now is 80 pounds. Our design goal in the preliminary design of the follow-on spacecraft is something like 250 pounds, and this looks like it is reasonable to expect. As a matter of fact, as far as weight is concerned, you can get considerably more than that; maybe up to 700 or 800 pounds. Then there is the problem of center-of-gravity location, and that sort of thing, to keep the L-over-D aspect proper.

SACKEY: That is for the command module?

TAYLOR: That is return to Earth in the command module.

HENRY: What is the current thinking so far as on-board controls are concerned? I am thinking specifically that we have heard quite a bit about synergistic action between essentially 0 G and radiation, and this, that, and the other. Is there any thought being given to the possibility of getting 1 G up there, so you could run controls at the same time?

TAYLOR: Yes. You mean variable G specifically.

HENRY: Well, specifically I mean 1 G versus some lower number.

TAYLOR: Let me break that down into variable gravity for man versus variable G for small biological samples.

HENRY: I was thinking for small biological samples.

TAYLOR: All right, fine. In the feasibility studies we have done, as a matter of fact, in that flight for which I showed you the engineering drawing, there was included a small sample centrifuge in the LEM laboratory space for just the purpose you describe. There was also included, if you recall, and I pointed it out, a concept of a one-man centrifuge for variable G dependent on the radial arm and the rpm associated with it. There are other concepts for getting artificial gravity in the spacecraft for the crew, namely, the separation of two portions of the spacecraft, or the spacecraft and the launch vehicle, and setting up a large rotation there. As far as we know, there are no adverse effects of 0 G on the crew, so we are not planning an artificial gravity capability as an inherent part of the spacecraft for the crew. We feel that we should do some sort of contingency planning in the event that you need some conditioning artificial gravity, but it seems to us that in putting experiments or putting spacecraft into space, the purpose is to determine the effect of the space environment, and so therefore unless forced to we would not provide artificial G for the crew. But for samples, laboratory samples, it certainly is possible. It does take weight and it takes power, but we seem to have weight and power capabilities within limits.

HENRY: Would it be possible to get copies of these illustrations?

TAYLOR: I talked to Dr. Gerathewohl.

GERATHEWOHL: We have not decided yet whether we are going to transcribe the whole meeting and publish it, or bring it out so you can have it, but if there is a demand for it, and since we have everything on record anyway, we will do this. I think from the many responses we have had so far, this will be the way we will do it. So you all, or at least the participants, will get the summary of this meeting in published form, including the illustrations.

TIBBETS: Will we be able to use fluorescent lighting in these systems?

TAYLOR: I do not know of any prohibition on it. It depends on the illumination levels, and whether there are any specific requirements of your experiment that require more volume than we have got, but there is certainly power and the volume available to do it.

TIBBETS: There is concern for the noise that fluorescent lighting puts out.

TAYLOR: Are you talking about continuous, or just for short intervals?

TIBBETS: No; continuous lighting.

TAYLOR: Well, we have specified certain light levels in the volume for the purpose of conducting the experiment, and at the moment I am not familiar with the illumination levels and whether fluorescent or incandescent is preferred. I would have to check on that. Except for the EMI problem, if you want a continuous fluorescent lighting, then you may have an electromagnetic interference (EMI) problem, or I am sure you would. The question is can we suppress it or live with it or isolate it, and I just do not know. I think if it is a requirement that you have to have fluorescent and incandescent or other types of illumination are not satisfactory, then it is an engineering problem for us to work out how it can be done. But I cannot give you the answer right now as to whether we can or not.

REPRESENTATIVE OF NORTH AMERICAN: I am wondering if you have given any consideration to the issue of placing an on-board radiation source in any of the configurations? I am involved in the first biosatellite experiment where we have the capability of doing a radiation-weightlessness interaction experiment, and this might be very valuable. This could be a generalized condition, and a number of people could avail themselves of it.

TAYLOR: Well, you are from North American, and I am sure your people know there are some radiation sources already on board of some of the missions. For example, the propellant-level-measuring device used in the propellant tanks is a cobalt 60 device. In the lunar mission, the lunar surface experiments package which is now under definition will involve an RTG employing an alpha-emitting isotope. There is no inherent reason why a specific reference source, as you, I think, are referring to, could not be involved, but it takes a systems look at the interaction between this source, whatever dose level or energy level you want to to operate it at, what its effects will be on the rest of the spacecraft or on other experiments. There is no prohibition to it. There is already artificial radiation, manmade radiation sources on board. So if a specific experiment requires it, it could be provided, but it would take a fairly careful look at its effects on the other activities planned. If you want a strong gamma source, for example, to test the effects of living cells, then because of the fact that you have the crew on there, there have to be fairly careful design provisions. But I will not say it cannot be done.

SESSION III

Morning, November 23, 1965

1. BIOSCIENCE EXPERIMENTS UNDER CONSIDERATION AND REVIEW FOR AES AND AAP

SIEGFRIED J. GERATHEWOHL
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BEEM: Now we are going to delve into the AAP concept a bit further. Our first paper is by Dr. Siegfried Gerathewohl, Manager, Life Sciences Projects, OSSA. He will be talking on "Bioscience Experiments Under Consideration and Review for AES and AAP."

GERATHEWOHL: It must have become clear to you from the previous presentations that NASA has a continuing effort underway to define experiments for the Apollo Applications Program. This is necessary to assure maximum utilization of the Apollo spacecraft when they become available, and to permit the planning of a program which is compatible with the technical and scientific requirements for doing research in space. About a year ago, a questionnaire was sent to a representative segment of the scientific community (including scientists at NASA field centers) to obtain their suggestions for experiments in Apollo spacecraft. In addition, advisory teams were set up in the various scientific disciplines for the review of these suggestions. I was appointed Chairman of the Manned Earth Orbital Technical Advisory Team on Bioscience. Dr. Walton Jones from OART was Cochairman. Other members of the team were Dr. Belleville, Dr. Fellows, and Dr. Saunders from NASA Headquarters; Mr. Lewyn and Dr. Soffen from JPL; Mr. MacLeod from Goddard Space Flight Center; and Dr. Winget from Ames. This group convened early in January of this year at the Washington office of the American Institute of Biological Sciences, and laid the groundwork for a report on Bioscience Experiments for a Manned Orbiting Laboratory. This report was then used by the individuals in charge of this exercise—Mr. Dennis and Mr. Garbarini—for their "Advanced Earth Orbital Mission Definition Document" (dated January 19, 1965), which contains "the preliminary description of the rationale, content, structure and proposed method of implementation of a comprehensive, cohesive manned Earth orbital experiment program."

Before I present a survey about the contributions of the biologists to this document, let me briefly report on earlier efforts on this same subject.

Nearly 2 years ago, Dr. Soffen was called to the newly created Manned Space Science Division at Headquarters, NASA, to prepare recommendations for a bioscience program to be conducted in a Manned Orbiting Research Laboratory. Dr. Soffen gathered a group of life scientists, mainly from the Washington area, and discussed the problem individually and during several sessions with this group. This work resulted in the "Preliminary Bioscience Recommendations for MORL Program," which describes the problem areas and possible biological investigations in very general terms. It was undoubtedly of value to the follow-on studies, which were undertaken by the Bioscience Team for the so-called Garbarini Exercise, which led to the "Advanced Earth Orbital Mission Definition Document," which is also the basis of the present Apollo Applications Program.

Some of the facts and some of the fancies of such an effort must be pointed out at this conjunction.

(1) We are faced with the reality of big boosters and large spacecraft which will be manned and available for Earth-orbiting flights in the 1968-72 time period. We can now assume with a relatively high degree of certainty that astronauts—and eventually scientists—will be able to experiment in space.
(2) We are aware that scientists of various disciplines are proposing experiments for manned spacecraft and that—for example, in the areas of space medicine, space technology, and the geological sciences—impressive programs are already under development.
(3) We know of quite a number of biologists who are interested in the opportunities offered by manned space flight and want to participate in our program. As a matter of fact, that is the reason why you are here.
(4) NASA and the National Academy of Sciences have already selected the first astronaut-scientists, and a curriculum for their training is being worked out at present.

On the other hand, there are all sorts of contingencies or limitations which confront the scientist who is planning to submit experiments. The major contingencies are listed as follows:

(1) Availability of appropriate launch vehicles and spacecraft
(2) Provision for adequate flight and mission profile
(3) Requirement for manned inflight experimentation
(4) Man's tolerance of spaceflight conditions
(5) Capable and competent scientist-astronauts

First of all, the launch vehicles and the spacecraft to be used must be appropriate. I am not quite sure whether the LEM, which will be made available for accomodating experiments, will suffice as a laboratory facility. The nominal capabilities and characteristics of the spacecraft and launch vehicles include minimal modifications of Apollo hardware for Earth orbital missions. Moreover, it is not clear yet whether or not adequate flight and mission profiles can be provided because of the high acceleration loads during launch and reentry. Our present launch vehicles are "man rated" only in regard to the astronauts. If a strong case for scientific inflight experimentation can be built—and I intentionally use this terminology—flight and mission profiles will have to be adjusted to the scientific requirements. For example, the guidelines for our exercise specified that if particularly significant experiments require modifications, such experiments should be proposed with a qualitative indication of the required changes, as well as any additional spacecraft capability that may be needed.

At present, we have three sources which provide leads to the requirements for experimentation in manned spacecraft. The first one is the manned space-flight program by itself. Although 21 Russian and American astronauts were exposed to space-flight conditions with no lasting detrimental effects for periods up to 8 days, man's tolerance to long-term weightlessness and its interaction with other factors has not been established yet. The experiments, which were conducted in manned spacecraft, yielded interesting but inconclusive results. I am referring, for instance, to Dr. Mack's experiment on bone demineralization and Dr. Bender's experiment on radiation and weightlessness effects on human blood. These experiments therefore should be continued. The second source is the demand from the biological science community for doing research in space. So far, this demand was not very strong—partly, I think, because of lack of information about the opportunities, partly because of the biosatellite project, which is our third source of information. Until recently, the biosatellite was the only projected source for obtaining data about basic biological phenomena in the U.S. space program. However, the first of the biosatellites will not be launched before the end of 1966, and results of the experiments in the last spacecraft of this series will not be available until perhaps 2 years later. If no provisions are being made for continuity now, there will be a lack of information essential to the planning of a comprehensive flight program.

As to man's tolerance of space-flight conditions, it is reasonable to adopt the Air Force standards. The MOL assumes stay times from 30 to 90 days. The experiences gained by the 8-day Gemini flight are very encouraging. In order to do inflight experiments by man, we need—at least for the next few years—the scientist-astronaut who will combine the qualifications of an experienced scientist with those of a capable astronaut. It is unfortunate that none of the biologists, who volunteered in this program, qualified; and this shows that the physical standards should be revised or that other measures must be taken to assure scientific competence in the manned bioscience flight program.

The opportunity to leave the surface of the Earth and to enter a foreign environment for long periods of time should be a challenge to biologists. The space environmental factors, which are accessible for study on terrestrial biology, are listed as follows:

(1) Position above the atmosphere as a vantage point for observations
(2) Subgravity and weightlessness
(3) Ultrahigh vacuum
(4) Van Allen, solar, and cosmic radiation
(5) Lack of Earth magnetic field
(6) Escape from terrestrial periodicity
(7) Exposure to astrophysical factors
(8) Synergistic effects of space parameters

They are so well known that I do not have to spend time on their discussion. They are shown here because they determined the scope of our effort. These areas, which were roughly outlined in the guidelines for the "Manned Earth Orbital Mission Definition Document," are as follows:

(1) The role of environmental inputs for the establishment and maintenance of normal organization in the living system
(2) Investigations about the effects of gravity on life forms, including the fundamentals of gravitation biology
(3) Basic biological processes and forms of life as they may have developed under extraterrestrial conditions
(4) Basic concepts of life and its generation and distribution in the planetary system

In essence, they cover the same subjects which form the basis of the biosatellite project, which shows an orderly progression of experiments commensurate with increasing scientific knowledge and technical experience.

As a matter of fact, the biosatellite project was one of the main sources of potential experiments considered by the Technical Advisory Team for the Garbarini Exercise. These were mostly proposals which could not be accomodated in the biosatellite for one reason or another. They had been turned over to Dr. Gill for consideration for the Mercury or Gemini flights. Other proposals were submitted in response to Dr. Gill's call for proposals in 1963, and the questionnaire which I mentioned earlier. When the Advisory Team convened in January 1965, we had a total of 76 proposals to evaluate. Some of them were quite old, rather sketchy, or did not comply with the guidelines. Some of them had been previously reviewed by the Bioscience program offices and the Bioscience Subcommittee and were turned down for various reasons.

The Technical Advisory Team reviewed a total of 76 experiments. They were grouped in four major experimental areas:

Environmental biology:
- Genetics
- Molecular and cellular biology
- Morphogenesis and growth
- Biorhythms
- Ecology

Physiology:
- Systemic physiology
- Pathophysiology

Psychobiology:
- Neurophysiology
- Ethology

Exobiology (life in free space)

The above also shows the major subgroups which were formed by the various proposals. I will now say a few words about the experiments which were selected for consideration for the AES program and why they were selected by the Technical Advisory Team.

In environmental biology, the dramatic changes of the developing organism are of immediate interest to the investigator. After fertilization, cell division and differentiation proceed at a high rate and are sensitive to environmental influences. On the other hand, the development and growth process follows a well-established plan.

It has been theorized that lack of gravity should affect vital biological processes such as fertilization, cell division, differentiation and metabolism, tissue and organ formation, and related functions. According to some calculations made by Pollard and Sagan, gravity is supposed to influence the behavior of cells which exceed 10 microns in diameter. Whether or not this is true, down to what magnitudes of mass and size the effect of the gravity vector can be verified, and how it operates to determine the physical form and the biochemical character of the organism, are major subjects of investigation in the Gemini, Apollo, and biosatellite programs. Experiments suggested for AES were:

A. GENETICS
   (1) The effects of weightlessness on the replication and recombination of DNA
   (2) The effect of the space environment on the feeding, survival, and production of Daphnia pulex
   (3) The independent and synergistic effects of 0 G and radiation upon growth rate and mutation rate of bacteria (transport of material across the cell membrane)

B. MOLECULAR AND CELLULAR BIOLOGY

This area contains experiments on basic life processes other than reproduction and early development. They concern changes in cytochemistry, cellular ultrastructure and cellular metabolism associated with exposure to weightlessness, radiation, and their synergistic actions. Photosynthesis was included as a special area of investigation because of its implications for the development of closed ecological systems in which OART is particularly interested. The experiments concern—

   (1) Development, testing, and use of a 0 G growth chamber
   (2) Morphological changes in cells exposed to prolonged weightlessness
   (3) The effect of 0 G on paramecium and HeLa cells
   (4) Biological effects of weightlessness as a factor in gas-liquid separation in metabolites of micro-organisms
   (5) The effect of 0 G on protozoa
   (6) Effects of radiation and a gravity-free environment in space on cell division and growth

Observations of the external morphology and dynamics of growth in plants and animals as affected by the absence of gravity are listed in our third subgroup. Studies in this category emphasize detection of changes in the normal patterns of geotropic response occasioned by the absence of Earth's gravity. The following experiments were considered:

C. MORPHOGENESIS AND GROWTH
(1) Modification of phage production in bacteria
(2) Effects of prolonged weightlessness on the growth rate of Escherichia coli
(3) The effects of 0 G on the fertilization rate and development of various types of eggs
(4) The independent and synergistic effects of radiation and 0 G on differentiation in the flour beetle (Tribolium)
(5) Activated sludge in waste management (a bacterial study)
(6) The effect of weightlessness on plant morphogenesis, seeds, culture, and leafy plants

Another subject under study is biorhythm. Two major schools of thought emerge in this area. One group maintains that periodicity in biological organisms is of endogenous origin. The other school believes that it is caused by exterior factors. Experiments will be conducted in the biosatellite, and supplements are considered for manned spacecraft. These may include investigations of the responses of biological systems to subtle astrogeophysical factors which may induce or affect terrestrial biological periodicity. Moreover, systematic observations of the Earth from manned satellites can lead to a better understanding of the relationship of biology to its environment. Periodic or random movement of fishes, birds and game, the changes of growth patterns of plankton in the oceans and that of crops, forests, and jungles may have far-reaching importance in world economy.

Although the study of simple biological systems is scientifically very important, higher animals must be used to determine the effects of space factors on specific physiological functions. Under the heading of "Physiology," we want to study, first, dynamic processes in animal systems to supply the basis for an understanding of 0-G phenomena, which might be detected in human biomedical experimentation. There is also a higher degree of transfer validity for extrapolations from animals to man.

In the subgroup of Systemic Physiology, the following experiments were judged to be of value:

(1) Effects of weightlessness on
 (a) Gross body composition; and
 (b) Cerebral, neuronal, and glial chemistry of animals
(2) Effects of weightlessness on cardiovascular, respiratory, and renal systems; metabolism; and behavioral correlates in the primate
(3) Metabolic adaptation to 0 G appropriate dietaries
(4) Mineral and water metabolism under weightlessness and ionizing radiation

Under the caption "Pathophysiology," the study of effects of the space environment on processes, such as the healing of wounds and intercurrent infections, were proposed. The specific experiments were:

(1) Effect of weightlessness on immune defenses
(2) Liver regeneration (mitosis) at 0 G
(3) Study of tissue regeneration and wound healing during weightlessness
(4) Limb regeneration during weightlessness

There is also a possibility that a set of experiments using the reduction or absence of gravity as a tool for the investigation of selected disease states, such as cardiovascular hypertension, may be developed in this area.

It must be recognized that theoretical analyses have significantly contributed to the prediction of human behavior under weightlessness before appropriate means of experimentation existed. After high-performance aircraft and spacecraft were available, experiments were conducted on various psychological functions. The results showed that certain functions, in particular eye-hand coordination, spatial orientation, touch-and-pressure sensation, and reaction time, are rather unaffected by weightlessness. However, episodes of "space sickness," that is, vertigo and nausea, were experienced in two of the Soviet manned space flights. The experiments envisioned in the area of psychobiology are designed to shed light on the effects of weightlessness on fundamental behavior of infrahuman organisms and the physiological substrate associated with this behavior. The following neurophysiological studies were selected:

(1) Monitoring of electrophysiological performance of the nervous system by neuromyography
(2) Effect of weightlessness on the behavior of statocyst-bearing organisms
(3) The pathophysiological effects of weightlessness on primates, with special attention to the role of the vestibular organs
(4) Monitoring of neurophysiological, physiological, and performance functions in the primate under prolonged weightlessness

It is still hypothesized, and there are still the unexplained episodes of the Soviet astronauts which point in this direction, that the absence of gravity may be a disorganizing factor in psychobiological phenomena. Experiments which may contribute to the solution of this problem are:

(1) Discrimination and communication of animals under 0 G conditions
(2) Experimental analysis of animal adjustment to various degrees of gravitational force (including 0 G)
(3) The effect of drugs on behavior and performance in space flight

Finally, two sets of experiments are considered in the area of "Exobiology." The first one concerns a test of the so-called Panspermia theory. According to this theory, life may have migrated in the planetary system. It will be informative to determine whether or not living material can survive in the space environment with and without various degrees of protection. The second task consists of a continuation of the search for extraterrestrial and terrestrial life forms at orbital altitudes in a more sophisticated manner and over more extended periods than this was possible at previous attempts.

These were the experimental areas and the individual experiments which we suggested for study in the AES. Of these, the following were selected by the Manned Earth Orbital Review and Integration Team (of which I was not a member) as representative examples for the Extended Apollo Development plans:

(1) Genetic effects in micro-organisms (DNA recombination, mutation rate, and phage production)
(2) Effects of space flight on morphology, growth, and gas/liquid separation in micro-organisms, unicellular organisms, cells, and animal tissue
(3) Limb regeneration and wound healing during weightlessness
(4) The effects of drugs on animal behavior in flight
(5) The effects of weightlessness on cardiovascular and respiratory functions, hormone, mineral and water metabolism, ANS, CNS and brain mechanisms, operant behavior, and biorhythms in the primate
(6) Soft capture, enumeration and identification of space-borne micro-organisms

However, the preliminary draft of the "Advanced Earth Orbital Mission Definition Document" contains the following 11 experiments as representative examples:

(1) Study of tropic and toxic phenomena in plants and animals
(2) Study of lifetimes and ability to reproduce of bacteria in the space environment
(3) Synergistic effects of 0 G and radiation upon growth rate and mutation rate in bacteria
(4) Determination of effect of 0 G and/or radiation on cell-free protein synthesis
(5) Fertilization experiments
(6) Effects of weightlessness on immune defenses against pathogenic agents
(7) Effects of weightlessness on dividing human cells in culture
(8) Effects of weightlessness on the replication and recombination of DNA
(9) Study of photosynthetic action spectra during exposure of algae cultures to true space illumination
(10) Origin of biochemical components
(11) Collecting and sampling of micro-organisms in near-Earth orbits

The discrepancy between these two representative samples of biological experiments for the same AES program has never been explained to my satisfaction. However, it is clear that they all fall in the same problem areas which we had previously established.

It was understood that—since this was an exercise and not a final selection of experiments—principal investigators should not be appointed. As you know, this can be done only after proper review and acceptance of a proposal by the scientific subcommittees—in our case by the Bioscience Subcommittee—and the Space Science Steering Committee of the Office of Space Science and Applications. So, even if you should recognize one or the other of these representative experiments as coming out of your own shop, you must know that none of these experiments has been submitted to or accepted, respectively, by the Space Science Steering Committee.

There are several reasons for this delay in action. The first one was the opinion of the biologists that the submission of experiments for a manned orbiting laboratory would result in hasty and unsound proposals; particularly, since the participation of man in such a facility was still very doubtful. Moreover, partly because of this, only a relatively small segment of the prospective experimenters would participate; and therefore the proposals would not express the opinion of the biologic community.

Second, two other approaches had been employed in the meantime to solicit the cooperation of the scientific community in the AES program. One was a contract with the American Institute of Biological Sciences. The other one was a "Feasibility Study of Promising Stability and Gravity (Including 0-G) Experiments for Manned Orbiting Missions." The major problem areas and study objectives of the AIBS contract are as follows:

Problems to be investigated:

(1) Can the space environment be used as a unique experimental condition?
(2) Can man be utilized as a scientific experimenter and/or as a competent observer?
(3) Can adequate instrumentation and environmental conditions be provided in proposed vehicles and missions to accommodate life science experimentation and man as an efficient experimenter?
(4) Can an orbiting laboratory designed specifically for biological and/or life science experiments be justified?

Proposed study objectives:

(1) Review of pertinent information

(2) Optimum utilization of man as an experimenter during Earth-orbiting missions
(3) Critical research requirements and essential problem areas for investigation
(4) Pertinent research tasks, adequate methodology, appropriate experiments, competent scientists, and organizations
(5) Comprehensive bioscience research program

Mr. Beem will give a brief survey on the progress made by the AIBS.

BEEM: One of the purposes of the American Institute of Biological Sciences is to cooperate with national organizations concerned with biology and biologists. One way of doing that is by cooperating with this MORL program. The project that we have undertaken will encompass these study objectives, although some are more important than others. Basically, the program will define the problem areas requiring inflight investigation, including the hypothesis to be tested, general research design, essential experimental equipment, and operational procedures, and a listing of optimum experimental specimens and their husbandry requirements. Although the research program will be as specific as possible, it is not anticipated that detailed experimental plans can or need be developed. On the contrary, the objective will be a scientifically justified biological research program that can be used as a guide by future experimenters.

Any such program should benefit from the thoughts and knowledge of as many of the Nation's biologists as possible. Therefore, to achieve this objective, we ask for the help, and receive the help, of our adherent scientific societies, of which we have 42. They submit the names of people who they think will be capable and qualified to sit on regional study councils. There are now five such councils. The Chairmen are Dr. Gilbert Levin, Dr. James Henry, Dr. Theodore Sudia, Dr. George Davis, and Dr. Ralph Baker.

The regional councils have just been organized. They have all had at least one meeting, or will have had one meeting within the next few weeks. Of course, we have not yet done anything definitive on the problem. It is just an organizational procedure so far. We would hope by probably a year from this time we will be able to put something into print.

We also have an internal advisory committee on this program. Robert Lindberg is here. Robert Krause is on this advisory committee, Kenneth Timon, and John Olive.

GERATHEWOHL: Another reason for the delay in action was that none of the old proposals were written on the forms handed to us for the Garbarini Exercise, and most of them did not contain the information which the AES planners needed. It was hoped and planned that this meeting of potential experimenters would help in establishing the necessary professional contact between scientists and engineers, and also between biologists who may want to cooperate in one experiment; that is, pool their knowledge and experiences in order to come up with a good experiment which has a better-than-average chance to be accepted by the scientific committees. We have to be very selective because of the long leadtimes; the technical difficulties of preparing a complex experiment for flight; and the high costs involved, which amount to an average of about $250,000 for a single experiment.

The "Advanced Earth Orbital Mission Definition Document" has been used in the meantime for defining the envisioned equipment for the representative examples, and for obtaining preliminary cost estimates. The next step involves a revision of the Flight Mission Assignment Plans, which were also established. To assure the planning of a realistic program, detailed descriptions of the experiments are now required. They are available in most of the other participating disciplines, such as geology, remote sensing, technology, and space medicine. These descriptions will be used by the Apollo spacecraft contractor, under the direction of the Manned Spacecraft Center, to conduct more detailed experiment integration studies. Hence, it is necessary and urgent that the biological flight program be finalized in a way which satisfies the scientific and the operational—I mean to say the OMSF—requirements.

I would like to conclude my presentation with a few comments about the need for an accelerated effort in our area of interest. The opinion has been voiced that such an effort is unnecessary, since any biological experiment, which can be done in an unmanned vehicle, can also be done in the AAP. This is a very superficial statement. First of all, we do not want to duplicate the biosatellite project for various reasons. At best, we want to implement it. The criteria which were used for selecting the AAP or AES experiments were different also. They are: The experiments would provide data of immediate interest and/or would aid in establishing the technological capability and the most effective methods for conducting future missions and projects—both manned and unmanned. Furthermore, the experiments should require the presence of man as an experimenter. We want to get the scientist-astronauts involved in space experiments as early and as much as possible. With respect to the latter criterion, it is recognized that, in a few cases, some of the suggested experiments do not require man's immediate presence and participation. However, in many cases, the technical difficulties inherent in studies, which require many specimens or statistically reliable samples, man's presence will be essential. In all these cases—even if the scientific objective of the experiment should be similar—the experimental conditions in the space laboratory will differ significantly from those in a small automated capsule, the design of the experiment will differ, and the equipment to be used will be different. That is why we have to make provisions now for the development of promising experiments in the AAP.

In short, we do not envision that the same equipment, the same techniques, and the same instruments, which are used in the unmanned biosatellite, will be adequate for the much more sophisticated work which scientists will perform in a manned orbiting laboratory. It is expected that the biological laboratory science, which still is mainly a hand-operated science, will undoubtedly profit from the degree of miniaturization and automation, which is mandatory for remote experimentation in space. On the other hand, we expect that the space biology program, which has been anchored so far mainly to the biosatellite project, will profit from the work of biologists in a manned orbiting laboratory. Hence, attention should be given to the preparations for this work, to the experiments which should be conducted, and to the equipment and facilities needed in manned spacecraft. They should be specifically designed to meet the characteristics of the space environment, but they should be general and flexible enough to permit work in the main areas of biology as outlined before. In this way, the true concept of a laboratory in space will be established, and the capability of the scientist-astronaut will be fully exploited.

2. ADVANCED BIOSCIENCE EXPERIMENTATION IN A ZERO-GRAVITY LABORATORY

FRANK CRANDALL
Electro-Optical Systems, Inc., Pasadena, Calif.

GERATHEWOHL: Mr. Crandall of the other contractor is the next speaker on the program. He will present the state of the requirement study for advanced bioscience experimentation in a 0-G laboratory.

CRANDALL: We heard a great deal about the various programs that are being utilized for bioscience research. I think it might be well at this point to put some of these things in perspective just a little bit. I think the keynote here is the acquisition of baseline data for what I think we could look at as the long haul in bioscience research. We are just now entering an era of what might be called gravitational biology as a rather new field in much the same way that we have had marine biology in the past, or other such fields dealing with a rather specialized part of biology, but one that cuts across the entire field. It is not limited to merely plants or animals or one of the other evolutionary groups or functional specialties.

So what we have done with our program up to this point is to increase the sophistication progressively, and gather the data that will provide us with a solid foundation. I think, in a sense, we could use the construction of a skyscraper by analogy. Much work goes on laying a solid foundation which is not at all obvious to the layman. It is only when you begin to throw up the steel framework that it does begin to be obvious, and it is only when you begin to throw up this steel framework that you begin to go up and get the broad view that you are really seeking.

I think we can compare the work that has gone on over perhaps the last 50 years in building the new experimental biology, as opposed to the older descriptive biology, as the foundation. Now with the advent of our various vehicle programs we are beginning to put up this framework. When we get this framework up, it then becomes our job to flesh out this structure, and construct a rather enduring edifice in gravitational biology.

The reason I emphasize gravitational biology is because this is certainly the unique feature of the space environment. All of the other parameters that have yet been discovered can to a greater or lesser extent be duplicated on the ground for even fairly long periods. Certainly there are exceptions. If you are looking for high-energy radiation at the level of 10^{18} eV per particle, certainly you are not going to duplicate it on the ground tomorrow, but I have not had anyone yet seriously propose an experiment that immediately requires such energies.

We can also look at this large-building analogy to say a few words about the sophistication of the various vehicles. Just like a hotel, generally as you go toward the upper floors, you find your more elegant rooms and suites, and this is certainly true of the vehicles that we are using in this type of program. We have started out with the Mercury flights which were hardly an elegant laboratory, and we have progressed through the various parts of the manned program. We have the biosatellite program, and these things are getting progressively more sophisticated. Finally, we contemplate moving on into the era of manned vehicles devoted, we hope, primarily to scientific purposes, where science is not just a subsidiary portion, almost an afterthought in some cases, but rather the fundamental reason for the existence of the vehicles.

Let us examine our concept of an advanced manned vehicle program.

Figure 1 shows that a manned space bioscience laboratory includes the three critical factors—the experimental samples and specimens of interest to us, the necessary physical environment, and, as Dr. Montgomery pointed out so well, the experienced scientist. You will recall he mentioned the fact that biology is in many respects not a very numerical or quantitative science at the present time, but is rather heavily dependent on the highly trained and skilled observer, who makes value judgments about what he is seeing.

The following summarizes some of the unique capabilities of the bioscientist in situ:

Sensory: Particularly discernment of fine detail and patterns in fragmentary data.

Manipulative: Ability to perform extremely diverse and complex mechanical functions where each action may depend on the unpredictable outcome of the last one.

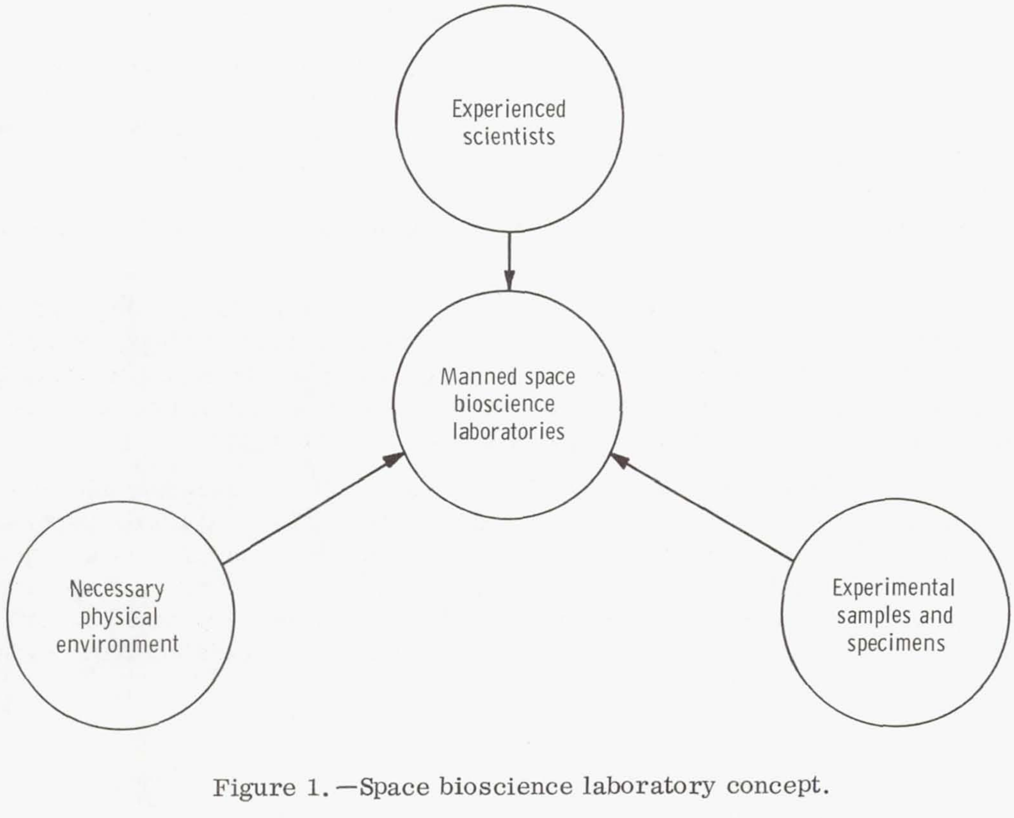

Figure 1.—Space bioscience laboratory concept.

Intellectual: Ability to evaluate data of great complexity.
Highly selective, flexible, and extensive memory.
Ability to deal effectively with unforeseen situations.
Capacity for combining inductive and deductive reasoning.
Ability to make judgments.
Communicatory: Unique ability to extract and communicate significant information from large quantities of data.

We need not belabor this, but certainly we are all familiar with the ability to discriminate patterns from fragmentary data and the ability to perform very complex movements. I think we could for a moment cite an example—I am sure most of you are familiar with the work of Spemann, separating the blastomeres of an embryo with fine hair loops. I do not think we can conceive, at the moment, of doing this satisfactorily and having a meaningful experiment in the absence of the investigator. It is one of those experiments that is just simply not suited to performance in something like the biosatellite. So I think we see the emergence of two categories of experiments, those which are perfectly well done in an unmanned way, and others that simply require the presence of the investigator for any meaning at all.

The intellectual capabilities of man are quite obvious. I would like to touch on one point in regard to communication. If you stop and think about it a moment, man has a unique capacity to observe and understand a long series of events and finally reduce this entire process to a few well-chosen words. For example, he can say, "This experiment turned out exactly like the last one," and summarize a month of work. I think this is a point not to be overlooked. Or he can say, "This experiment is just like the last one, except for third cleavage which was not perfectly horizontal," which summarizes only the key point. So this is something that we have not programed into machines yet, a further area where the man is an essential feature.

In examining experiments for a program of gravitational biology, the first thing we did was to collect a very, very large number of ideas, as follows:

(1) The experiment must have a definite scientific purpose.
(2) The experiment must provide information of value to future scientific operations.
(3) The experiment must utilize the unique capabilities of experienced scientists at the site of the experiment.
(4) The experiment must be incapable of being performed on Earth because of
  (a) Uniqueness of the space environment
  (b) Potential invalidation of results if samples are transported to the ground for processing
  (c) Involvement of cumulative environmental effects over prolonged time periods too impractical for Earth simulation

Then you can screen these ideas along these general lines to select those which have a place in an experimental program of this sort. Others would be more suitable for other types of experimental programs.

First of all, your experiment must have a definite scientific purpose. I think here we can take a look at the use of the hypothesis in research. If you establish a suitable hypothesis constructed properly—in other words, ask the right questions—you will never have a meaningless experiment, or one that does not return some data of value. The experiment must also provide information of value to further scientific operations. It should not be a simple one-shot experiment, what we might call idle-curiosity experiment, but rather should have a place in an ongoing look at a particular area of biology.

Next, the experiment must necessarily utilize the unique capabilities of experienced scientists at the site of the experiment, or we would recommend that it go in the biosatellite program.

Fourth, the experiment must be incapable of being performed on Earth, because of one of three factors, or all three. It must require: (1) the uniqueness of the space environment; (2) the invalidation of results if samples were transported to the ground for processing—in other words, we cannot use a reentry vehicle such as has been used in the Discoverer program; and (3), we should have the involvement of perhaps cumulative environmental effects over long time periods. If this were not the case, we would either do it in a vehicle of shorter orbital lifetime, or perhaps on a rocket flight, or something of this sort.

For convenience we can divide up biological space research into the following four areas: biosciences, biomedicine, bioengineering, and behavioral biology. There is nothing magical about these. I am sure any one of you could pick a scheme that would for your own purposes be just as satisfactory. However, what we have attempted to do is to segregate these into categories involving nonapplied work, work involving the nonconscious functions of organisms, let us say. This would more or less specifically exclude problems of a medical nature. In biomedicine, of course, we are concerned principally with the physiological functions of man. In bioengineering we are concerned with applied science problems dealing principally with things like life-support systems, problems inherent in spacecraft design itself. Behavioral biology, of course, might just as well be called psychobiology. It involves an assortment of behavioral considerations in psychophysiology and things of this sort.

In examining the bioscience area (in this work we selected bioscience as the area to cover) it was necessary to pass potential experiments through some kind of filter to separate out ones that were of particular interest at the moment (see fig. 2). In doing this, the first thing that one wishes to do is to determine the scientific merit, if you will; for if an experiment has little merit, there is little point in performing it, although in the past I am sure all of us have seen experiments that would fall within this category.

Next is the interest to the scientific community, and this really is another way of saying that the experiment must have some value for future scientific investigations. Certainly the taxonomy of the Nemertean worms is of little interest to the scientific community at large. You could perhaps find half-a-dozen people in the entire world that were even vaguely interested. On the other hand, the problems of cell division and morphology of organisms are of consuming interest, and I think it is fair to say that we can excite perhaps 99 percent of the scientific community with work in this area.

Next we have the various considerations of environment. We are directing our attention here to research in a vehicle of a degree of sophistication beyond the Apollo, beyond the AAP concept, beyond the biosatellite concept. So we can screen the experiments that we come up with, and in this case it was more than 400 that were examined by passing through the filter. Some were routed toward rocket flights. Some were more appropriate to an AAP. Some were more appropriate to a biosatellite. In this way you wind up with some smaller number of experiments. Here the key point becomes to examine these for the availability of the baseline data you need to design the detailed experimental protocol. It turns out that in many cases the baseline data simply do not exist, at least do not exist in the detail and sophistication that is needed to do a proper job of planning.

So here you have feedback which runs the experiment back into one of the other programs in order to develop the needed data. I think we can see a program of continuing work in unmanned vehicles to develop the kind of data that will be needed in order to do the more sophisticated experiments in advanced manned vehicles.

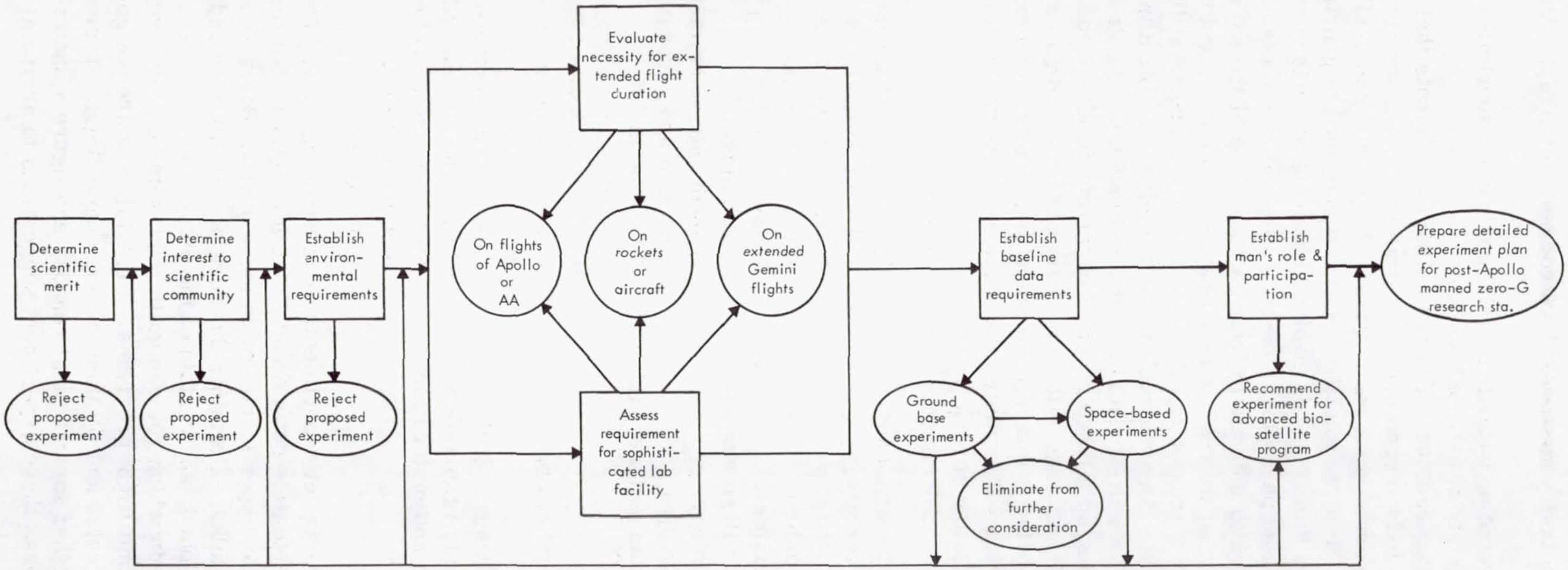

Figure 2. —Screening of potential biosciences experiments.

Then, finally, you can take your experiment concept and plan a detailed experiment around it.

After doing this, we come up with still a fair number of experiments, so it is interesting to break them up into a variety of categories.

Figure 3 shows seven categories. You can define experiments that fall into the group mainly concerned with the extraterrestrial life forms and precursor substances. You can define a group that encompasses what we might call biophysics and cytology, a group on cell division and embryology. Some of you will ask, What happened to genetics? I think maybe genetics lies somewhere in this area. It involves elements of various experiments. Microbiology, plant morphology and physiology, the physiological and whole animal work.

What we have attempted to indicate in figure 3 with some of the solid, dashed and dotted lines are the primary (or what we regard as primary), secondary, and tertiary relationships between these areas. These areas (microbiology and extraterrestrial life forms) are obviously very closely related. An area such as microbiology and plant morphology is less closely related. Finally there are even slimmer relationships. But it does provide us with a convenient way of breaking up a large group of experiments into areas. In this way, we can then take individual experiment suggestions and compare them with a small number of other suggestions to attempt (hopefully) to arrive at some larger integrated experiment, or perhaps series of experiments, which will examine the features of interest in a stepwise logical program of experimentation lasting several months.

Some typical bioscience experiments are as follows:

Extraterrestrial life forms and precursor substances:
- Determination of existence
- Life chemistry studies
- Morphological studies
- Propagation and culture studies

Biophysics and cytology:
- Cell membrane studies
- Cytoplasmic motion and mechanics
- Virus replication
- Biological transport

Cell division and embryology:
- Meiosis
- Mitosis and cytokinetic studies
- Differentiation and organization
- Tissue formation and maturation

Physiology and biochemistry:
- Calcium metabolism
- Nitrogen metabolism
- Endocrine function
- Hemochemistry

Microbiology:
- Growth rate and metabolite transport
- Induction and reversion phenomena
- Mutation studies
- Immunological studies

Plant morphology and physiology:
- Gravotropism and gravophobism
- Morphogenesis
- Auxotrophic phenomena

Sensory phenomena and biomechanics:
- Static and motor reflexes
- Kinematic reflexes
- Hemodynamics

These are not necessarily elegant experiments or outstanding ones. These experiments are certainly not going to immediately get a Nobel Prize for any one, but they are typical of the suggestions that you find for experimentation in these areas. Some of the areas have already been alluded to in earlier talks. Certainly the work on cell division and some of the virus replication has been mentioned, and certain of the other areas.

Figure 4 shows a way in which you can go through some of these experiments now, and attempt to combine them into flight programs. Certainly you are not going to take all of the experiments that are suggested and fly them on any single flight. There are some things you would like to combine together for practical reasons and figure 4 shows the kind of process through which you would pass these experiment suggestions to arrive at that.

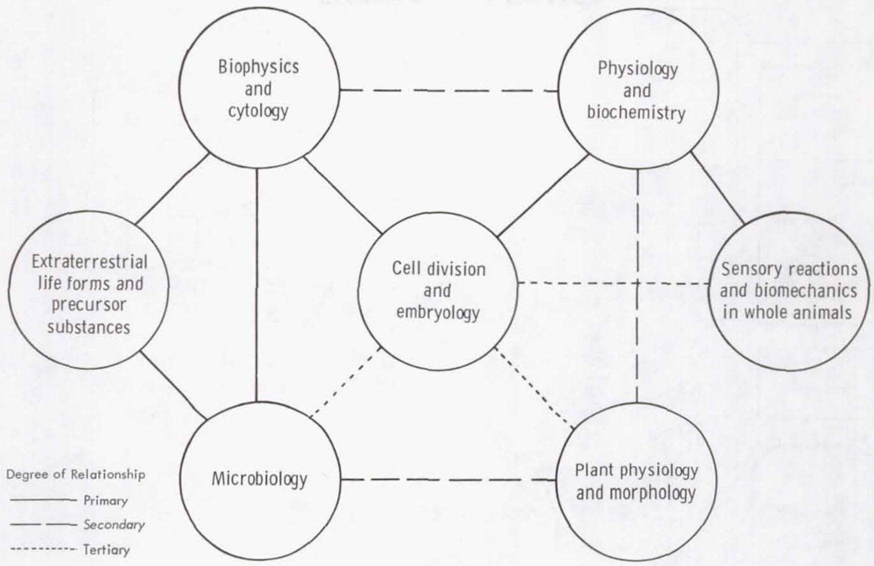

Figure 3. —Interrelationship of bioscience study areas.

Figure 5 illustrates the concept of a program package, if you will, the experiments that you would want to bind together and take on one flight as your program of bioscience experimentation for that flight. What we are concerned with is selecting experiments that involve a commonality of equipment and facilities, of experimental techniques and methodology, and of the background required of the investigators. In this way we can accomplish more with less, and more efficiently.

Figure 6 shows some of the considerations in hardware and facilities where we wish to find common features. We can break these things up into the four areas shown for convenience. We regard instrumentation and apparatus as being different to the extent that the instrumentation is directly involved in data collection. The apparatus is involved in manipulation and support of the specimens.

Experimental areas that were selected as being interesting to look at for hypothetical experiments are as follows:

Biological transport phenomena: An investigation of the effects of gravitational forces upon the means by which the individual existence of the fundamental unit of life is sustained.

Cell division and cytobiology: Cell division and the synthesis of protoplasm are the basic mechanisms in the propogation of life and the source from which the sustained flow of biological continuity derives.

I would urge you to remember that these are hypothetical. This is not an ongoing program at the moment. This is done for planning purposes to attempt to identify the kinds of experiment programs that the scientific community is going to be wanting a few years from now, and is interested in planning for at this point.

The biological transport area investigates the means by which individual cells are able to sustain the life process, and cell division, of course, is the key to the propagation of life and to the continuity of life. These, I think, are of obvious interest.

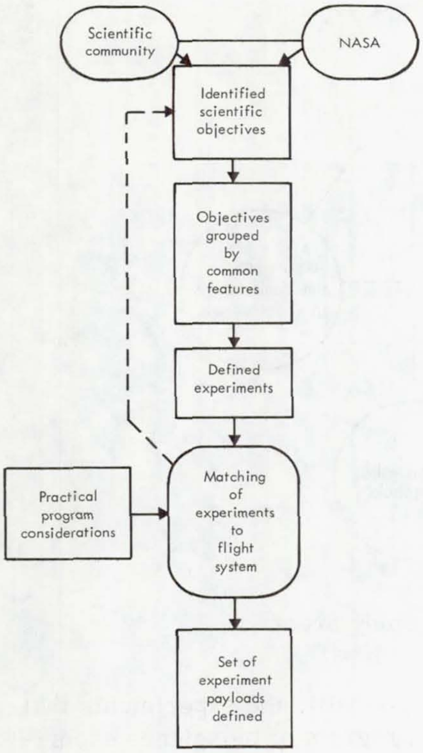

Figure 4. —Steps used in the selection of potential flight experiments.

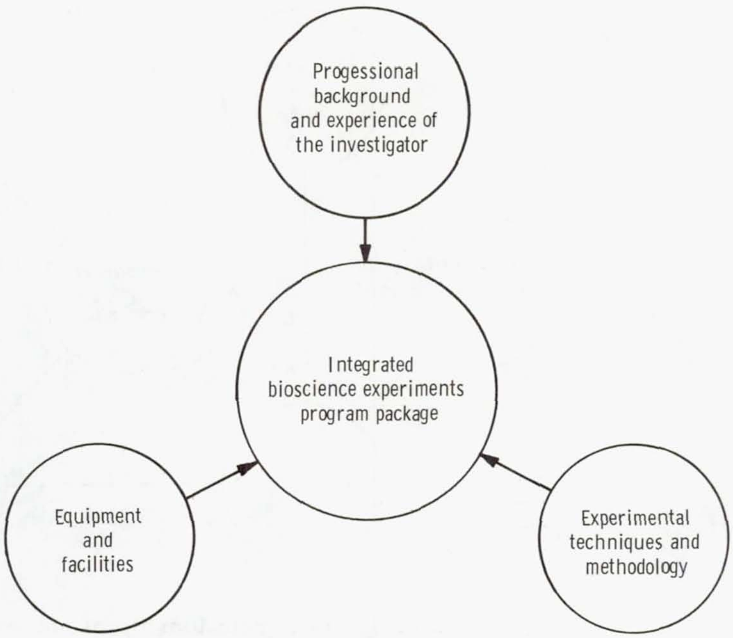

Figure 5. —Bioscience program concept.

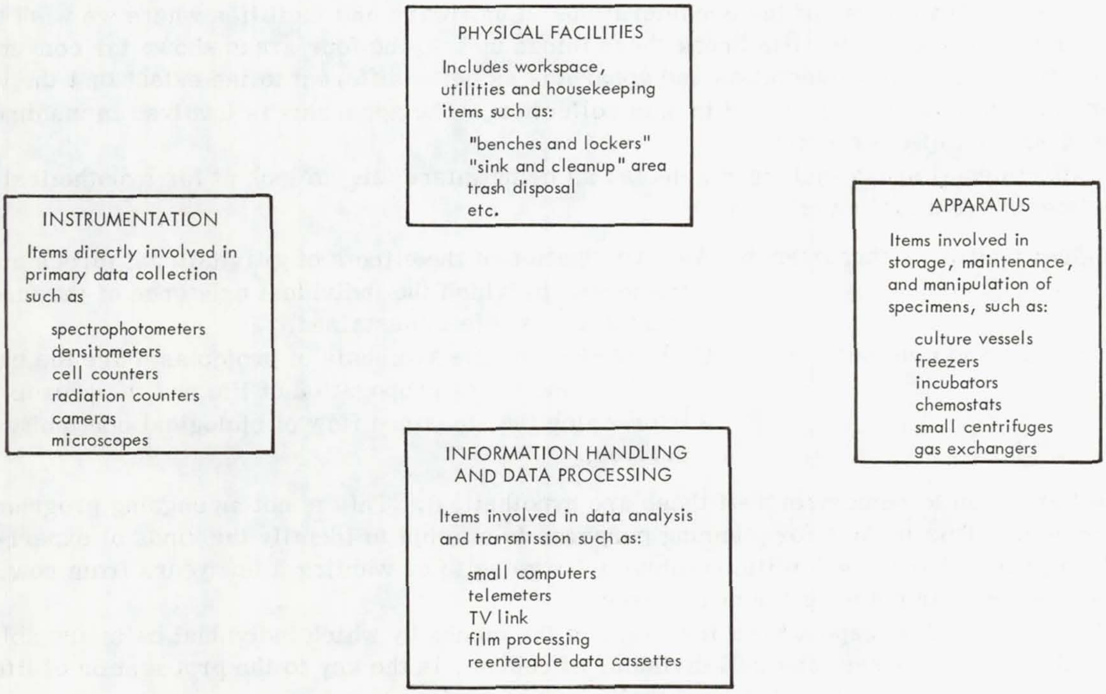

Figure 6. —Hardware and equipment requirements.

Experiments involving the three groups of living things are as follows:

Protista:

Investigation of phenomena involved in growth, mutation, synthetic activity and morphology with respect to gravity.

Animalia:

Investigation of the role of gravitational forces in embryological differentiation and early morphogenesis.

Plantae:

Study of the mechanisms by which gravity plays a controlling part in tropic responses and morphogenesis of plants.

Let us invoke Heckel for a moment, and use the idea of the three broad groups of living things, (1) Heckel's Protista (and we could as well use Stanier and van Neil's Monera), (2) the animals, and finally (3) the plants. By selecting one group of experiments from each of these areas, we can, I think, give a broad representation of the world of biology.

Now, before we discuss some of the possible experiments in detail, I think we might say a few words about the gravitational force considerations in such a program. As was mentioned yesterday, the biosatellite vehicle is contemplating 10^{-4} G during maneuvering modes, and under optimum conditions 10^{-5}. The manned vehicles are not—the Apollo, for example, is not going to perform that well according to the indications that we had yesterday. It will perhaps be in the neighborhood of 10^{-3} at best.

One of the things that was pointed out yesterday also was the fact that plants are conceived of as being able to see a few times 10^{-6} G. This is based on work with Clinostats. If we want to take a detailed look at tropic responses and morphogenesis in plants, it indicates that we are going to have to go down to less than 10^{-6} G. One would say probably we would like to have a vehicle that would operate at 10^{-7} G. Quite clearly this is not possible if you put a man in the vehicle. Putting a man in the vehicle with his heart beating and his breathing, you are going to turn the vehicle into a giant ballistocardiograph. This certainly is going to exert a perturbing force on your experiment.

How do we get around this problem? First of all, we can establish a vehicle made up of various regions of G. We can take a large manned vehicle that is normally operating at, say, 10^{-3}, in the worst case, 10^{-4} in the optimum case. This is something that can be built and can be designed. Within this vehicle we can then put a platform which can periodically be uncaged, if you will, or allowed to free float by detaching from all connection with the main vehicle. This, however, will only buy you some limited time period of low G, because eventually this floating platform is going to strike one wall or another unless you chase it with the vehicle, and can continually drive your vehicle under the thing to keep the platform free floating. This consumes a lot of attitude control propellant and is clearly not attractive for long durations of G. However, it is very good for short periods up to, say, 2 or 3 hours, depending on your exact design.

For very long-term 0 G down at very low levels, perhaps the most attractive means is to have a small maneuverable subsatellite which can be placed outside of the vehicle, perhaps with windows in it where it can be observed with a small spotting telescope, or something of that sort, and allowed to drift freely. You can even let the thing drift for 30 to 60 days and then bring it back to the main vehicle. This is a possible approach to getting very long-term low G, such as you might wish to have for long-term plant morphogenesis. However, for periods up to some number of hours, perhaps even 2 or 3 days, a small floating platform would provide you with adequate levels.

The main difference between the floating platform and the little subsatellite is the duration required.

Another factor that enters into considerations of gravitational biology is the fact that you can only achieve an approach to 0 G. As long as you are in Earth orbit you can never completely escape the gravitational gradient problems. These in low orbits amount to approximately 3×10^{-7} G (along a line which passes through the center of the Earth), which says that if you have a 1-meter plant shoot, for example, between the two ends of it you will be seeing 3×10^{-7} G, and willy-nilly, you can never get lower G-forces than that, across the specimen. So this is a point to definitely consider.

If we take a look at some of the experiments that have been thought of for the various subareas of gravitational biology that we alluded to earlier, we have picked the areas toward the left-hand side of figure 3 showing the seven divisions that we have broken bioscience into. Mainly because there is greater commonality of equipment between these areas it enables you to set forth a sort of hypothetical program and conceive of a hypothetical vehicle to identify the requirements you have for trained scientists, what kind of training, and what kind of equipment they would wish to have in order to perform their experiments.

In the biological transport area, we envision experiments in the general area of cell membrane investigations, particularly transport of material into and out of the cell, and studies in detail of such notions as convectional instabilities within the cell as a means of transporting materials (once they are through the membrane) throughout the various parts of the cell. Many of you are perhaps familiar with the work that has been done on stable laminar flow systems, and the transport of material from one layer to another by microconvectional instabilities.

In this type of system—and this has been done in vitro—you can set up layers of flowing material in a cell consisting essentially of two glass plates with a thin space between them, and have several layers. In one of these layers you would have something like, let us say, dextran, which has a molecular weight of around 70 000. In the layer immediately below it, you would have, say, sodium chloride with a molecular weight about three orders of magnitude less. What happens, in this case, is that you actually have migration of molecules (of NaCl) by diffusion up into the dextran layer, migration, which then form regions of instability and literally drag down whole little microglobules of material into the layer below under the influence of gravitational forces. So here we see a mechanism which could be invoked for the transport of material, and which can be studied for its effect both in vitro and in vivo in the weightless environment.

The experiments on cell division, I think, were quite adequately summed up yesterday. What we would envision here is continuation on a much broader base along the same lines, based on the wealth of baseline data that is being accumulated in our current efforts.

In embryological experiments, which form a very interesting area for a look at the animal world, we can take a look at such factors as inductors and the nature of the induction process. If we examine something like a flat fish, we find the eyes have migrated to one side of the organism, presumably due to the action of gravitational forces at some time in the past, which have influenced the whole way of life of this organism. It would be interesting to determine whether gravity still remains a primary inductor in this case, or whether there is a secondarily derived mechanism that has been prompted by the influence of gravity.

With plants we can explore the basic mechanisms, at very low G-levels, of the perception of gravity, how the stimulus is perceived, and how the information is transmitted. We already know part of the story through the transport of auxins throughout the organism. But exactly how their production is prompted in the first place is a matter of quite keen interest.

Finally, an area that we can mention as having considerable interest is the matter of biological rhythms. It turns out that the variation in gravity due to the Earth rotating and having a specimen located at one point on the surface of the Earth, say near the Equator, rotating around during the 24-hour period, first being toward the Sun and then away from the

Sun, occasions a variation in gravity of approximately 1.3×10^{-6} G. The effect due to this same rotation in relation to the Moon is 3×10^{-6} G. The combination of these factors is, of course, additive, and you can get a rather complex cycle which fluctuates during the 24-hour period, and also over the lunar cycle. To the best of my knowledge, this is an area that has not even begun to be explored in terms of circadian rhythms, partly because we have not had a vehicle that would get us down below levels of this magnitude. So this is a further area. We have not at the moment outlined a definitive experiment here, but I suggest that this is something you might be interested in thinking about.

DISCUSSION

NEFF: Dr. Gerathewohl, I wonder if you have given any thought to any qualifications for an astrobioscientist? What are those qualifications?

GERATHEWOHL: The qualifications for an astrobioscientist? Let me ask you, what is an astrobioscientist?

NEFF: Well, a space bioscientist.

GERATHEWOHL: A space bioscientist? I think we have so many here in this room that I would say the main qualifications so far have been that he is a biologist affiliated with an organization which is interested in doing research in space biology, who is actually motivated to do this, either as a ground scientist, which means to do biological experiments in laboratories in support of flight experiments or, as I pointed out, we will have most probably in the future, I would say in about 3 or 4 years, to be trained to be an astronaut-scientist, or scientist-astronaut, and has the qualifications to do this. That is about all I can think of.

NEFF: What I was getting at was the astronaut-bioscientist.

GERATHEWOHL: The astronaut-bioscientist. I cannot give you all of the standards at the present time for the selection of the first scientist-astronauts. I can give you some very general statements. First, it was specified that the volunteer should have a background in his particular scientific discipline; in this case, biology. He should have a Ph.D., or an equivalent degree—I think a master's in biology was also acceptable—enough experience, and a number of publications as evidence of his theoretical and scientific endeavor and accomplishments. Furthermore, he should meet the standards which have been used for selecting astronauts, because he is going to go through at least the basic type of jet training. These, I think, were the major selection criteria which have been used for selecting the first scientist-astronauts.

As to the scientific part, if that is what you are mostly interested in, the scientific standards were developed by the National Academy of Sciences which was involved in selecting the scientist-astronauts in accordance with their background and the necessary scientific documentation of their experience.

BEEM: When you say he will go through jet training, should he be qualified for jet training?

GERATHEWOHL: He has to go through jet training. He is going to be sent to Houston for, I think, about 6 months' basic training in flight, including jet flight.

TAYLOR: He does not have to be a qualified jet pilot when he applies, however.

GERATHEWOHL: No, but he has to go through jet-flight training. I do not know for how long.

TAYLOR: I think it is something like 6 months to a year.

GERATHEWOHL: So he has to learn how to fly a high-performance aircraft, jet aircraft, and in order to do this, of course, he must meet the medical standards of any pilot who is going to be accepted by the Air Force or the Navy, or any of the flying organizations, to meet these standards of physical condition.

GEORGE: I think there is also an age limit.

GERATHEWOHL: Yes; there is also an age limit, and there also may be a height limit. I think he cannot be over 35 and he cannot be taller than 6 feet, or something like this. This is again according to the physical standards of pilots.

TAYLOR: There is one other point. In the physical qualifications, the jet qualifications are 20-20 vision uncorrected, and this is not just an arbitrary thing, because in space operations the wearing of glasses or contact lenses is a real detriment. So there is a real practical reason, not just so that he meets the prescribed standards. He has to have eyesight that will permit him to do his job without glasses.

PITTS: One of you discussed the titles of a number of proposals for AES and AAP, and I would like to ask Dr. Gerathewohl whether I have interpreted his remarks correctly that at this time you are not buying off on specific proposals and specific personnel to start out with the proposals. You are, in a sense, buying off on ideas for studies, and are reserving the prerogative of making various permutations and combinations of the scientists who have made the proposals. Is that essentially correct?

GERATHEWOHL: No; that is not quite correct. We have quite a number of scientists in this audience who have previously submitted proposals, and who do not know what happened to them. I have been asked again and again, "I sent in a proposal to do this, and I know that this proposal has been channeled over to your office, to Manned Space Sciences. What happened to it? Is it going to be considered? Has it been thrown out, or what is the status?" What I wanted to do was to give you an idea of how your previous proposals have been used for defining some of the major areas of research which we think are worthwhile to be covered by experiments. That is No. 1, and this, I think, is accurately what you asked. I think I could turn this right over to Mr. Taylor, and he would say, "But now, we are in the status where the experiments must be defined in detail." So we would like you to submit the proposals for the AAP program as soon as possible with all the necessary conditions, detailed documentation of the proposal, so that it can be processed through the Bioscience Subcommittee as a flight proposal for the AAP program.

I would like to say again in many of the other disciplines, this is already underway. The second part of my talk was to try to defend myself, and say why this has not been done in the biology area. I was trying to give you the major reason why we were somewhat reluctant to proceed. But I think now is the time where we need proposals in order to make the mission definition and integration work possible that is being done by the Apollo Applications system people. So what we would like to get from you now is to work out the actual flight proposal and submit it.

Now, another purpose was, and I indicated this, that we have parallel proposals in several areas, and that it may be beneficial if some of the principal investigators or scientists who have suggested proposals in a specific area to talk this over, and maybe to come up with a combined proposal. I have had several indications that this may be so. This, of course, I think would add to the value of the proposal, and also to increase the chance that this proposal will be accepted by the Bioscience Subcommittee, and the people who will judge the proposal as to its scientific merit.

KING: Dr. Gualtierotti, I would like to get a little more information on your implementation of your vestibular nerve. When you put your probe into this nerve, you are probing for the otolith unit, there are obviously other units in this nerve, and I was wondering what these units are, and how do you distinguish one from another? What is your experimental procedure for distinguishing one unit from another?

GUALTIEROTTI: There are four kinds of units in the vestibular nerve. One is acoustic. It is very easily distinguished from the others, in the frog in a very peculiar way, and in mammals simply by finding out that it does answer to sound, any kind of acoustic stimulation. In frogs the situation is somewhat luckier, because the vestibular nerve of the frog is divided very neatly into two branches. The anterior branch contains all of the acoustic afferents. The posterior branch contains most vestibular fibers. There are some occasional acoustic fibers also in the posterior branch, but they are so few that it is very seldom that you find one.

Of the proper vestibular fibers, there are three kinds. One is vibratory, possibly coming from the sacculus. Another is from the semicircular canal; and another one is from the utricle, namely, the proper utricular unit.

Now, it is very simple to distinguish these three kinds one from the other. The vibratory ones do not respond to slow tilting, do not respond to centrifugal acceleration except if some vibration takes place at the same time. So if you tilt a table by hand very slowly without applying any vibration, there is no vibratory fiber. The control is just to scratch very slightly on the surface of your support, and in this case the only response is from the vibratory fibers, which are extremely sensitive, by the way. There is no response from an otolith or a semicircular canal unit.

To distinguish a semicircular canal unit from an otolith unit, the only thing to remember is that the semicircular canal unit responds only to transients, to changes in angular speed, and not to steady-state acceleration. So if you tilt or if you centrifuge at a constant speed, you do not have any response from the semicircular canal if you keep the head of your animal fixed; namely, if you do not have any additional movement which might provoke some excitation of the semicircular canal through the Coriolis effect.

Generally speaking, it is very easy to distinguish semicircular canal units from otolith units, because when you tilt, for instance, you get a response from both, but when you stop tilting, whereas the otolith unit goes on firing at the same rate, or with a slow accommodation that is acquired due to the excitation, the semicircular canal units stop responding, immediately. If you have seen it once, this kind of discharge, it is very easy to distinguish one from the other.

So the method is functional.

PRUETT: I have heard of this Apollo program that they went through a series of experiments, and I am thinking of the complications that these experiments would encounter going to a trajectory, as described in the model. This would go through the radiation belts. I wonder if there is any experiment just to pass the specimens just through the radiation belt just as a control for the effects of this problem, because of this radiation belt. Do I make myself clear?

TAYLOR: As I understood the question, it was, Is there any experiment planned which will be primarily oriented to measuring the radiation in the radiation belts as a control for other experiments on the same flight, the same mission, as to what the background or the influence of that radiation is on the other experiments? Is that the question?

PRUETT: This is on the biological specimens. I do not care whether the radiation is measured, but I am talking about the effect on the biological specimens, finding out the effect of this high radiation on this package of biological specimens.

TAYLOR: As I think I tried to indicate yesterday, we do not have a complete set of defined experiments that we are planning and building to fly. However, in the studies we have done of the various missions, including those that pass through the belts, for example, going into synchronous orbit does take you through a major portion of the belts, in all of the missions that we have planned in those areas, we have included the monitoring of the radiation environment through which the spacecraft passes, and also during its quiescent time on orbit.

Now, if there is a particular parameter that needs to be measured as a control for a particular experiment, certainly in a mission whose primary objective is biological, then in our planning of that mission we would include some sort of control measurement. I think any proposals that would come in for biological experiments should indicate the requirements for any control measurements, so that we could either specifically provide this, or if the experimenter feels that there are peculiarities to his experiment for which there must be control data, then that might become part of his experiment.

JENKINS: There would be difficulties in sending a manned mission into the radiation belt where the man would be exposed to high levels of radiation. If experiments in the biosatellite involving known sources of radiation, combined with weightlessness, are positive—in other words, if we had any antagonistic or synergistic effect which we do not expect—there would probably be a great deal of interest in studying the ambient radiation effects with certain specimens, and it might make us interested in sending up a biosatellite into an eccentric orbit, into the radiation belt. This is not planned at the present time, but could be a result of positive data from the biosatellite program. A recoverable unmanned satellite would be a better vehicle for studying what you have mentioned, Dr. Pruett, than sending a manned Apollo vehicle.

TAYLOR: That is true. In planning a manned mission, one of the factors we have to look at pretty carefully is what is the accumulated integrated dose that the crew would incur, and so, as far as long-duration missions are concerned, we would probably be flying either below 200 miles' altitude, or in a region at synchronous orbit where we have enough shielding in the spacecraft to protect the crew, although experiments that are intended to make use of the radiation belt in one form or another could be mounted in different parts of the spacecraft where they are not shielded. But I think the suggestion here, if it is particularly desired to put a biological experiment in a very high-dose area, or a very highly energetic part of the belt, for example, in the intermediate range between, say, 200 miles and 1000 miles, this might best be done on an unmanned spacecraft.

MUCHLER: I would like a little clarification. It is my understanding that the AAP pallet concept is a combined manned and unmanned experiment. There seemed to be a little conflict here in what the different speakers said. Does this mean that for future planning for experiments that this is the opportunity for orbital bioscience experiments? Will there be any more unmanned systems?

TAYLOR: I think we ought to keep this pallet concept in its proper perspective as far as the Apollo Applications planning is concerned. The pallet concept is one concept for carrying experiments. Of course, other parts of the spacecraft, in the command module or in the lunar excursion module adapted to an orbital vehicle, could be carried in those experiments which require more direct monitoring. The categorization of experiments as manned or unmanned can be the subject of discussion for hours. Really, I have heard Dr. Newell say that all experiments are manned. It is just a matter of where the man is. He may be on the ground in some cases. He may be right next to it, twiddling the dial in some cases, or he may be in a command module with the experiment in the pallet. I do not think, though, that that is the question you are asking. You are asking in view of Apollo Applications, does this mean there are not going to be any further unmanned, purely unmanned launch types of biological experimentation. So far as our planning is concerned, in Apollo Applications, this is not the case. As a matter of fact, the experience and data gained from orbital experience with experiments in the Apollo Applications could well lead to improved unmanned experiments, unmanned spacecraft beyond Apollo Applications. So I do not think you should conclude that because we are thinking now in terms of using the Apollo systems for experiments that this is going to preclude any future unmanned experiments at all.

Dr. Gerathewohl, do you want to elaborate on that a little?

GERATHEWOHL: I think I would just emphasize and restate this again. As it was just pointed out before, there may be a lot of experiments which require exposure to certain hazards or certain conditions where it would be very unwise to use the Apollo system to do that. As Dr. Jenkins just pointed out, for instance, in elliptic orbits through the radiation belt, just to use one example. In this case, the combination of unmanned experiments using animals, for instance, in conjunction with manned space-flight experience, would be very valuable. I think that the unmanned biosatellite or unmanned space probes, regardless of whether they contain biological specimens or not, will be a very valuable tool for the exploration of space. I do not think that any manned system is going to make them superfluous.

TAYLOR: There may be two other thoughts, without stretching this out too long, that are worth mentioning. One concept that appears to have a lot of merit is the launching from a manned spacecraft of an unmanned capsule. Thereby the design and testing of the unmanned capsule is relieved from the constraint of having to be automatically set up on the ground and survive the launch environment, and then go into its operational mode. This is one thing that we are looking at, not necessarily only for biological experiments, but also for geophysical or other types of experiments.

The second thought I wanted to mention was another thing we are looking at is the possibility of periodically revisiting spacecraft or spacecraft modules which might be placed in orbit, either manned or unmanned, and by means of using the Apollo system rendezvous with it, and perform whatever operations are necessary, and then leave it for continued operation in an unmanned mode.

So both of these are included in our mission planning, which is some sort of a blend of the so-called manned and unmanned.

REYNOLDS: I have a comment leading off from this, looking at the problem as a biologist.

It seems to me that man has the following kinds of uses in conduct of biological experiments in space. One, skill in manipulation, particularly biological experiment manipulations; two, experience in observation, and here I am talking about observing biological phenomena; and three, a background of relevant information in biological and other sciences. This is in order that he can perform sophisticated operations, recognize significant unexpected occurrences, and improvise as a means of capitalizing on these unexpected observations.

The disadvantages that accompany the presence of man in most biological experiments include the following, some of which have been mentioned before: Disturbance of low-gravity states, production of circadian stimuli in the experimental environment, and what you might call social interaction of man with the experimental animals. (A simple example of the latter is that men do not like the smell of monkeys, and vice versa.) Another consideration is the limitation to various parameters of the flight, such as duration in orbit, which may turn out to be a problem. (In other words, we do not know now that it is going to be a very convenient or happy thing for the same man to have to spend 90 days in orbit to tend to the monkeys.) So he may, if he must always be in the environment of the experiment, constitute a limitation that you would not want to impose on the experiment itself.

Still another disadvantage is the cost of launching and maintaining human habitability in the spacecraft, especially for long duration.

All of these things add up to me to a requirement, first of all, for biologically experienced astronauts, unless there is a passenger capability and a self-sufficient unmanned animal colony or greenhouse, perhaps including a biological laboratory, which is separable from the manned compartments, but with which the command module can rendezvous and dock at appropriate intervals.

TAYLOR: There was one comment there as to whether or not Apollo can accommodate passengers. I would like to just mention one word here, that in the early flights, which are more of a development nature than accomplishing experiments, namely, the first few flights, it seems that the experience on Earth is applicable, that all of the members of the crew must be capable of performing the operations just to get there, stay there and come home. So we certainly see in the future in our Apollo Applications planning, after we get into several years of manned space-flight experience and long-duration missions, that it is highly desirable, and is in our long-range planning, that there will be a scientist-passenger concept that everybody that goes along does not have to be able to fly a jet aircraft, for example, or perform a landing maneuver.

There are certain practical limitations. The one I mentioned earlier of wearing glasses in a space helmet, for example, or extravehicular operations, where contact lenses could be a rather severe limitation on effectiveness. So there are certain physical requirements, at least as we see them now, that have to be met. Maybe ultimately we can make it so comfortable that a lot of these limitations can be taken off.

GUALTIEROTTI: I would like to add one comment on that. We are talking very much about direct observation of phenomena, especially unexpected phenomena during flight. Everybody that works in a laboratory knows this is the most difficult part of any experiment, and it requires the highest possible skill. I am afraid I do not see a very easy match of a highly trained scientist who must be rather older than average and the possibility of being an astronaut or jet pilot. So I would add a note of caution about using human material until we can get the passenger up there, because to have at the same time a completely trained and highly intelligent scientist, which takes time, and somebody who can in emergency pilot the spacecraft, I think is nearly an impossibility.

TAYLOR: I guess my only comment would be, number 1, I think I agree with you, but number 2, in the last selection of the current six scientist-astronauts, there were some thousand who met the criteria, and there was quite a screening operation.

GUALTIEROTTI: You are very lucky to have a thousand people who can qualify as highly trained scientists, at a young age.

TAYLOR: But we did not. As Dr. Gerathewohl mentioned, the Academy of Sciences helped screen the men.

GERATHEWOHL: You would be surprised how many smart young men we have in the country.

I would like to ask a question of Dr. Crandall. He said that in orbit around the Earth, let us assume orbital altitudes where we have spacecraft, that there is a gravity gradient which would make it almost impossible to measure certain types of growth effects at distances more than about 2 meters or so?

CRANDALL: The gravity gradient effect in near-Earth orbit amounts to approximately 3×10^{-7} G/m. What this means is that if you have a specimen that is 1 meter long, there will be a gravitational potential difference between the two ends of it of approximately 3×10^{-7} G.

GERATHEWOHL: I think we all understand this. This is not my question. My question is, Does this apply only in the vertical direction or also in the direction of the orbit? I would like to make a little drawing on this.

The gravity gradient in this direction here is on the order of about 3×10^{-7}. This has been calculated several times, if we assume an Earth orbit of about 500 kilometers. My question is, Does this also apply in this direction? It should not, according to geometry and orbital mechanics.

CRANDALL: Well, what happens, you see, is an entity moves around—let us assume that you take a rod. We have a rod and it moves around. The gradient across this will be in this direction. Now, when you get down here, it obviously will be greater, because it is operating over a longer distance. In other words, the difference between the ends here; as it moves down to this point, now, it will be only through the thickness. Of course, in this case, on a rod-shaped object, it becomes much smaller because the distance is less. As it moves around another 90°, of course it increases, and so forth. So this is essentially the nature of it.

GERATHEWOHL: If this is so, then the limiting factor would be the difference in the radius.

CRANDALL: The difference in the size of the specimen.

GERATHEWOHL: Over the gravitational constant. Since you have to orient it either toward the Sun or toward the Earth, this factor between 2.5 and 3.75×10^{-6} G cannot be overcome without stabilization.

CRANDALL: Right; because if you spin the object itself, you see, as you rotate around, then you are inducing a local gravitational effect, due to spinning. If you take an object like this and spin it with respect to the inertial frame of reference, with respect to the fixed stars, essentially, in order to overcome this Earth-based gravitational force, then you are inducing a different force based on rotating the object itself.

[The following statement was supplied subsequent to the meeting by Mr. Crandall in order to clarify the matter of gravity gradient forces.]

So there are certain limitations that you have inherently on the size of certain specimens. For example, if you were to put up a redwood tree, as Ernest Pollard facetiously suggested one time, you would certainly be detecting large amounts of gravity gradient phenomena.

JENKINS: An item which has not been brought up is whether an on-board centrifuge would be necessary as a control in studying gravity and weightlessness.

Gravity is measured on a scale based on the gravitational force unit of 1 G. We have biological data from increasing gravity several times this 1. There is a question of what happens when we have less than 1 G, and down to 0 G.

I would like to ask Mr. Crandall if he has considered using an on-board centrifuge to make exact comparisons of 1 G or less with weightlessness. Is there a continuum of gravitational effects above 1 G, and below 1 G to 0 G?

CRANDALL: Well, to answer that question, it has not been a question of whether to have 1 or not. It has been a question of how many to have, because it is rather unlikely that you are going to want to have just one centrifuge. You probably would wish to have anywhere up to a couple of dozen, some of them perhaps very small, some of them perhaps quite large. Yes, I do agree, you certainly are going to run these at different levels, perhaps at different times, in order to be able to study a continuum of cases.

GUALTIEROTTI: I would like to make one comment on that. In my experiment that I described yesterday, we have something like that. We have a centrifuge on the package. The centrifuge would reach a maximum gravity of about 0.5 G. That would be one intermediate point. Of course, we would have a number of intermediate points, because we will be starting the activity of the vestibule immediately after maneuvering, and maneuvering might be at any level from zero to 1 G. So we will study both transient effect from zero to any G below 1, and also the effect of a steady 0.5-G acceleration on the vestibular organ, because we keep the acceleration steady for about 30 seconds each time, and that is one of the problems we are going to solve in the followup experiment, in which, according to the results we will have, we will provide a longer period of spinning at a different level of G. So that is something that is already in preparation. Partly it will be done in our next experiment, and partly it will be done in the followup experiments.

BEEM: Dr. Salton, did you want to comment?

SALTON: Is there someone who is following the data on the ground-based experiments, those things which are relevant to the problem of gravity? If so, is there someone who could give us a short status report?

GERATHEWOHL: If I understood correctly, you would like to have somebody talk about the relationship of ground data which are being collected, and their application to proposed flight data. Now, I think one who could do this is Dr. Gualtierotti, because he has actually done an experiment.

Another one who can do it is Dr. Montgomery, because he has done experiments on cell behavior during increased G's. Unfortunately Dr. Grenell is not here today. I met him last night, and he was quite excited because he had just finished experiments with increased G's, on the RNA concentration in cells, and he found that there was a dramatic change of RNA in brain cells after centrifugation of several days, up to about several weeks. He would like to go now into the realm of weightlessness or 0 G, as we can define it, if we neglect these millionths of a G which are acting in orbit, and investigate the effects of zero G or subgravity on the RNA changes that he has observed. But since neither Dr. Grenell nor Dr. Montgomery are here, maybe Dr. Gualtierotti would like to say a few words about his experiences so far with the application of ground experiments to flight experiments.

GUALTIEROTTI: Well, I have two comments to make. First of all, you have to perform ground experiments extensively before you start going into space. For instance, I could not possibly have had enough information to have a sensible program without doing a lot of experimentation on the ground on the mechanism of the vestibular system. So much so, which is my second point, that during the actual 3 days' flight, we will have a perfect duplication of the experiment on the ground, and we will have an exact item, a centrifuge and a package exactly similar to the one that is in orbit, which will follow the same routine stimulation and the same recording as in space. So that we can compare the two responses, and the behavior of the two different packages. This I think is of paramount importance.

Another thing is any time it is possible, it would be very illuminating to have a similar experiment. For instance, we found that performing the plane-flight experiment in which we have a short period of 0 G, and in which we could compare directly the response of the same item from the same unit in 0 G and 1 G, because we could stimulate the unit during level flight at 1 G and 20 seconds later at 0 G exactly the same way, it was very helpful, because now we have a very good idea of what to look for. For instance, some phenomena that have been provoked by 0 G, and by the transient from 1 G to 0 G, passing through high acceleration, was very important. For instance, we found out that in a parabolic flight in which you cannot go to 0 G from 1 G except passing through about 2 or 2.5 G of high acceleration, this transient, especially from 2.5 to zero, is a very remarkable biological effect, and we are planning now to fly a different path with a different plane going from 1 G to 0 G without passing through the 2.5-G profile, just to check this point. I think all this makes clear how ground-based experiment and any kind that can be done to help the space flight is important, because to take off the unexpected, you really cannot understand the completely unexpected. You cannot even be aware of it. It is very difficult.

SALTON: This is the baseline you are talking about. I am wondering, is there some NASA plan for stimulating or getting plane-flight experiments or clinostats, or this sort of work?

GERATHEWOHL: Of course we do. As a matter of fact, many of the flight experiments that are under consideration are coming from experimenters who have been receiving NASA grants and contracts for years to work out ground experiments. We had recently an experiment that was suggested for flight which was turned back to us from the Bioscience Subcommittee, saying, "This seems to be a quite interesting project, but the scientist should first make his experiments on the ground using a clinostat in order to see how it works out there." So we are encouraging this.

We have had only one negative experience so far, but in the experiment which failed in flight, we were not satisfied with the type of ground experiments which we had expected would have been done before. It is one of the reasons why we now more stringently require the principal investigators to do baseline experiments first. Then the package should be tested in airplane flight, not only because we get 0 G or weightlessness or subgravity for a few seconds, but to see how the whole package stands up under these flight conditions. Then, after we have established the compatibility of the experiment, and we have the baseline data from the ground, we are putting it into an orbit, using the spacecraft to do that.

GUALTIEROTTI: I want to add one thing. For instance, our package, the engineering model that we will have now in a few days, one of the tests we will perform is just to have it go through the plane flight, the package as it is, just to find out what happens. If it works properly or if there is any problem, we can gain some information going through the plane flight.

GERATHEWOHL: Furthermore, you saw in the film on the biosatellite that the same standards are being used for the biosatellite. The unfortunate delay in some of the experiments to be flown, which is true for the biosatellite as well as for the flights in Gemini or Apollo spacecraft, has a beneficial effect insofar as the experimenter has more time to do ground experiments.

We also have, for instance, an experimenter who has withdrawn an experiment which is already approved for flight because it is scientifically very meritorious, because he felt that he should do some more baseline studies on this particular type of species before he could be sure that he would get values which will be statistically reliable in an actual space flight.

PITTS: From the standpoint of the 21-day mission on the biosatellite, in the absence of on-board controls, of course the ground-based controls assume great significance, and it is our experience that we did not appreciate in advance how complicated and costly appropriate ground-based controls are. Now that we appreciate what they should be like, it is frequently difficult to convince other people of their importance. We envision ground-based controls of this sort. As you will recall, we are putting eight rats into orbit for 21 days, and we envision an appropriate ground-base-control system as including one population of rats which will control merely the effects on the flight animals in transport to the cape, you see, a parallel group of animals which will be transported to the cape, and then we will study the effects of this perturbation of our daily activities, our daily regimen; and another group of animals which would control the stress profile of launch; a third group of animals which would control the stress profile of reentry; and finally a group which is probably most important of all, and which we would call our primary controls, which will be a group of animals which will be fed day by day and preferably with minimal delay the precise experiences of the flight animal insofar as we can learn of them and duplicate them day by day throughout the entire mission. This involves, if you are going to do it with a minimum of delay, a quick-look capability for knowing what is going on up there, and rather complete data indicating just what is going on up there. So when you put all of this together, it is quite a large and expensive series of controls, which I maintain are essential.

SEADAHL: I would like to make a further contribution to the baseline work. We have some work at our lab which, of course, is not a planned biosatellite experiment, but certainly can be used for one. Some work is being done by Dr. McDonald with the vestibular apparatus, studying postrotational nystagmus using the eye as a guide pole, and thus far using high-energy alpha particles to irradiate the inner ear, and to see at what point the postrotational nystagmus is eliminated, and also to study the excitability.

Now, this is supposedly a problem, at least the Russians believe it is, and I think this is something that certainly bears some kind of investigation, that is, to irradiate possibly the inner ear, and then send the animal—in this case Dr. McDonald uses rabbits—send them up in a weightless environment and see the interaction of this radiation with its hyperexcitability in weightlessness.

We are also doing some work which is really very preliminary with combined stress, at this point just studying the combination of high-energy proton radiation and hypoxia. There was no work related here thus far for looking at total mammalian systems and studying the effect of a dose distribution that you expect in a solar flare combined with other stresses. We have just recently worked on simulating a solar flare, using the proton and alpha beam and a variable absorber, which would give a dose distribution and LET distribution just like that which you might expect in a solar flare. It will be worthwhile, I think, possibly to plan some experiments around this baseline, Earth-based work with some satellite work.

Then there is also some work by Paul Todd with mammalian systems, namely, Chinese hamster cells, and human kidney cells, which studies the survival of these cells as a function of high or variable LET radiation. Here, again, this would point up possible areas of interest where we could study the effects of this radiation with weightlessness with these mammalian systems.

GUALTIEROTTI: The experience we had with radiation, as I said yesterday, I think, is that in the actual space-flight profile we are very far from the threshold for any change in the vestibular system. Of course, if we go up in the Van Allen belt, or if there is any device on board which might reach or come near the threshold, that of course is another matter.

One question, in this particular case, which has not been studied, I think, is: What is important, the absolute value given instantaneously, the absolute dosage, or the cumulative effect? From our very few experimentations, it would seem that what matters most is the absolute value. We irradiated a frog for a couple of days, across a weekend, with a very low dosage, the total amount of which was equal to the threshold for instantaneous effect, and nothing happened. So we have to find out if a low dosage over a long period of time would have some effect or provoke some effect, or if the absolute values is the main important factor.

SEADAHL: Dr. Gaspard has shown a dose of about 200 rad in some cases is sufficient to cause a certain amount of excitability, and may have some significance in terms of the response in the mammalian species, in disorientation or other effects.

GUALTIEROTTI: There is another point here. We discussed that yesterday probably. But the point is that the nearby structure is much more sensitive than the vestibular organ to radiation. For instance, the Purkinje cells in the cerebellum, which are very nearby in a small animal—it is only a matter of 1 millimeter or so from the vestibule. Sometimes we get results of disorientation effects like that, not because of an effect on the vestibular system, but because of an effect on the cerebellum.

SEADAHL: Yes; but as I said yesterday, in those cases you could use charged-particle beams whose ranges you could control, and in this way deposit the energy where you would like to, and keep the energy in those areas which you want to keep free of radiation, relatively free.

KRATZER: I was wondering whether this problem mentioned yesterday on the launch vibration has a hoped-for solution in the future, or whether this is a definite characteristic of the flight?

TAYLOR: That is a difficult one. There is, I think, probably a practical lower limit to how much you can eliminate launch vibration. I think the order of 5 to 10 G's is what we are designing systems to withstand now, as far as the launch environment is concerned. It is a question of how low do you want to go, and how much it costs you to achieve it, and there is a practical limit as to how low you can go. It is probably more effective to isolate particularly sensitive devices by isolation techniques, rather than to try to reduce the vibration of the overall vehicle. This certainly can be done. It does add some complexity to a particular experiment, but if it is the difference between success and failure of the experiment, it can be done by localized isolation. I am not sure that is a very satisfactory answer, but there is a cost problem that has to enter into it.

GUALTIEROTTI: I think that a problem like this might be solved, as a suggestion, when you have a manned space platform, because then you could keep some animals or some items over there, and then from that, I do not think we need any special high acceleration or vibration launching vehicle. So from an already established space station, you might perform biological experiments with animals brought there previously, or born there, and therefore they do not have any vibration to start with.

CRANDALL: I might add this is a thing we have considered for this advanced 0-G station. You can think of many examples. A case in point would be you are not really sure when you use frog eggs, for example, that they should not have gone through oogenesis in orbit, and if this is the case, you are going to take the parent animals up there and let the full cycle of oogenesis take place in orbit. You can cite probably dozens of examples of this sort, and you do it for the simple reason that this kind of procedure is required to get data that you can feel completely comfortable with.

GUALTIEROTTI: About the experiment on frog eggs, and the vibration effect, it is known that high vibration might by itself provoke differentiation in frog eggs. How do they manage? What is the experience in preparing the orbital experiment with frog eggs?

SMITH: The control runs we have done for the biosatellite, the eggs being in a liquid medium did not see the vibration of the spacecraft. Therefore, there was no question.

BEEM: In other words, the water damped the vibration.

GERATHEWOHL: I would like to comment on this. Since the frog egg is in a very soft medium, and can be suspended in water, it may be very effectively protected against vibration and acceleration. You may know that water submersion, for instance, has made it possible for men in the centrifuge to withstand accelerations up to 20 G. So, if you have frog eggs which are suspended in water or in a liquid medium, they are partially protected against acceleration, and particularly against vibration. I think this is also true for Dr. Gualtierotti's frogs in his experiment.

Let me put it this way, and it is a question to Mr. Taylor. I know that you can protect objects against vibration by shielding and by suspending them so that some of the vibrations are damped out. I know that you can also protect objects by water immersion against high acceleration. But how do you think you could, for instance, protect certain objects, including biological specimens, against high acceleration? I do not see any possibility of how you can do that.

CRANDALL: May I enter an objection at this point? It turns out that in large part what you are really concerned with in the frog egg is the placement of the yolk material, and this is not going to be affected one bit by whether it is in water or out of water. It is actually moving the inert cellular inclusions to one side of the cell, so placing it in water is no protection against acceleration in this case. It protects the exterior from external mechanical forces, but certainly not the internal material.

MARTON: As a matter of fact, it turns out to be a perfect mechanical coupling. If you want to disintegrate something in water, you hook it up with acoustic energy and you can vibrate it to bits.

CRANDALL: Right; ultrasonic.

MARTON: What might give you some protection——

GERATHEWOHL: Water gives you some protection because it reduces contact forces which are acting on the surface of the specimen. That is the reason why it is being used for man. Of course, it has only a certain partial protection.

CRANDALL: What happens is that you will not drive this sphere into a very oblate spheroid is what it amounts to. Everything contained within the cell wall or within the cell membrane is going to be acted on in the same fashion, regardless of the water.

GUALTIEROTTI: That is exactly what I meant. We had in Milan an extensive experiment. I think we were the first to use immersion in water as a protection, and we found out that, for instance, in a cat, a fetus in a cat can withstand acceleration up to 10 000 G without being destroyed. But it really does not protect from vibration and from acceleration the inside of any dishomogeneous material. For instance, when we applied high acceleration in rats immersed in water, we found out that the lungs, which are of course, the higher density difference, are impaired in high accelerations. So what I thought about the frog egg is this: that first of all, orientation of the frog egg during the launch should be determined by gravity, by the high acceleration, 10 times gravity, so the orientation of the frog egg to start with during the launch. The orientation of frog eggs, as you know, is very important for further development. It would be fixed along the line of acceleration, and vibration would be transmitted to the internal area of the frog egg in the same way. So I wonder. Of course, you must have done a lot of testing on the centrifuge and on the vibrator, but did you try wide noise vibration? That is what provokes most of this effect, combined vibration forces on the eggs.

CRANDALL: This is why I made the point about let us conduct oogenesis in orbit, and develop the egg completely in the low-gravity environment. Then we will know what history it has seen.

GERATHEWOHL: I think it boils down to this: If we have the possibility of doing these experiments by keeping animals in orbit, and having them born there, and raised there, and so forth, we would get a much purer baseline for doing experiments than if we have to get them through the acceleration profile.

MARTON: There is one other possibility, of course, and that is that the vibration levels, if they are that critical, could be erased with adequate sensors and servomechanisms that would just damp it out, but it costs an awful lot of weight, volume, and power. I think if it were critical, we could do it mechanically. It is not that big a problem.

CRANDALL: I think the vehicle would weigh probably more than a manned vehicle that could accomplish the same thing by just taking these animals up there and letting them live through several life cycles in orbit.

TAUB: As long as there is discussion on animals having a major part of their lifespan starting before oogenesis, I should think there would be more interest than what has been shown on animals with short lifespans, rapid reproduction rates, and parthenogenic reproduction where you do not have to initiate things by fertilization. I have been interested in this, but I have not seen very many other people going toward animals that have some of these features.

CRANDALL: I quite agree with you. However, I think one of our big stumbling blocks here is having an insufficiency of the baseline data we need to be able to plan experiments centered around just this sort of approach.

TAUB: Well, does one have to submit for particular flight plans, or is this going to be a general area of interest?

TAYLOR: No; one does not have to submit for a particular flight plan at all. I think once a proposal comes in, just to amplify on what Dr. Gerathewohl was saying earlier, a fundamental thing we do not have now is principal investigators associated with specific requirements, but that principal investigator does not have to be omniscient about what our future plans are going to be as a target for a particular flight, or a particular characteristic. The proposal should specify what flight regime, and what constraints and limitations his experiment would place, and then it is up to us to get with the principal investigator to work out a compatible flight plan, along with other experiments, that meet these requirements. You do not have to specify a flight plan unless a peculiar flight plan is essential. For example, minimizing the vibration and the acceleration environment during launch is something that we would have to work with you very closely on, to see what is the threshold you can withstand, and that sort of thing.

CRANDALL: I am going to make a suggestion that I think might solve some of these problems. I think what we need are a series of symposia in gravitational biology held perhaps on a quarterly basis where we can get together and discuss some of these things, and perhaps find out where needed data do not exist and do a little thinking about it.

GERATHEWOHL: This is one of the reasons why we have the contract with the AIBS. By going around and finding out what the critical problems and most interesting problems in gravitational biology are, we can point out the areas in which further studies are needed. I think this is the purpose of the meeting that we have had today, and I think it has served this particular purpose very well.

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NASA-Langley, 1966