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955 L'Enfant Plaza North, S.W.
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date: January 25, 1972
to: Distribution
from: R. E. McGaughy
subject: Use of Shuttle for Life Sciences
Case 236

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ABSTRACT

The sortie mode of a future operational shuttle system can be a useful way of carrying out life sciences investigations for several reasons:

- 1) It is the first step in extending manned space flight opportunities to a large population of specialists who are not full-time astronauts. This will improve our knowledge of human responses to weightlessness and therefore lead to better crew selection and training procedures.
- 2) Scientists or technicians intimately familiar with their particular biological specimen can carry out experiments in space.
- 3) Experiments can be developed with relatively short lead time and small spacecraft integration effort using standard laboratory equipment.
- 4) A high flight rate permits the step-by-step development of zero-g laboratory skills.

This memorandum examines the capabilities of the sortie mode for doing life sciences investigations and the demands these experiments make on the shuttle system. It is found that:

- 1) A general purpose shuttle sortie module is capable of accommodating all of the biology experiments now being contemplated except for those involving large specimens or large populations of smaller animals. A special module is needed for these to take care of waste handling and ventilation problems.



- 2) The specimens are not sensitive enough to small accelerations to require actively-controlled gravity-compensating platforms. The ambient vehicle accelerations should not interfere with the experiments.
- 3) A sortie duration of at least two weeks is required to do a meaningful survey of biological effects.
- 4) The biology experiments can be expected to generate requests for about 2-4 flight opportunities/year for 3-5 years. A program of this size will be adequate either to establish space biology as a discipline of long-term interest or to show that space does not offer any unique window into the nature of basic biological processes.
- 5) A sub-satellite, deployed from the shuttle after men have prepared the specimens and recovered for on-orbit analysis after an arbitrary time, is also an attractive mode. It would be an important mode for biology experiments if the sortie were constrained to seven day missions.



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Sciences Case 236

MEMORANDUM FOR FILE

This paper examines the use of the shuttle in carrying out biological and medical research programs, with emphasis on the sortie mode. In this mode, scientists can perform experiments in space with their own laboratory equipment on a short lead-time basis, without having to direct extensive engineering developments which have typically taken several years in both the Skylab and automated programs. This memorandum will review the goals of the space life sciences disciplines, illustrate how the sortie could contribute to these goals, and point out the shuttle design features necessary for a viable biological and medical experiment program.

Quite apart from the scientific program, it is recognized that there are significant medical and behavioral questions to be resolved before the sortie mode can be regarded as feasible for a wide variety of people. It is known that astronauts in peak physical condition who are trained thoroughly can adapt successfully to weightlessness and perform well in space for as long as two weeks. Skylab should demonstrate the same for eight weeks. Operation of the sortie mode, however, assumes that people of the general population can perform close to their pre-flight baselines for at least the shorter periods. This assumption must be tested in the early phases of the shuttle program, and some in flight monitoring may be required in the operational phases.

I. Goals of Space Life Sciences Programs

The following statement of goals combines the ideas of a NASA planning document (Reference 1) and a prestigious organization of biologists (Reference 2) and is fully consistent with recommendations by the President's Science Advisory Committee (Reference 3) and the National Academy of Sciences (Reference 4, 5).



Extraterrestrial space is a new environment where man and other organisms can be removed from gravitational forces and the periodic phenomena associated with the rotation of the earth. All terrestrial life has evolved under the influence of these constant factors and has been structured by them. The advent of space flight makes it possible to remove living systems from these environmental factors and to investigate systematically how they depend on terrestrial phenomena. This knowledge will be important in understanding the evolution of life on earth as well as in determining man's effectiveness during extended exposures to the space environment, in setting limits to duration of manned space flight and in enlarging the range of individuals and species that can be sent into space.

In addition to studying man and other earth organisms in space, space flight gives us the opportunity to search for life in other worlds. The intriguing possibility of finding life of any kind which has developed independently of our own will always be a major driving force in our exploration of extraterrestrial space.

The study of closed systems of living organisms is a third area stimulated by the advent of space flight. The design of a life support system and a habitable living space for man in a sealed spacecraft cabin for an extended period requires both identification of the important interrelationships between living systems and the manipulation of environmental factors to reach a desired level of stability. This type of knowledge is obviously needed for our problems on earth as well as for space flight.

A fourth area of activity stimulated by the advent of space flight is the surveillance of life on earth from space. Developments in electromagnetic sensors for use in space make it potentially possible to identify patterns of growth and the spread of disease among crops and forests, measure the biological productivity of ocean water, and monitor a large number of parameters which characterize the physical environment of the earth's surface. The developing technology of spacecraft navigation and communications is enabling us to locate ground targets accurately, and the tracking of animals during migration is already possible.

The role of the space shuttle in carrying out these life sciences investigations has not been adequately explored. This memorandum attempts to define this role for the activities which will require significant manned participation. It is



believed that man as a laboratory scientist and a living subject can contribute heavily to the study of terrestrial organisms in space and therefore these subjects will be emphasized in this paper. Our initial approaches to the exobiology explorations have been unmanned, so that the sortie missions support exobiology only indirectly by developing laboratory skills that could eventually be used during a manned Mars mission. The development of closed life support systems is covered here as the area of biotechnology. The surveillance of life on earth is covered by other work (Reference 6).

It is assumed that the shuttle has been developed along the lines of the present phase B studies and will be launched and recovered often enough to meet the needs of the life sciences activities. In describing the "sortie" mode of shuttle operation it is assumed that small experiments can be put in the payload bay cheaply with short lead-time. This is equivalent to saying that the necessary scientific apparatus will require little specialized "man rating" beyond that for common laboratory installations.

II. Description of Current Life Sciences Programs

In this section the biology, medicine, and biotechnology programs foreseeable in the next 10 years are discussed in order to provide a background for considering the uses of a space shuttle in the 1980's.

A. Earth Orbital Biology

The two fundamental biological questions for which experiments in space are necessary are: 1) How do terrestrial plants and animals grow and differentiate in the absence of gravity and how do specimens born and raised in the earth's gravity field react to a lack of gravity? 2) What changes in biorhythms occur when the periods of all physical phenomena associated with the earth's rotation are completely altered by going into earth orbit?

Since earth orbit is a new environment, the first task to be done is to find out how a wide variety of species react to space flight. Some of the phenomena to be studied are (Reference 2):

Plants:

1. What kinds of plants detect gravity, and what is unusual about those (if any) that do not detect it?



2. How do plants detect gravity, and how do they use this information to change growth direction?
3. Does the lack of gravity cause plant tissue to develop from the seed so abnormally that plants could not be raised in space?
4. Are there any changes in cellular metabolism caused by the lack of gravity?
5. Is there some stage in the life cycle of plants which cannot take place in zero gravity?
6. Does lack of gravity cause periodic phenomena in plants to be alerted (e.g., periodic responses to changes in light and temperature, such as flowering, periodic leaf movements and growth rates)?
7. Does space flight have any direct or indirect effect on the genes, such as in increased rate of mutations or of chromosome deletions or crossovers?

Many of these questions could be answered with ground based experiments using a platform rotating in a vertical plane, and the exact role of space flight must await further developments in earth laboratories.

Animals:

In small invertebrates, the same fundamental questions about basic biological phenomena are important. In higher animals, questions about the adjustment of organ systems to lack of gravity and the nervous system to a new environment will be studied. Some examples are:

1. How does the cardiovascular system change in zero-g to new ways of controlling the distribution of blood to the tissues through the elastic vessels of the body?
2. What body control processes are responsible for the altered water balance we have consistently observed in weightlessness?
3. Bone calcium turnover rates need more study in extended durations of weightlessness.
4. Sleep patterns and altered biorhythms of higher mammals in space need further study.



5. What long-term adaptation processes do the gravity and posture sensors undergo when they are not being used in earth orbit?

The existing flight opportunities within NASA for carrying out the earth orbital biology experiments are:

1. Skylab -- three experiments are planned: a) S015 Effects of Zero-g on Single Human Cells; b) S071, Circadian Rhythm, Pocket Mice; c) S072, Circadian Rhythm, Drosophila. These three experiments are first steps in the survey of space flight effects.
2. The post-Skylab manned missions have not been defined, but past studies have included a primate physiological experiment along with several other experiments using rats, higher plants, frog embryos and cultures of various invertebrates.
3. A Bio-research module which can be launched on a Scout rocket, is being developed to carry small (400-pound) non-recoverable payloads into space. The spacecraft, which is a modification of the Orbiting Frog Otolith spacecraft, can be outfitted with a centrifuge designed so that animals can be placed at any desired gravity level between zero and one g. The design is flexible enough to accommodate a variety of gravity test conditions. It will also be possible to let animals seek their own gravity level. A centrifuge providing one g on a weightless spacecraft is a very important facility for biology experiments because it allows a direct comparison of weightlessness and gravity conditions without having to take into account the effects of launch vibration and acceleration. The lack of such a facility has been a built-in weakness in previous space biology experiments, where the one-g controls have remained on the ground.

Until the space shuttle becomes a reality, these missions are the only planned opportunities for doing any biology experiments with animals or plants in space, except for the possibility of sounding rocket experiments. Flight opportunities for the shuttle are discussed in section IV below.

B. Human Biology and Aerospace Medicine

The problems of Aerospace Medicine are: 1) to understand how the human body adapts to the space environment



over an extended period of time (2 weeks to 2 years); 2) to expand the crew selection procedures to a larger variety of people than the current test pilot population, a task which requires testing of many people in space flight; 3) to refine methods for training this expanded population to deal with the many unusual factors of space flight; 4) develop a real-time crew status monitoring system (Reference 7).

The currently-believed limitations to man's duration in space are: 1) the fluid-balance problem; 2) cardiovascular performance on earth after extended flight; 3) a possible gradual de-calcifying of the skeleton and degradation of muscles when they do not support body weight for a long time; 4) psychological problems of adjusting to a new set of tasks in an unusual environment for a long time with the same few associates.

The flight opportunities for investigating these problems before the shuttle is available are: 1) Skylab, where one 3-man crew will be in space for 28 days and two crews for 56 days; and 2) if approved, a follow-on Skylab, which could last as long as ninety days for 3 crew members. Other options exist for the use of Apollo hardware, but are less useful for aerospace medicine. None of these flight opportunities will yield information about the general population.

C. Biotechnology and Bioinstrumentation

The main biotechnology problems in the 1980 time frame will be in 3 different areas:

- 1) The development of closed life-support systems with an operating life extendable to two years without a linear increase in weight with lifetime.
- 2) There will be a continuing need for non-invasive techniques in the measurement of the internal physiological state of the human body during space flight. For measurements which must be made inside the body, it will be necessary to expand the technology of implantable sensors coupled to near-field telemetry to make them safer and more reliable.
- 3) The techniques of fitting the spacecraft and its operations to man's abilities and limitations will always be in need of improvement. This involves



the "soft" problems of small group dynamics, planning of off-duty activities and work-rest cycles as well as the hardware design of man-machine interfaces at all levels from cabin habitability to the operation of complex electronic gear.

The opportunities for investigating these questions are the same as for aerospace medicine problems, with the additional possibility of using the unmanned Bio-research module to test biosensors on animals.

III. Advantages and Limitations of Pre-Shuttle Flight Opportunities in Carrying Out Life Science Missions

A. Skylab A

1. Earth Orbital Biology - Skylab A gives the biology program only a small beginning in the important survey of flight effects referred to above.

2. Aerospace Medicine - The 56-day duration is ideal for carrying out human experiments directed at problems of long-duration flight. This is especially important since the next opportunity may not come until well into the 1980's with the space station. However, Skylab A can study only a restricted range of people.

3. Biotechnology - The reliability of the current design of life support components will be tested.

B. Follow-on Skylab *

1. Earth Orbital Biology

There would be an opportunity to house several specimens in a follow-on Skylab. It could include several rats, plants, and a work bench equipped with laboratory equipment. It would provide the opportunity to test the experimental skill of scientists in zero gravity as well as to perform several interesting biology experiments. Note that recent studies of a follow-on Skylab show only a few experiment facilities beyond those in Skylab A.

2. Aerospace Medicine

A Skylab B flight would permit follow-up studies of questions raised by the 56-day Skylab A missions and could extend the duration of continuous flight to 90 days.

* Skylab capabilities are described for completeness. No follow-on Skylab flights are planned.



The same type of laboratory skills important for biology experiments could be used in the inflight analysis of blood and urine samples from the crew. Skylab B has the same limitations of restricted population as Skylab A.

3. Biotechnology

A follow-on Skylab flight would not offer a significant challenge to develop or test new vehicle life support systems concepts, since the hardware would duplicate the Skylab A. Improvements in some subsystems, however, could be tested. Some examples are EVA suits, life support systems, waste management systems and gas monitoring sensors.

IV. Shuttle Flight Opportunities

A. Launch/Revisit Operations

The shuttle has the capability of carrying modules to earth orbit, leaving them there and coming back later to retrieve them. This mode of operation provides the opportunity to perform some new types of experiments.

1. Earth Orbital Biology

The Bio-research module, which will have been operating for some years before the shuttle, could be deployed using the shuttle. It makes possible a new class of biology experiments where men could experimentally manipulate the specimens in weightlessness before setting them free in space. At this time observers could fertilize eggs or set up the growing conditions for the experiments. After the species has spent a period in space long enough to grow to maturity, the spacecraft (free-flying module) could be revisited using another sortie flight; experiments could be done in weightlessness on the specimens born and raised in space. Their adaptation to one g could then be studied after landing.

Such an experiment would require manned access to the sub-satellite experiment package from the shuttle before deployment and after recovery of the sub-satellite.

2. Biotechnology

The capability of designing a life-support system for a set of biological specimens has already been developed in the Bio-research module program. Therefore, this operation does not serve as a pacing mission for the development of new systems.



B. Shuttle Sortie Operations

In the sortie mode of shuttle operation (Reference 8), several men and a variety of equipment use the payload volume during the flight as a laboratory for doing scientific experiments or engineering tests. This mode could contribute heavily to the life sciences program if the flights last long enough to do meaningful experiments and if the sortie module provides an adequate low gravity environment for experiments. The next sections discuss requirements on duration and gravity level.

1. Duration of Life Sciences Experiments

When living specimens are placed in a new environment, they undergo both immediate responses, which take from a second to several days, and slower adaptation processes which could last for months.

a. Immediate responses

It takes only a few days, at most, for higher animals (mammals) to complete the initial phases of adaptation to weightlessness. This involves immediate changes in the nervous system and in hormonal balance, such as learning to manipulate body weight, adapting to different control dynamics for blood circulation, distributing weightless blood evenly to the body tissues, and eliminating part of the body water. The immediate responses of plants to changes in their environment, such as leaf movements toward the light and root growth toward gravity and moisture are also complete within a few days.

A seven-day shuttle mission is an attractive platform for survey experiments designed to explore the immediate responses of a range of species to gravity. The 3-day Bio-satellite, flown in September, 1967, will have been the only earth orbital mission devoted to such a survey until the Bio-research module flights. These survey experiments are necessary precursors to later in-depth studies of biological processes in zero g.

However, a seven-day flight does not provide enough time to do very much experimental manipulation of the specimens after the initial adaptation has taken place. For example, one might want to grow plants at some g-level (using an onboard centrifuge) after they have gone through their initial phases of adaptation. Many experiments involve the injection and/or feeding of hormones or radioactive tracers into an already-adapted specimen. These experiments would be impossible to do in a flight as short as seven days.



b. Slow adaptation

Many biological processes believed to be influenced by the lack of gravity or other space flight factors take much longer than 5 days to occur, and therefore could not be studied completely in a seven-day flight. Any change in the chemical composition of the body takes at least two weeks to equilibrate throughout the tissues in large animals like man and well over one week in smaller animals. Some examples are 1) changes in the diet or in dietary requirements; 2) accumulation of toxic substances (e.g., CO₂); 3) changes in the calcium content of bone; 4) equilibration of any added radioactive labels. In addition, there are slow nervous system changes to be studied in larger animals such as adaptation of gravity sensors in animals (and maybe plants), adjustment of several types of biorhythms and changes in sleep patterns. In many plants and insects, it takes at least 2-3 days for the biorhythms to change to a new level after an environmental change (Reference 9 and 10), and it would take an additional 8-10 days (or cycles) to get a good statistical estimate of the new period.

In conclusion, an initial survey of immediate responses could be carried out on seven-day shuttle flights, but at least two-week flights are necessary to conduct any meaningful investigation. The mission capabilities of various durations are summarized in Figure 1. If significant effects are found, space biology would be established as a discipline of long-term interest, but if the specimens behave no differently than on the ground or in completely predictable ways, then the program could be terminated with the confidence that no real opportunities have been missed.

2. Required degree of weightlessness

The most important reason for doing biology experiments in space is to study the phenomenon of weightlessness. (Reference 2, p. vii). The question arises as to what kind of special provision is needed in the shuttle sortie module to enable these experiments to be carried out. The 3-day Biosatellite II unmanned spacecraft was actively controlled to maintain a gravity level of 10^{-5} g for 95% of the time in orbit (Reference 11). This low level was chosen to keep the acceleration of the spacecraft a factor of 10 less than the level to which the most sensitive plant system was known to respond.



The threshold for the detection of gravity by plants is discussed in a comprehensive review by Audis (Reference 12). He states that each species of plant responds to a given change in gravity level, Δg , only after a certain time, Δt , at that level; to a first approximation the product $(\Delta g) \times (\Delta t)$ is a constant, for a given species and standard growing conditions. This constant ranges from 0.5 in units of $(g) \times (\text{minutes})$, where $g = 1$ at sea level, to about 30 for various species. This means that if one changes the orientation of the most sensitive shoot by 90° in an earth laboratory it will begin to respond in 0.5 minutes. At this rate the experiment would have to last for 8.3 hours to detect a steady level of $10^{-3} g$ acceleration, assuming that the same constant, $(\Delta g) (\Delta t)$, remains valid at lower g levels. Since this assumption has been tested at g -levels down to $10^{-4} g$ (Reference 13), one can use the value of $(\Delta g) (\Delta t) = 0.5$ as a planning guideline describing the gravity response of the most sensitive plants.

The gravity levels expected in an orbiting shuttle sortie need not be much different than for Skylab, since both vehicles have about the same mass and will require the same type of stabilization for viewing the stars and earth. For Skylab with control moment gyros operating, these g levels are expected to be only $10^{-5} g$ at most (averaged over several minutes) during planned spacecraft maneuvers, and will reach transient peaks of about the same magnitude due to crew motion (Reference 14). They can be expected to add vectorially to a small fraction of $10^{-5} g$ over a few days. If a very sensitive plant were exposed even to a unidirectional field of $10^{-5} g$, it would not begin to respond until about 1 month.

The Skylab thruster attitude control system has been estimated to give short (0.04 second) pulses of $2 \times 10^{-3} g$ (Ref. 14). Since some investigators (e.g. Reference 15) think that short acceleration pulses could trigger responses in a sensitive plant system, it would be preferable to use control moment gyros to control the vehicle attitude. With such a CMG-stabilized spacecraft, it is not considered necessary to provide a special platform actively compensated to counteract vehicle accelerations. The experimenter could provide shock mounts to his experiment platform if he needs to prevent local acceleration pulses from reaching his specimen.

3. Earth Orbital Biology

Since the aim of the biology experiments is to observe the reactions of living specimens to the space environment, the main job of the experimenter is to observe the specimens and to



make sure that they remain healthy. This will have to be done through some kind of barrier for many specimens because demands of experiment reproducibility require more rigidly controlled atmosphere (temperature, composition, and humidity) than is necessary for the health and safety of the crew.

Before and after the exposure period the scientists will be experimentally manipulating the specimens. This includes activities such as adding chemicals to bacterial suspensions, observing cell cultures through a microscope, making detailed observations and photographs of plant specimens, transplanting shoots, and performing simple chemical analyses. The experiments investigating gravity responses may reasonably require groups of control specimens on a centrifuge at the same time the experimental specimens are being exposed to zero-g.

In order to do any experiments with mammals larger than mice, the ventilation system of either the entire crew living quarters or of the animal cage area must be capable of reducing the animal odors to an acceptable level.

The ventilation problem could be simplified if the animals were isolated in an enclosure provided with gloved portholes to permit manual handling of the specimens and chemicals. As with all animals the waste handling procedures and equipment require careful design for zero-g operation.

To accommodate these experiments, the shuttle vehicle and the sortie module must have the following characteristics:

a. Shuttle vehicle characteristics:

- 1) Launch times should be predictable to within a few hours for some specimens so that their life cycle can be timed properly.
- 2) Access to the experiment is usually needed a short time before launch. The access time in previous missions has been 4 hours, 15 hours, and 5 hours for Biosatellite II, III, and Frog Otolith launches.
- 3) The experiments must be powered up continuously from before launch until after recovery.
- 4) No special orbit is needed for these experiments, except to keep the radiation dose to the men within accepted limits.



b. Sortie experiment module characteristics:

- 1) Specimens must be made non-hazardous to crew:
 - a. adequate solid waste disposal for all specimens.
 - b. urine and feces removal system for large animals.
 - c. either auxiliary ventilation or a separate atmosphere is needed for the large mammal cage volume.
 - d. animals must be securely confined and handled only by trained personnel.
- 2) The following standard laboratory equipment will probably be furnished; water, electric power, refrigerator, oven (incubating chamber), centrifuge, chemicals.
- 3) Onboard data storage is required and both gross and microscope photography will be needed. The presence of the investigator reduces the requirement to telemeter large amounts of raw data.

Several laboratory skills will be needed by man in future long-duration flights, and the shuttle flights would make it possible to begin learning these skills. Some of them are:

- 1) doing animal surgery in space.
- 2) zero-g handling of fluids and techniques of wet chemistry.
- 3) learning to culture bacteria, soil samples, and tissue preparations in zero-g.

Virtually all biology experiments would gain many times more information with the participation of a trained scientist than if they had to be completely automated. Laboratory research in biology has always required a high degree of experimental skill, and the real advances are usually made by the scientist who has found a new and better way of extracting information from biological material. Most scientists would like to "nurse along" their system directly and would welcome the opportunity to do so in space.

4. Aerospace Medicine

The biggest disadvantage of the shuttle in doing medical investigations on man is the short duration of the flights. As mentioned above, a 30-day period in space would enable many more phenomena to be studied than is possible in



a seven-day flight. But even a 30-day capability is not enough to study the important problems of long-duration flight.

The chief advantage of the shuttle is the high frequency of flights and the large number of subjects that can be studied per year. The high frequency makes it possible to try different types of measurements and to refine them on subsequent flights. The large number of subjects makes it possible to assess the effect of space flight on different types of people and thus leads to better medical criteria for selecting and training crew members and more accurate knowledge of the performance limitations of the general population in space.

There would be several types of medical activities appropriate to shuttle flights in addition to the standard measurements of exercise tolerance, heart rate and blood pressure, food intake and solid and fluid outputs. New ways of measuring physiological and psychological stress in real time must be validated in flight. This involves the systematizing of many different kinds of data by means of stress models which will be becoming increasingly refined. Some types of data that might be promising are: 1) continuous EEG recording, even during the waking hours; 2) urinary hormone constituents; 3) investigation of saliva as an indicator of stress; 4) galvanic skin response, electrocardiogram and any other electrical signals obtainable which could indicate nervous system functioning. The constant aim in these measurements will be to make them as unobtrusive as possible so that they do not interfere with the tasks for which the men are going into space. If the ground-based research develops very unobtrusive measurements, then it will be possible to use them on almost every person that flies; the more objectionable a measurement is, the less likely it will be used.

5. Biotechnology

The shuttle flights offer an ideal opportunity to test the conceptual design of life-support system components operating in zero-g. However, it is too short a duration for zero-g reliability evaluation.

6. Characterization of Sortie Experiments

Inherent in the concept of a shuttle program with sortie missions as frequently as once/month (Reference 16) is the expectation that the equipment will be inexpensive and will require a short lead time for installation because it will need no major engineering development before it is bolted to the



sortie walls. The shorter lead time is advantageous to the life sciences because experiments and tests can be more responsive to past results and new ideas.

However, there is a significant difference between supplying equipment for zero-g laboratory studies (biology, manufacturing, fluid physics) and for observations of phenomena outside the spacecraft. The former involves manipulation of objects in zero-g, which is fundamentally different than on the ground, whereas the latter primarily uses optics and electronic equipment, which operate no differently in space. Therefore the three selling points characterizing vastly improved experiment procedures for sortie mode science, namely short lead time, inexpensive equipment development costs and frequent flights, do not imply instant experiments for zero-g laboratory science as they may for space and earth observations. Specially-designed equipment will be needed for zero-g, and therefore it cannot in general be lifted from earth laboratories and flown unaltered in the sortie. Instead, these sortie characteristics imply that promising techniques and the skills necessary to employ them can be tested frequently and implemented cheaply. The sortie mode is a testing ground for development of man's skills and laboratory equipment as much as a place to perform significant scientific studies.

To illustrate the way in which the sortie would be used by the life sciences, we shall describe the type of experiment hardware that could be flown. The exact experiments cannot be outlined now because ground-based research is needed before the experiments can be defined. (Reference 4).

A list of typical equipment might include:

- 1) A one-g centrifuge for plant and small animal specimens.
- 2) Refrigerator, incubator chamber.
- 3) Microscope and accessories for tissue culture growths.
- 4) Trial electrophoresis units for chemical and cellular separations. These separations might be cleaner in absence of convection currents.
- 5) Cages for small-animal behavior experiments.
- 6) Modification of existing hardware (Bio-research module, possibly Apollo or Biosatellite) to accommodate a wider range of species and experiment improvements.
- 7) New biosensors.



- 8) Selected equipment for testing physiological and psychological stress in human subjects.

Table I outlines the type of apparatus that would be suitable in a general-purpose shuttle sortie flight. In many cases, commercial equipment would suffice. Notice that some items are common to several disciplines but that other equipment must be tailored to the individual experiment.

As the shuttle program develops, there will be a gradual build-up of life sciences activity if important phenomena are discovered in the early flights. Figure 2 shows in general terms how a sortie life sciences capability could grow. It must be acknowledged that if a representative survey of biology specimens consistently yields negative or trivial results (i.e., shows that space flight has no effect (or completely predictable effects) on basic biological processes then it is unwise to continue looking for more effects. Program managers should expect continual disagreement about when that point is reached. The medical activities portrayed in Figure 2 will lead to a real-time crew status evaluation system incorporating stress models valid for a wide range of individuals.

7. Expected sortie traffic in life sciences

Since the aerospace medicine investigations are designed to be unobtrusive additions to every sortie flight, it is thought that no special missions are required for them, after the flight program becomes operational.

If some unforeseen medical problem arises, it is possible that an in-depth animal experiment will be required to explain, or test countermeasures against, the phenomenon. This type of problem would be the responsibility of one group of investigators, say at Houston, and it is not likely that they would need any more than one or two flights per year. Since this is a contingency, these flights are not included as line items in calculating the traffic which an operational shuttle will be carrying.

To conduct the space biology survey, the necessary number of flights per year can be calculated with some reasonable assumptions, and the answer can be checked by examining its consistency with the likely demand for shuttle flights among space biologists in 1985.

The calculation goes as follows: If ten scientists are doing their experiments in the general-purpose module, it



is not unreasonable that three of them could be biologists -- five would be an upper limit. If each man were responsible for three experiments, then each flight could support somewhere between 9 and 15 experiments. The total number of experiments being considered by a 1969 Space Biology Planning Panel was about 100, so it will take between 7 and 11 flights altogether to complete this survey. Since a careful survey, with time for skill development and thorough analysis of data should take perhaps three to five years, the flight rate could range between $11/3 \approx 3.5$ flights/year to $7/5 \approx 1.5$ flights/year.

If NASA is planning to provide facilities for the academic biologists to conduct a survey, the flight rate must be frequent enough to maintain their interest. It is doubtful that this could be done with fewer than 2 flights/year, whereas one every three months would probably be about as frequent as the limited number of potential investigators could handle. Therefore, both lines of thought converge to an estimate of 2-4 flights/year as about right for the demand among life scientists for sortie flights.

A 7-day sortie would not be nearly as attractive as the 2-week sortie because it would rule out many important experiments. A count of a model program suggests a 60-80% reduction. This should be translated, not into a reduced demand for flight rate, but instead to a shorter and less conclusive sortie program, perhaps supplemented by launch and revisit operations as described on page 8.

V. Summary

The existence of the space shuttle, with its flexibility of operating modes, its potential for accommodating scientific experiments and engineering tests on a short lead-time schedule, and its ability to fly the investigator along with his experiment, will greatly increase the variety and quality of the biological science that the space program can support.

The ability of the sortie scientist to do many small experiments in frequent flights is an ideal situation for the earth orbital biology program, where a survey of weightless effects among a variety of specimens is needed. This capability is also important in biotechnology, where the conceptual design of new life-support system components can be tested in zero gravity. The sortie mode can be combined with the satellite launching mode to do a new class of biology studies where the experiment is initiated by the scientist in weightlessness before being put in the satellite, and, after an arbitrarily long period in orbit, the satellite is recovered and the specimen observed and tested while still in weightlessness. The frequent sortie flights offer the field of



aerospace medicine the chance of testing the capabilities of different types of men in weightlessness, and will make possible the refinement of laboratory skills needed for later flights of longer duration.

If the shuttle is to accommodate these experiments, several design requirements should be met. The sortie mode must be capable of flying at least two-week missions in order to accommodate more than the most elementary type of biology experiment. Experiments with mammals larger than mice will require special waste management devices and procedures. Access to the experiment is usually needed immediately before launch. The survey of biology effects will probably generate a demand of about 2-4 flights per year for 3-5 years.

It is believed that special attention to the use of the sortie mode as a scientific laboratory will make the entire shuttle program more useful to the country.

Acknowledgment

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TABLE I

UTILIZATION OF EQUIPMENT BY LIFE SCIENCES DISCIPLINESEarth Orbital Biology

	<u>Cultures</u>	<u>Plants</u>	<u>Animals</u>	<u>Aerospace Medicine</u>	<u>Biotechnology</u>
One g Centrifuge	✓	✓	✓		
Laboratory Centrifuge	✓	✓	✓	✓	
Refrigerator, Incubating Chamber	✓	✓	✓	✓	
Microscope	✓	✓	✓	✓	✓
Camera	✓	✓	✓	✓	✓
Animal Cages			✓		
Culture Chambers	✓				
Plant Holders		✓			
Near-field Telemetry Equipment			✓	✓	✓
New Bio-sensors			✓	✓	✓
Physiological and Psycho- logical Test Equipment			✓	✓	✓
Previous Flight Hardware	✓	✓	✓	✓	

FIGURE 1

EXPERIMENT PROGRAM CAPABILITIES VS. DURATION

<u>MISSION DURATION</u>	<u>CAPABILITIES</u>	<u>TIME CONSTANTS</u>
7 DAYS	<ul style="list-style-type: none">◦ TEST A VARIETY OF PEOPLE◦ SURVEY OF INITIAL RESPONSES TO WEIGHTLESSNESS	TYPICAL IMMEDIATE REACTIONS (CIRCADIAN RHYTHM ADJUSTMENTS, CARDIOVASCULAR CHANGES, WATER BALANCE, ORIENTATION OF PLANTS SPROUTING OF SEEDS): 2-4 DAYS
14 DAYS	<ul style="list-style-type: none">◦ LIMITED MANIPULATION OF ADAPTED SPECIMENS◦ METABOLIC TURNOVER IN SMALL ANIMALS◦ MEASUREMENT OF NEW CIRCADIAN RHYTHM◦ MOST CURRENTLY PROPOSED BIOLOGY EXPERIMENTS	METABOLIC TURNOVER IN SMALL ANIMALS (E.G., DIET CHANGES, EQUILIBRATION OF INJECTED RADIOACTIVE LABELS, ACCUMULATION OF TOXIC SUBSTANCES): 6-10 DAYS
TO 30 DAYS	<ul style="list-style-type: none">◦ STUDY IN SPACE OF <u>FULLY</u> ADAPTED SMALL ORGANISMS	

FIGURE 2

EVOLUTIONARY DEVELOPMENT OF LIFE SCIENCES CAPABILITY USING SORTIE MODE

	<u>Ground Research</u>	<u>Precursor Flights</u>	<u>Early Sortie</u>	<u>Later Sortie</u>	<u>Dedicated Modules</u>
<u>Biology</u>	Develop definitive experimental systems.*	Bio-research module: Exploratory studies Variable -g tests.	Microscope BRM centrifuge Lab centrifuge Camera	Wet chemistry facility General purpose lab	Animal Facility
<u>Medicine</u>	Physiological and performance tests	Skylab: 2-month duration, 3-6 individuals	Near-field telemetry. On-board sample analysis.	Real-time crew status evaluation. Many individuals	

*Looking for effects of space is not warranted indefinitely.

Subject: Use of Shuttle for Life Sciences



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