THE USE OF A SPACE STATION TO ADVANCE THE GOALS OF SCIENCE

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Briefing on Space Station Plans and Programs

Paris, Jun. 1970

INTRODUCTION

We are now in NASA's second decade and we believe we have fulfilled our commitments to the first generation of space science projects. Apollo has visited the moon twice, building upon the brilliant pioneering ventures made by Ranger, Lunar Orbiter, and Surveyor. Mariners have already been to Mars and Venus, and they will revisit Mars to gain more detailed knowledge in the 1971 orbital missions. We are well along with plans to venture to the outer planets of the solar system, and to carry our explorations down to the surfaces of the planets, starting with Mars in 1975.

In earth-orbit we can look back upon the magnificent accomplishments of six Orbiting Geophysical Observatories (OGO), more than two score specialized Explorer and applications satellites, a half-dozen Orbiting Solar Observatories (OSO), and that magnificent achievement, the Orbiting Astronomical Observatory (OAO). While we still will launch additional satellites in these series, this is the year of transition from the first generation of spacecraft and missions.

The major protion of the next decade will certainly emphasize and exploit the tools and techniques that have been perfected and used successfully so far. New materials, components, techniques, and processes which have been invented will vastly increase the flexibility, reliability, and overall usefulness of existing classes of spacecraft. In addition, we hope to develop new tools to work in areas that have not yet been touched. Discoveries of the past decade have revealed unexpected phenomena (like X-ray stars) which we do not yet have the tools to study in depth. We need, therefore, to develop much more complex tools to intensify our study of newly discovered phenomena.

In mapping our course for the second decade, we must make choices of modes of operation as well as direction in which to proceed. Mercury, Gemini, and Apollo have developed to an advanced degree the ability to send men into space, to sustain them through a period of days to weeks, and to enable them to perform useful activities. The Skylab I program, to be carried out in the early years of the next decade, will test and demonstrate important extensions of the existing capabilities with the addition of man in the loop. Then the latter part of the next decade of space science in earth-orbit will find large scale use of fully automated small satellites, of remote controlled satellites and modules associated with the space station. The principal use of man for science in space is in decision making, real-time control, and in exploiting an individual's feedback from senses to motor response. Astronauts in orbit are expected to be cost-effective for many operations because of man's ability to repair or update instruments, thus taking advantage of a human's versatility and flexibility of control and judgment.

Thus, in the last part of the second decade and through the third decade, the space station and its modules should provide important support to experiments in Bioscience, Astronomy and Physics.

Let us look at these three areas in some detail now, and speculate on what role the Space Station will play in each.

Bioscience

In the Biosciences area, a space station can help us to attain a thorough understanding of the effects of the space environment on terrestrial organisms. By the same token, such research in the space environment will undoubtedly extend our understanding of most biological phenomena. Attendant to this expansion of our understanding will certainly come uses for space technology and the application of the resultant scientific information to health care, treatment of disease and ecological problems.

Our specific objectives in space biology which are particularly appropriate for investigation on the Space Station include the following areas:

First, a determination of the biological effects of weightlessness. Gravity, per se, is an omnipresent force in our environment and, as such, has a very important role to play in the origin and nature of all living things. Our object in this regard is to investigate the changes in form and function when organisms accustomed to gravity are plunged into weightlessness.

Second, the role of gravity in biological processes. The force of gravity has had a profound effect in the course of evolution and development of all plant and animal species. Since living organisms are really quite adaptable when it comes to form and function, the factor of gravity must be of prime importance to the processes of living, including the action of the heart, blood flow, filtration in the kidneys and other vital life processes. Certainly, there is a great deal to be learned about many basic life processes when we are able to investigate the physiology of the blood system at another point on the "G" curve other than unity.

Third, the origin and nature of biological rhythms. Rhythmicity is an essential property of life itself. An understanding of innate and induced rhythms in organisms is an essential part of basic biological research. In a more practical sense, biorhythms are important in medicine, too. Examples include Cushing's disease, and Addison's disease, where loss of the cortico steroid rhythm is proof positive of the existence of these diseases. Such diseases can be discovered and understood best in terms of their loss or alteration of specific rhythmic functions. There are, however, some very fundamental questions regarding these biological clocks, particularly the circadian (24 hour) rhythm which remain unanswered and are, in fact, unanswerable in terrestrial laboratories. In the matter of the circadian rhythm, for example, there is a disagreement regarding the role of cyclic geophysical forces or the inertial effect of rotation of the earth in setting the biological clock. The majority of chronobiologists contend that the clock is an internal and autonomous oscillator which does not require the input of information from the environment but is reset daily by light or other synchronizing signals. Yet this position is not subject to proof in the terrestrial laboratory, where certain pervasive forces are not susceptible to control. Here, then, is a situation where research in the space environment is able to provide the only solution to questions arising at the earth's surface.

Fourth, the biological effects of radiation. Another area of great interest to the space biologist is that of the biological effects of radiation. Here we are interested primarily in the combined effects of weightlessness and heavy particles or primary cosmic radiation. These concepts become much more clear upon examining specific results of previous and planned Bioscience flight experiments.

Let us look at the results of the Biosatellite II, which orbited the earth for approximately three days. It carried thirteen experiments (on seven types of specimen) designed to study the interaction of biologic systems with weightlessness, and the combination of weightlessness and onboard gamma-radiation provided by strontium-85 source. The studies included the effects of removing these living organisms from the direct influence of the earth's periodicity.

The effects studied by the experimenters included cell division and differentiation, development and growth, chromosome damage and mechanics, genetic mutations and biochemical regulation of cell nutrition and metabolism. Two classes of controls were used--exposure of the flight packages prior to launch, and study of identical subjects on the ground during the mission.

The more significant results are tabulated as shown

S21 in the following two charts which show the chromosome

S22 translocations in the vinegar gnat, Drosophila, and the gross body abnormalities of wing and thorax in flies hatched from Biosatellite II eggs. Note on the fly at your right the hemi-thorax, vestigial wing and missing wing defects.

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The results of Biosatellite III illustrate the complexities of conducting advanced biological experiments in space. On 29 June 1969 Biosatellite III was launched with a highly instrumented pigtailed-monkey aboard. The objective of the flight was to study the effects of the space environment on a small primate over the course of thirty days. It was necessary to return the spacecraft and monkey to earth on the ninth day, and the monkey expired within twelve hours after landing. The data from Biosatellite III are still under investigation and going through corroboration in the laboratory. However, the following preliminary results can be reported.

a. The monkey displayed pendular eye movements indicating disturbance of the organs of balance.

b. He suffered disruption of the normal patterns of sleep. When such a pattern persists in humans it is almost always an indication of incipient disease.

c. He displayed an increase in central venous blood pressure. Ordinarily central venous pressure is slightly negative in healthy speciments. In the case of the Biosatellite III monkey the pressure rose to the positive region and remained so throughout the course of the flight.

d. Data taken during the flight and investigation after recovery of the spacecraft showed that the animal had negative nitrogen balance, had lost a significance of muscle mass, and

e. About 20% of his preflight body weight due primarily to evaporative loss of water through the skin. He also showed a gradual decrease in body temperature despite elevation of the metabolic rate.

Clearly, space flight had a profound effect upon this monkey. This mission has convinced many experts of the need for extensive primate research in the Space Station. Other experts contest some of the tentative conclusions of Biosatellite III, but there is a general feeling that further space experiments are needed.

Bioscience Experiments in Skylab I

S23 On the chart is shown Bioscience experiment flight hardware to be flown in the Skylab I program. These

Instruments are for three experiments dealing with the nature of circadian rhythms and a fourth with the effects of weightlessness at the cellular level.

At the left side of the screen is the hardware for two rhythm experiments which have been combined to share common life-support data systems. The first of these two experiments deals with the hatching rhythm of vinegar gnats from their pupal cases. Normally, the gnats hatch in "batches" each 24 hours, timed so as to emerge at a time of the day when they will not become dessicated. In the space flight experiment the pupal "clock" will be set by a short flash of white light. Then at six-minute intervals the pupal cases will be examined by red light through fiber optics to see the effect of space flight on their circadian rhythm.

The second experiment will deal with the deep body temperature, heart rate, and locomotor activity rhythms in the "little pocket mouse" (Perognathus longimembris). This mouse is an ideal experiment subject weighing approximately 10 grams and requiring no drinking water. In addition, the pocket mouse also shows pronounced oscillations of deep body temperature having a period of 80 to 90 minutes.

In the center of the chart is a device to study the effect of "zero gravity" on 24 colonies of single human liver cells using time-lapse photomicrography. The techniques used include radioisotopic tracers of metabolism, periodic serial staining and fixation at preset times.

At the right is shown the automatic respirometer device which will be used to follow the time-course of oxygen respiration of sprouted potato tubers which, on earth, display a very interesting and well studied 24-hour rhythm. A typical daily curve shows maxima at sunrise, noon, and at sunset on earth. The objective is to learn what happens in zero g to this rhythm.

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Let us now look at areas of interest to biology in the space station laboratory. The goals and objectives do not change; however, with the possibility of such an orbital laboratory staffed by professional bioscientists, the type and character of the research possibilities can be dramatically different than the customary preprogrammed, automatic experiment such as we have seen. The space station also offers wider latitude in the kinds and amounts of biological materials which can be placed in orbit.

Areas of interest in <u>general physiology</u> which will be
S24 represented in space station payload planning include experi-

ments to corroborate evidence from the earlier Biosatellites in addition to experiments of types which have not flown earlier. They deal with the following broad areas:

1. Physiology of the cardiovascular system and changes in hemodynamics resulting from weightlessness.

2. General metabolism, bioenergetics, and metabolic pathways.

3. Electrolyte metabolism, water balance, body fluid studies and renal physiology.

4. Reproduction development, growth, and aging.

Biological materials for the above experiments include, for example, primates such as the pig-tailed monkey or chimpanzees, rodents such as the picket mice or other mammals; turtles, amphibian eggs, insects, flowering plants and woody plants to name only a few.

Areas of interest under the general heading of <u>behavior</u> deal with changes caused by alteration of the gravitational environment and the customary cyclic geophysical forces or
S25 other space environment factors. These areas are concerned with:

a. Changes in plant growth and form

b. Gravity level preference in animals, such as in rats and other animal species.

c. Mechanisms of the biological clocks in primates, small mammals, insects, plants, and crustaceans.

d. Learning and performance in weightlessness of primates, rats, spiders, and fish to name a few.

The last major area of interest in concerned with

S26 genetics and the possibility that genetic alterations may result from either weightlessness or radiation or the combination of the two. In this area we are concerned with both spontaneous an radiation-induced mutations or chromosome alteration in the space environment.

Astronomy

S3 The Apollo Telescope Mount (ATM) represents a major effort to capitalize on the resources of Apollo-Saturn capabilities to carry out high resolution observations of transient solar phenomena. The experiments were first developed for the Advanced Orbiting Solar Observatory (AOSO), a program cancelled in 1967. Its goal was to obtain 5-arc second resolution observations of active solar events. Transferring these experiments to a manned spacecraft meant the astronauts could watch the sun, recognize unpredictable incidents like flares, and commence a series of special observations. The ability to return film from orbit meant one could collect data at a very much faster rate than was possible on AOSO. Furthermore, once on the Skylab, the relaxation of programmatic constraints enabled these same instruments to strive towards one-arc second resolution, so the original five telescopes grew in size and number. ATM is mounted external to the Skylab, separated from the astronauts except for singular film retrieval by extra-vehicular sorties, so they will not be able to adjust or repair the instruments. Nevertheless, the ATM represents a bold step in the direction of using astronauts to carry out complex astronomical investigations.

S4 The instruments on ATM include the major categories of instruments at a well-equipped solar observatory--spectrographs, spectrometers, a coronagraph, photoheliographs, flux monitors, and a visible light monochromator to enable the operator to detect a flare and point the instruments at it. Except for this (and the coronagraph) the ATM telescopes operate at UV and X-ray wavelengths not accessible to ground-based telescopes.

The AOSO had a goal Skylab-I cannot satisfy--a full-sunlit polar retrograde orbit which allowed continuous observations. A Czek astronomer has identified the "Saturday effect," describing the perversity of important flares to occur on Saturdays and holidays, when the astronomer is away

S5 from the telescope. The ideal space telescope works con-
tinuously in an orbit where the earth, the sun or the space
station do not block the view periodically of the object
under observation. Furthermore, the dynamic and thermal
environment of a manned spacecraft are expected to set an
upper limit to the resolution performance of telescopes.
Finally, the neighborhood of a manned spacecraft is known to
encompass optical contamination, the result of outgassing,
attitude motor exhaust, liquid waste dumps, and bits of
paint, cork and other debris flaking from an inhabited
vehicle. The eventual space observatory will operate away
from these influences, but will depend vitally on a manned
S7 space station or shuttle for essential services. Astronauts
will erect the instruments, collimate and adjust them, repair
worn or defective components, and periodically replace
expendables and interchange auxilliary instruments like
photometers, spectrometers and image tubes. Between visits
S6 the observatory will operate automatically, or under remote
control from the space station or the ground. To accommodate
astronauts when they arrive for servicing, the observatory may
S8 be temporarily converted to a small space station providing the
so-called "shirtsleeve environment."

A different approach to designing a man-assisted space
S10 telescope carries a 3-meter diffraction-limited telescope in a configuration with the instrumentation external to the telescope, accessible to astronauts in a "space tug" through an airlock inside a cabin at the end. As the slide indicates, stellar or solar or X-ray telescopes could be accommodated. The weights and dimensions suggest the awesome size of such a module.

S11 A third concept is shown in the next slide designated the "evolutionary Orbiting Astronomical Observatory." In this arrangement the instrumentation is also at the rear and external to the spacecraft. The "tug" makes a rendezvous
S12 and docks, and the telescope is serviced by retrieval of critical elements through an airlock into the cabin of the tug.

S13 Even the High Energy Astrophysical Observatory could be supported in this dual mode by rendezvous from an associated space station. The instrumentation is different, but the basic relationship to the manned spacecraft is the same. All these modules are highly versatile--the ATM could carry a stellar telescope, the common module could carry a solar or
S14 X-ray telescope, and even the HEAO spacecraft could be applied to a diverse array of astronomical instrumentation.

The important image to carry away is that a manned space station should allow flexibility in its functional role

S9 of supporting astronomical observations, allowing tightly integrated, gimballed, or free-flying observatory modules, and be able to reach remote, autonomous telescope modules.

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Time precludes our dwelling on all the opportunities for astronomy in a space station. Special facilities are needed for infrared and microwave telescopes. These inherently low-resolution instruments make less stringent demands on the stability of a spacecraft and purity of the environment, so hard mountings are more feasible. A space station serviced regularly by the shuttle is well suited to maintain the cryogenic subsystems of such instruments. It is unlikely that VLF radio telescopes would work in close association with a space station, because of the orbital requirements of such instruments (to escape the ionosphere)--but a space tug could deliver the instrument to its station, erect it, check it out, and periodically visit it for repair and maintenance.

Physics

In physics we can identify four areas of research:

1. Plasma Wake Investigation
2. O/B Plasma Laboratory Research

3. Studies of Environmental Perturbations

4. A High Energy Cosmic Ray Laboratory

S15 The purpose of a Plasma Wake Investigation is to map the plasma disturbance behind a large vehicle in space. This requires instruments to be swept, repeatedly, across the wake. This could be done using an articulated boom, or a controllable subsatellite, as shown. In either case, local intelligent control is needed, since the wake structure depends on the plasma concentration, the main vehicle motion with respect to the earth's magnetic field, and ambient plasma "wind" motions.

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A plasma laboratory would provide facilities for performing plasma experiments (more than observations) sufficiently versatile so that they can be used for a number of different purposes. Basically, one or two antennas, a transmitter, receiver and spectrum analyzer are needed (allowing polarization and phase measurements, if desirable). Supplementary ion sources and ion spectrometers should also be provided. Experiments to be performed in the space environment, away from wall effects, include the following.

First, stimulation of plasma resonances, examination of their detailed structure, resonating volume, sensitivity to orientation of the exciting antenna with respect to the local magnetic field. Sensitivity to local composition, dissociation and ionization, and unpredictable solar stimuli. Apart from the basic phenomena of plasma physics involved, the resonances, because of the interaction with large volumes of space, hold out the promise of providing the means of measuring electron concentration and ambient magnetic field without significant contamination by the spacecraft. A large "test" body is needed.

Second, plasma memory effects. In the laboratory, pulses can be stored and recovered from a confined plasma. These phenomena have not been studied away from walls. The non-linear differential equations defy analysis, so theoretical physics must become experimental.

Third, investigate the plasma cross-modulation effects discovered on the UK Ariel III satellite.

Fourth, wave/particle interactions. The generation and amplification of radio emissions by particle streams, and conversely, the acceleration or deceleration of particles by properly modulated radio transmissions are phenomena believed to occur naturally, but have yet to be studied, in space, under controlled conditions.

Fifth, wave propagation studies. The propagation of

Very Low Frequency (VLF) waves is profoundly influenced by the medium. Using a known source of signals, ground receivers could perform studies of signal strength, frequency and spatial dispersion not possible with natural sources. This is a natural extension of the satellite beacon, one of the oldest and most powerful techniques of space plasma research.

What are the arguments in support of the use of man?

1. A true laboratory "facility" has more versatility than can readily be programmed into an automated system. A large number of phenomena is to be investigated. The basic instruments can be used in a mainfold of configurations, so flexibility is a premium.

2. Many experiments can be performed in a time of the order of one month--they do not need 1-8 year lifetimes.

3. The large body of the Space Station provides a means of erecting equipment, spatially well spearated--distances are larger than on a typical unmanned spacecraft.

4. Individual portions of experimental equipment can be changed in light of initial results. This is what is usually meant by "laboratory experiments" as opposed to "preprogrammed observations."

Environmental perturbations is the third area of space physics. These can take the form of injecting substances to produce airglow, to stimulate ion recombination of barium or strontium to map electric and magnetic fields. (Important questions of conductivity changes are yet to be resolved--

S16 these could be studied better on a space station than by automated means.) In addition, particle accelerators can be used to produce artificial aurorae in a more controllable manner than by pre-programmed rocket flights.

These are the arguments in support of the use of man in such experiments:

A large observing platform can be used to mount several instruments--spatially separated for airglow conductivity, and electric and magnetic field perturbation measurements. Fast reaction time is available to vary the type and mass of released material, and vary release times in accordance with observed <u>local</u> plasma conditions, and velocity and angle with respect to observed <u>local</u> magnetic field. This area of research is a noteworthy example of the international flavor of such global experiments.

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<u>International Participation</u>

Scientists from without can be provided with observing time on an instrument, with data from a specified experiment to be performed in a laboratory facility, or with a specified "source" of radio signals or particle streams (like the "beacon"). The advent of the Space Shuttle would open up a new era of investigation, by enabling a scientist, in reasonably good health, to spend a few weeks in the station, to perform his own work, screen and reduce some of his data and return to complete his data analysis on the ground. He might even ascend with equipment to be temporarily attached to the station.

A fourth space physics program involves the High Energy Cosmic Ray Laboratory. The primary objectives of these investigations are astrophysical in nature. Cosmic rays are direct messengers bringing material from other regions of our galaxy and beyond, into our solar system. Information on the spectrum and composition of these particles will enlarge our knowledge of the dynamic processes occurring in stellar reactions and on the intervening interstellar material and magnetic fields. Cosmic ray measurements up to 10^{10} eV have been made on small, automated earth satellites. To extend this range to 10^{15} or 10^{17} eV requires very large, heavy instrumentation, which can be carried only on large manned and unmanned spacecraft.

The second objective is to use the cosmic ray beam as a source of elementary particles for nucleon-nucleon interaction studies at energies higher than can presently be obtained on earth. Several fundamental questions on elementary particle cross-sections at high energies, existence of heavy antiparticles, fractionally charged particles, or magnetic poles could be investigated with a cosmic ray laboratory. The intensity of cosmic rays is very low at these high energies, and therefore, the instruments must have very large area sensors to be able to record the rare particle events which occur.

A typical space station cosmic ray laboratory would be
S17 a two-level structure. The lower level would contain the
primary instrumentation for these studies. Typical instru-
mentation would be an ionization spectrograph, superconducting
magnets, spark chambers, scintillation counters, Cerenkov detec-
S18 tors, and plastic emulsions as shown here. These detectors
would be used in various combinations depending on the
particular investigation. The specific instrument configu-
ration would be arranged by the crew depending on the objectives
of the investigation and the interchangeability of specific instru-
S19 ment components. In this chart, the upper level of the
laboratory would contain the control consoles and data processing
equipment for operating the instrumentation. Trouble shooting
would also be performed here.

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Conclusions

The next decade will be one of transition in space science. We will be extrapolating our first generation techniques into much more sophisticated experiments, we will learn how to use man for space science in Skylab and then extend these beginnings into more mature efforts when the space station becomes available. We look forward to much that will be new and challenging.

The international character of scientific research, the universality of interest and knowledge in the these sciences promise that the space station will be a powerful research resource for us all.

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