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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACE STATIONS

Gateway to Our Future in Space

presented by

Dr. Robert R. Gilruth
Director
Manned Spacecraft Center
National Aeronautics and Space Administration

at the

Fourth International Symposium on
Bioastronautics and the Exploration of Space

June 25, 1968

San Antonio, Texas

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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Space stations orbiting the Earth have long been the dream of space engineers and scientists. There have been many concepts and designs proposed, and many reasons have been given for their use. One of the problems has been the difficulty of dealing with the very multitude of uses and the infinite variations of designs.

During the last few years, however, several things have happened to help clarify the picture: First, the recent development of the Saturn V rocket has provided one of the major building blocks for space station design.

Secondly, we now have a far greater knowledge of the environment desirable for working and living in space; and,

Thirdly, the programs of the work in science and technology to be done in a space station have been studied in considerable depth with the result that the use requirements can now be better defined.

In my paper today, I will discuss why the space station concept is attractive and what I believe are basic design requirements. I will describe briefly our present Earth orbital plans as contained in the Apollo Applications Program, and I will conclude with some speculations on what future Earth orbital space stations could be like.

Why Space Stations?

So much has been written, both in the science-fiction field and in technical documents about space stations, that it is useful to state what we mean by space stations. I have presented a fairly concise

[Chart 1] definition on Chart 1. It is important to note that, as the definition states, a space station is not so much a "thing" as it is a location in space which is developed to support men and equipment on a permanent basis in order to take advantage of the economies of size, centralization, and permanency. In other words, a space station is a "base" in space, equivalent in function to those used in many forms of terrestrial exploration, for example, those in the Antarctic. As the chart indicates, the base has six important characteristics: it is a central location for power, volume, logistics, experimental equipment, communications, and data reduction. Such a definition encompasses schemes in which all of these things might be located within a single volume, or alternately where there may be several devices which are orbiting the Earth in close proximity with one another. An example of this latter form would be a station which consists of a large living center surrounded by free modules containing telescopes, Earth Sensors, and specialized scientific satellites orbiting close enough so that they could be tended or serviced intermittently by personnel from the living quarters.

[Chart 2] On the next chart I have indicated the features from which we expect to profit by creating a space station program wherein all the individual missions contribute directly to the success of the total mission. First, as the chart indicates, we are seeking the economic benefits which will accrue from the achievement of a longer lifetime of the objects we place in space. Both the equipment required to support man and to run the station and the basic scientific equipment which we place in space can operate for long lifetimes. With proper logistics support, these items can be reused, can be refurbished where wearout phenomena or random failures have occurred, and perhaps more importantly, can be modified to take advantage of gains in technology or changes in experimental objectives. As will be noted later on, experimenting with permanency is one of the major goals of our Apollo Applications Program.

The creation of a permanent place in space to which we return again and again allows us to centralize the storage of expendables and equipment and to make maximum use of a limited number of logistics flights. Since logistics flights are the largest single cost element in any orbital program, this is an extremely important economic advantage of space station operation.

This logistic advantage is also important for the economical transportation of the crew, but there are other advantages to creation of a personnel "center" in space besides the economies of logistics. First, when we have achieved a crew size of over 10 to 12 people, we begin to realize the economy of large size since only a small percentage of total crew worktime will have to be spent on the functions of operating and maintaining the station, thus making available a greater percentage of time for the accomplishment of experimental objectives. The economies of specialization are also available since the concentration of a large number of people allows most of them to be specialized for individual experimental functions. This will relieve the considerable cross-training problems which are inherent in small crews. The concentration of personnel in a permanently established volume makes it feasible to provide relatively large amounts of volume devoted to personal comfort and convenience, and to establish, throughout the station, living conditions which are more Earth-like than we can afford in smaller space vehicles. This will be important in the selection and training of crews and in their efficiency in space operations as well.

In addition to the above advantages, which are primarily operational in character, there is one system which will definitely benefit from the economies of permanency and large size--that is the power system. The large size of the space station enables us to develop the structure necessary to support either the large panels required for solar cells or to provide the separation, shielding weight, and radiator areas required for large nuclear systems. The capability of a space station to carry power sources of 20 to 50 or even 100 kilowatts will be its most important technical contribution, since the availability of power is the basis of all system design and is fundamental to the capability of nearly all experimental equipment.

Apollo Applications Program - A Modest Beginning

We have long recognized these intrinsic advantages of space stations and the Apollo Applications Program is designed to explore

[Chart 3] them in a modest way. Chart 3 presents the basic Apollo Applications objectives and characteristics. The primary goal of the Apollo Applications Program is the establishment of man's capability to function in space for significantly long periods of time and to establish man's role in conducting complex investigations in space. The "wet launched" workshop will contain sufficient volume (almost 4,000 cubic feet per man compared to Apollo's 120) and support equipment so that the astronauts will be able to function and live in a manner more like that of the Earth's environment than has been the case with the closely packed spacecraft to date. This is to be accomplished by outfitting an S-IVB booster stage so that it can be entered by the astronauts after depletion of hydrogen and made into livable quarters. This "workshop" will be visited over a period of time by a series of Apollo Command Service Module flights.

[Chart 4] Chart 4 presents a view of the initially launched workshop with a Command Service Module attached, and shows the tubular docking adapter mounted at the front end of the S-IVB stage and connected with the airlock. The interior of the hydrogen tank has been outfitted with equipment originally stored in the docking adapter in a series of rooms mounted on the middle floor which was initially installed in the hydrogen tank. The power source (6 kilowatt solar cells) is shown extended from the mounting pods on the side of the S-IVB.

The next two pictures are taken inside a full-scale mockup at the

[Chart 5] Marshall Space Flight Center. Chart 5 shows the doorways leading into three of the four rooms on the main deck. These rooms will be used for sleeping compartments, waste management, and food preparation. These are all elements in one of the major test programs associated with the wet workshop, namely, that of ascertaining the habitability characteristics required to support astronauts in space.

[Chart 6] Chart 6 shows equipment for one of the elements of the very thorough medical test programs which will be another main feature of the Apollo Applications mission. This is the erogometer, which is the bicycle-like device in the foreground of the second picture. Also shown are three subjects, one seated in a Barany chair, another piece of test equipment for medical experiments. The second picture shows more clearly the area outside of the rooms equipped with experiments which have been brought into the area from their stowage place in the docking adapter.

The Apollo Applications Program also will include a major science experiment, a solar observation experiment which will be launched and rendezvoused unmanned with the wet workshop and which will be docked by an astronaut located in the docking adapter, using remote control. A view of this experiment located on the workshop is shown

[Chart 7] in Chart 7. This experiment will provide us with two very important steps toward our future space station programs. First, it will be our first chance to link man with a really complex scientific experiment and thus to explore his capabilities to function with such devices. Secondly, we will be developing techniques and equipment for sending experiments and supplies to a space station in an unmanned mode. This mode may be an important method for logistic supply in the future.

It is apparent from this brief description that the wet workshop will be fulfilling the role of a prototype space station. It will provide a generous living volume, the essential power and communications systems, and it will be operated over a period of time. Thus, our "modest" beginning will be clearly laying the groundwork for the development of future space stations by giving us basic data on man, the systems, and some of the experiments which will define our future programs.

In creating the wet workshop we have, however, been forced to neglect what may be one of the major requirements for successful operation of a space station--artificial gravity.

The Artificial Gravity Problem

The Apollo Applications Program wet workshop program, as now envisioned, will provide us with a good base from which to evaluate man's performance in space at zerogravity. In this section I will discuss some of the things we have been thinking about concerning the need for artificial gravity and for a test program to define its characteristics. As noted earlier, I have discussed some general reasons why we feel that space stations are advantageous in developing an economic program for the beneficial exploitation of space, and one of the main advantages I noted was that it could provide an Earth-like environment which would enable a wide segment of our scientific community to be potentially available for space work. This leads me to discuss what I believe is a very important aspect of space station requirements, namely, the need that the station be designed to provide a high level of artificial gravity. The principal reasons for this

[Chart 8] are indicated on Chart 8. First, note that our concern is not that man will not be able to adapt to zerogravity over the period of time that he is likely to be a crew member aboard a space station (3 to 6 months). The problem is one of providing relatively normal living and working conditions. This will be important for crew comfort and adaptation to living conditions and will, therefore, increase their basic efficiency and task effectiveness.

As noted on the chart, the environmental factors affected by artificial "g" can be divided into three types: those connected with processes involving fluids; those connected with locomotion and orientation; and those including general man/machine interfaces. By providing gravity, fluid processes such as associated with personal hygiene, cleaning, food preparation, chemistry, all can be performed in a manner identical to that which we are accustomed to here on Earth. With the establishment of normal gravity relationships, the ability to walk with the hands free will provide the basis for an environment which needs little or no training for adaptation. Artificial gravity will also provide normal man/machine interfaces with all types of equipment--both operational and experimental. Again, this would eliminate the need for special zero "g" training and would maximize the effectiveness of Earth training, especially for the more complex repair, refurbishment and modification tasks we can expect in the future. This advantage is a major feature of an artificial gravity station. As a corollary to this, artificial "g" will permit the use of equipment developed for use in Earth laboratories but otherwise applicable to space station tasks.

For all of these reasons, we conclude that the characteristics of artificial gravity are important objectives for a near-term Earth orbital activity and I will discuss some of the parameters which should be studied by special experiments before we can be firm about a conceptual design which would meet the space station objectives.

[Chart 9] As you will note on Chart 9, artificial gravity has two important parameters for any given level: the rate at which the vehicle is rotated, and the radius at which the man is stationed. We have indicated on the chart a so-called "comfort zone," namely, an area which ground-based tests have indicated man can tolerate without serious problems of adjustment. Parabolic airplane flights have indicated that most of the problems of locomotion and fluid transfer are overcome by gravity as low as three-tenths "g." Since rotational simulators on the ground have indicated that the average person can adjust to 4 revolutions per minute, we are led to a minimum rotational arm of about 50 feet. However, these ground tests are limited because they always have a one "g" field affecting the results, and we cannot be certain that when that field is non-existent that the rotational forces will not affect the subconscious adaptation mechanisms more strongly. Thus we are interested in even lower rotational rates and higher gravity forces. We would like to investigate radii as high as 200 feet and gravity forces as high as one "g." These considera-

[Chart 10] tions have led us to examine a system shown on Chart 10, namely, the rotation of an Apollo spacecraft with an Experiment Module, both tethered to an S-IV rocket stage in such a way that various radii can be achieved by the system. With this type of experience, we can be ready to construct the type of space accommodations which we feel will be necessary to meet the comfort and work requirements of the future space activity.

The Next Step - Experiments and Applications

Any discussion of a future space station program must be preceded by an understanding of the types of experiments which will likely be a part of that program. NASA has recently spent considerable effort in studying experimental programs for space stations as

[Chart 11] given in Chart 11. The results of these studies can be classified under two general headings: observational experiments which include astronomy and Earth sensing; and on-board experiments such as bioscience and biomedical experiments and high energy physics.

Astronomy

The sciences which make use of the observational advantages of Earth orbit will benefit most obviously from space station operations. Astronomy especially can be expected to produce dramatic results from being able to observe outside of Earth's dirty and shimmering atmosphere.

[Chart 12] Chart 12 is presented to give a feeling for some of the engineering work that has gone into the sizing and design of astronomy experiments. The chart presents, in hard outline, modestly-sized telescopes of the 40-inch objective type, which are the optical equivalent of land-based 120-inch telescopes. Even these are large enough to require a significantly large space station as a base. But these are just a beginning. Telescopes of 120-inch diameter have been seriously proposed by the National Academy of Sciences as an objective for space astronomy. A conceptual design of a 120-inch telescope is shown in the background at the same scale to give a feel for the size of things to come. Such a telescope would probably be flown adjacent to a space station and visited periodically for service and data retrieval.

Earth Sensing

The development of remote sensing equipment for the observation of the Earth's surface, and probably sub-surface, will be one of the major tasks of the manned space base.

To date, our principal experiments with Earth observation from space have been primarily photographic. As many investigators have shown, these photographs, taken with simple equipment, give us dramatically new and astonishingly useful views of our home planet. My next two charts are photographs taken on our last Saturn V flight.

[Chart 13] The first chart, Number 13, covers approximately 10, 000 square miles in the El Paso-Juarez area and includes the pure white sands of the White Sands National Monument. It is a clear example of the detail which is obtained with space photography. The communications system in the international metropolitan area is clearly seen. The agricultural utilization along the valley of the Rio Grande can be viewed over a large area. Unique volcanic features are seen to the west of El Paso. Snow covers the higher peaks of the Sacramento Mountains to the east of Almagordo. The unique capabilities of space photography result from the broad synoptic view of large features which can be seen in a single photograph. Large mountain systems can be visualized in a single photograph and important geophysical relationships are established over areas of up to 250 miles square. To obtain the same information by conventional aircraft and photo-mosaic techniques would require hundreds of photographs to be secured, all under different and changing conditions, and a cumbersome assembly would be required.

[Chart 14] The second photograph (Chart 14) indicates another use for space observation--oceanography. It shows quite plainly the east edge of the Gulf stream for a distance of about 50 miles. Techniques are being developed for routine observation of the ocean; the measuring of its temperatures, sea state, and currents.

But photography covers only a very small part of the information the Earth is sending into space. Chart 15 shows a concept of electromagnetic Earth sensing equipment which would have the capability of measuring the Earth's surface over nearly the entire electromagnetic spectrum. The large variety of experimental equipment which will be of interest in this area of investigation can easily be seen; and again, the rather significant size of the sensors is noticeable. There is little doubt that this field of endeavor holds great promise for future applications of direct benefit to a wide variety of professions and occupations, as well as to the scientific community in general. It will probably be so useful that we will want to spread its benefits to other nations, especially those nations which are just emerging into the world of modern industry and agriculture. This use of our space abilities may well become a great force for international cooperation and I, personally, look forward to the day when our space station crews will contain representatives from all the nations of the world.

Biomedical and Bioscience Experiments

On-board experiments can take a great many forms. Some will take advantage of the limitless vacuum of space; these may well involve manufacturing processes in the long run. Some will be in space to utilize the unique environment of zerogravity. The zero "g" environment is of special interest to the biomedical and bioscience researcher since it will undoubtedly open new avenues in research

[Chart 16] on the growth process in animals and plants. Chart 16 shows a typical laboratory with animal colonies and plant farms. It also shows some biomedical experiments, and again we can expect that the zero "g" environment will help immeasurably in the investigation and understanding of fundamental principles.

Physics

It is interesting to recall that the study of the fundamental particles of nature began with observations made from the natural cosmic radiation that exists in space. These initial experiments were made from balloons and mountain tops. Our space station capabilities will open the way for a return to the natural environment as a primary source of high energy particles. By placing a large

[Chart 17] cosmic ray facility in a space station, such as is shown on Chart 17, we will extend the basic particle energy available for investigation bythree orders of magnitude (from 70 BEV to 70,000 BEV). We can expect to increase our knowledge significantly about the nature of the fundamental particles in matter just as our recent increases in energy capability have so changed our simple electron-proton-neutron picture of the atom. But of equal excitement will be the clues that the nature of cosmic rays will give on cosmological questions--questions such as the possible existence of anti-matter in the universe.

The operation of such a laboratory will be a very complex affair, using the most advanced techniques for recording and analyzing the data. Because of these problems and because of the large size and complexity of the cryogenically cooled superconducting magnets which will be at the heart of the laboratory, the presence of highly trained scientists will be a necessity for such a space laboratory.

The Next Step - Space Station Configuration

Having examined the types and general characteristics of possible experiments, we can now proceed to examine what one of the first

[Chart 18] operational space stations might be like. On Chart 18 I have listed some general space station characteristics which I believe will be required to meet the type of experiment program discussed above. The first characteristic listed on the chart is that the station shall have an Earth-like environment. This means, principally, that the station will be designed for 10-14 psi (air) atmosphere system

(0_2+N_2 and possibly with trace elements) and for one-half to one "g" of artificial gravity in the major living and operational areas of the station. We must, of course, include a counter-rotating laboratory operating at essentially zerogravity. The station should have the capability of accommodating at least a 50-man crew initially, with the prospect of being able to expand its capabilities to at least 100 by additional launches. We must certainly plan to operate the station at higher inclination than those conducted in our space flights to date. Our studies have shown that about 50^o inclination, or somewhat higher, is a good compromise for operational and experimental reasons. That inclination provides a near minimum of radiation background which is important for minimizing its effects on the crew and on the sensitive film used in astronomical observations. It is sufficiently high to cover the majority of the occupied land masses even though it leaves out some of the more developed countries in Europe. It would include, of course, all of the United States, except Alaska, and it is within the continental United States that the majority of ground sites will be located which will be used to test orbital observation techniques.

The final general characteristic noted is that the station will have both attached and station-keeping Experiment Modules. For example, in the astronomical area we can expect attached telescopes up to 40 inches in diameter, while the proposed 120-inch telescope would be mounted in a separate module flying near the station in a station-keeping mode. This will mean the development of a technique for visiting such a device for operational adjustments and data-gathering and repairs. Smaller Experiment Modules will probably be clustered around the station also, and a hangar will be provided so that these modules can be brought back into the station for servicing by the station crew.

In order to stimulate your imagination, I have prepared some details of a space station of this advanced concept which is shown by
[Chart 19] the artist's drawing on Chart 19. As noted on the next Chart No. 20,
[Chart 20] the station would be large, having a 240 ft. radius to the rotational "g" living quarters; as much as a 375 ft. radius to the spinning balance and power section on the other end of the rotational segment. The station would be launched in three parts by three Saturn V rockets, and assembled in space. It would have a gross weight of about one million pounds, and we can expect to carry as much as 100,000 pounds of experiment weight. The volume in the living quarters would be about 50,000 cubic feet--while the zero "g" laboratory could contain as much as 45,000 cubic feet. The large radius would permit us to achieve nearly one "g" at 3.5 rpm and thus that becomes the maximum rotation we would need. Since the station will have a rather large inertia, it will require

7,000 pounds of fuel to spin up to its 3.5 rpm, and in that condition will have sufficient inertia that it will remain essentially fixed in inertial space.

The enormous stability of a large rotating station of this type has unique advantages for the observational devices located on it since it gives them a firm base which can be reacted against with conventional mechanical or hydraulic drives. In addition, its fixity with respect to inertial space is exactly suited for astronomical observations. The directional and tracking problems of Earth sensors are somewhat more complex, but this is partially compensated for by their less stringent accuracy requirements.

We have shown the station in operation with a 120-inch telescope floating nearby. The figure shows some of the fundamental features of the station. Note especially the hangar with a small satellite being taken into it for maintenance. The telescopes are mounted to the zero "g" hub on the top surface; the Earth sensors are mounted in a similar fashion on the bottom part of the hub.

It is interesting to note that the on-board experiments would be located in both the hub and in the artificial "g" volume. Basic bio-medical/bioscience zero "g" experiments would be in the hub, while the majority of other on-board experiments would be located in the rotating "g" section. Included in that section would be complete machine shops and repair rooms, as well as the living quarters and command and data reduction section of the spacecraft.

The station would be launched in three separate parts and

[Chart 21] assembled in space. Chart 21 shows the manner of launch and assembly.

It is important that such a station have growth possibilities and

[Chart 22] we have indicated on Chart 22 that with an additional launch of the Saturn V, we could easily double the accommodations by docking the payload to the rotating part and balancing on the other end by the booster which brought it up. A similar operation would enable us to add capability to the zero "g" hub. An even more economical way to expand our living and working space is available because of the use of the S-II stage as part of the basic structure. The empty tanks of these stages contain over 36,000 cubic feet of volume which can be entered, pressurized, and interior accommodations constructed with the same techniques we are developing with our Apollo Applications wet workshop.

I have tried to indicate to you the place of the space station in future space programs; the reasons why such stations will be important links with the future; the prototype steps we are taking in the Apollo Applications Program; and finally, a possible picture of the shape of things to come in terms of the conceptual design of a relatively large space station. A station such as I have described merges the space technology of the period with elements of both the pure and practical sciences into a single facility which can be logistically operated at a single place in space. Its purpose will be to reap an economical return from the use of space and to thrust basic research into a new and stimulating environment. Permanency and vastness will be the station's predominant assets and it will provide a stately reservoir of energy and utilizable volume. A philosophy of continuous reuse and the capability to expand its resources will enhance its long-term economic return. The ten's of thousands of hours of operational experience with men and equipment in the space environment that it will give us will assure that it will be a true gateway into the exciting space programs of the more distant future.

NASA-S-68-3298

MANNED SPACE STATION

- A LOCATION IN SPACE WHICH IS DEVELOPED TO SUPPORT MEN AND OPERATIONAL AND EXPERIMENTAL EQUIPMENT ON A PERMANENT BASIS IN ORDER TO TAKE ADVANTAGE OF THE ECONOMICS OF SIZE, CENTRALIZATION AND PERMANENCY
  - POWER BASE
  - VOLUME BASE
  - LOGISTICS BASE
  - EXPERIMENT EQUIPMENT BASE
  - COMMUNICATION BASE
  - DATA REDUCTION BASE

CHART 1

NASA-S-68-3293

SPACE STATION ADVANTAGES

- PERMANENCY
  - REUSE, REFURBISHMENT, AND MODIFICATION OF OPERATIONAL AND SCIENTIFIC EQUIPMENT
- LOGISTIC CENTER
  - CENTRALIZED SPACE LOCATION AND STORAGE CAPABILITY PERMITS EFFICIENT LAUNCH SCHEDULES FOR OPERATIONAL AND EXPERIMENT SUPPORT SUPPLIES
- POWER CENTER
  - PERMANENCY AND LARGE SIZE MAKE LARGE POWER SOURCES USEFUL AND TECHNICALLY FEASIBLE
- PERSONNEL CENTER
  - INCREASES RATIO OF EXPERIMENT TIME TO HOUSEKEEPING TIME AVAILABLE
- ALLOWS SPECIAL DISCIPLINE MEMBERS IN THE CREW
- FLEXIBLE CREW ROTATION PATTERNS CAN BE ESTABLISHED

CHART 2

NASA-S-68-3287

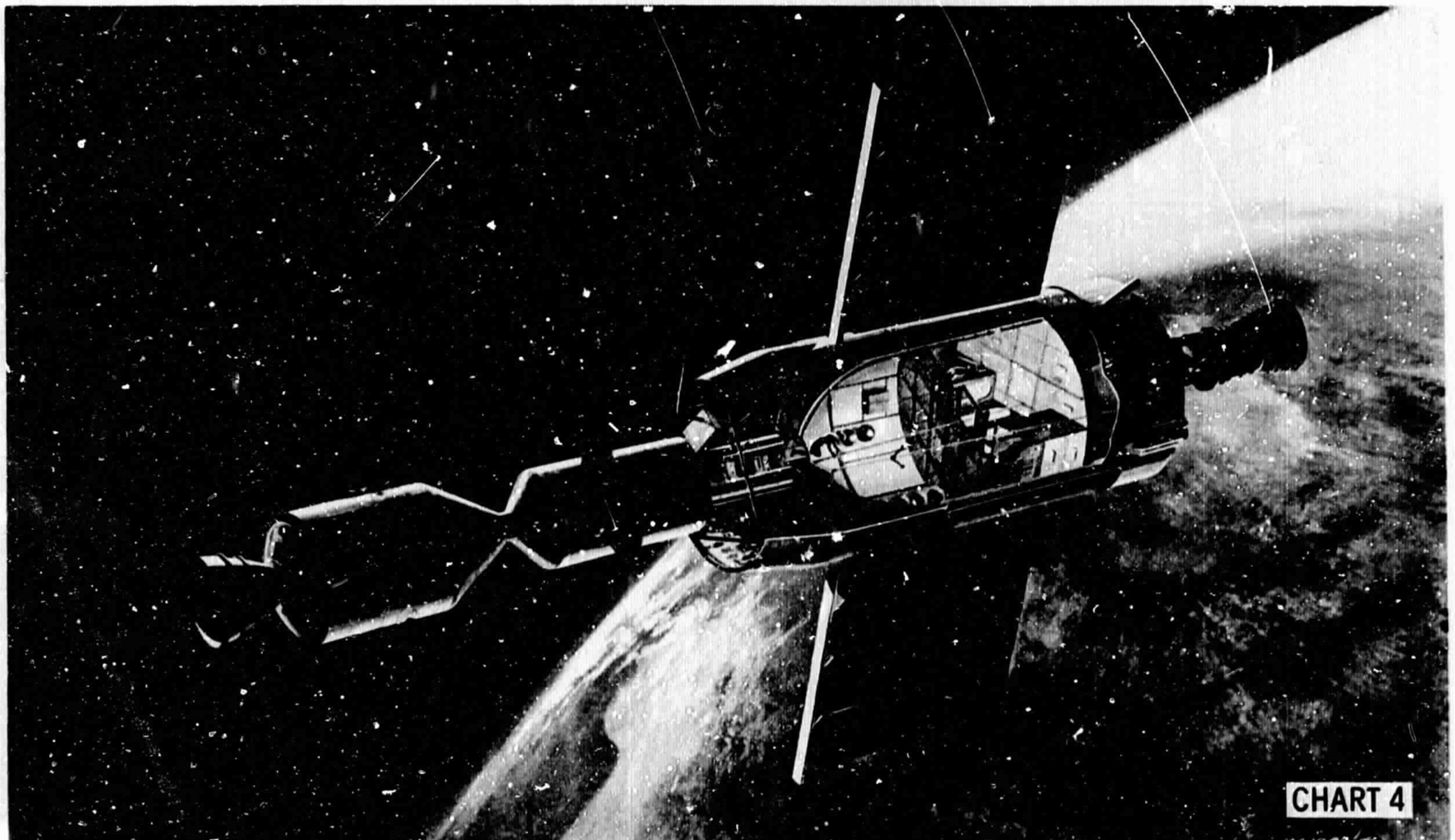
APOLLO APPLICATIONS PROGR.

- **OBJECTIVES**
  - ESTABLISHMENT OF MAN'S BIO-MEDIC L AND OPERAT CAPABILITIES TO FUNCTION IN SPA E FOR EXTENDED
  - ESTABLISH MAN'S ROLE IN THE OPERA ION OF COMPLEX SCI INVESTIGATIONS IN ASTRONOMY AND EARTH OBSERVATION
- **CHARACTERISTICS**
  - MAN'S FIRST EXPERIENCE IN SPACE W H ADEQUATE VOLUME AND SUPPORT EQUIPMENT
    - FIRST COMPREHENSIVE MEDICAL M ASUREMENTS CONTINUOUSLY FOR EXTENDED PERIODS
    - FIRST PROGRAM PLANNED PRIMARILY AROUND EXPERIMENTAL AND SCIENTIFIC OBJECTIVES

CHART 3

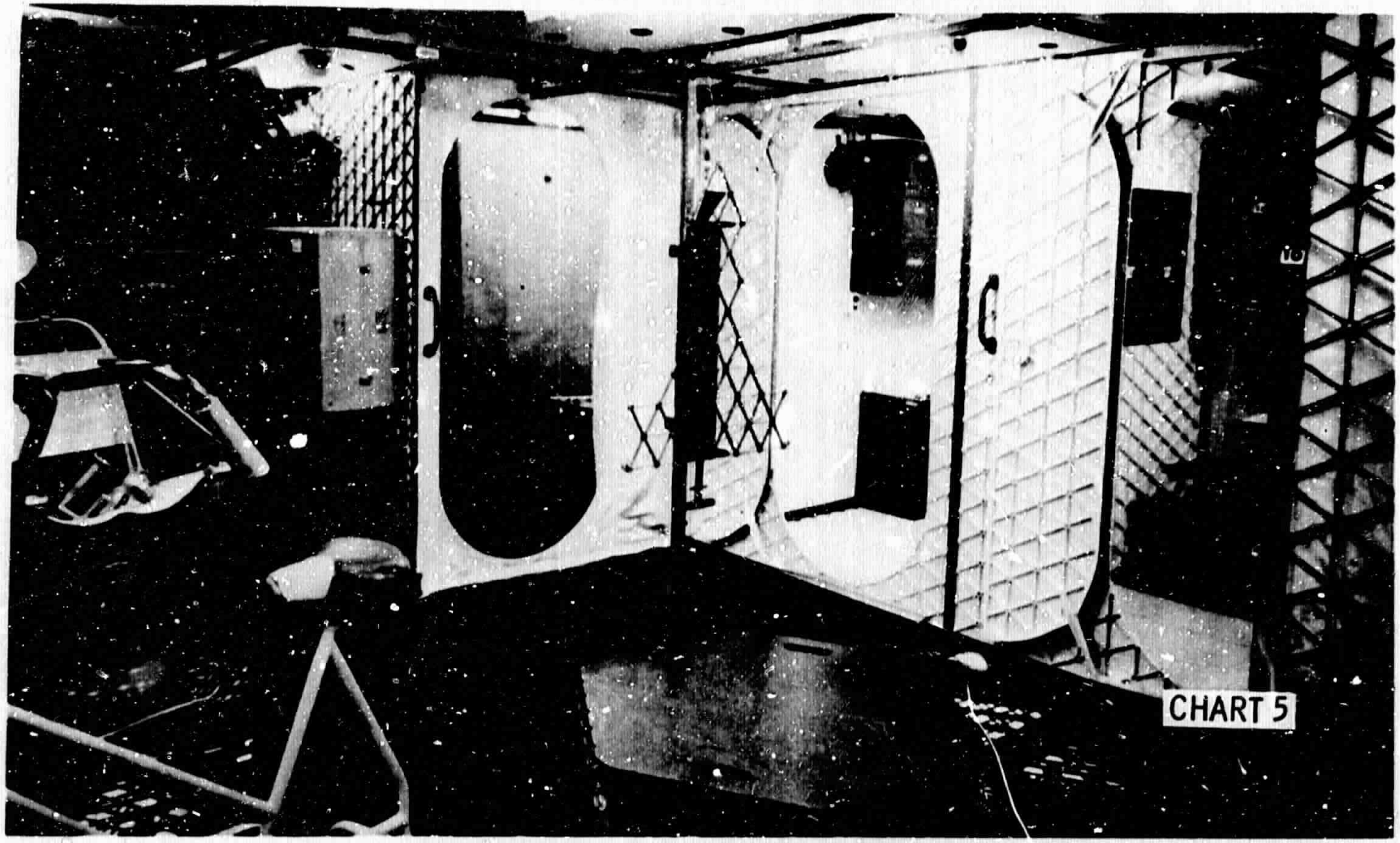
NASA-S-68-3284

AAP ORBITAL WORKSHOP - INITIAL MANNING



NASA-S-68-3299

S-IVB WORKSHOP MOCKUP SLEEPING AND FOOD PREPARATION CUBICLE



NASA-S-68-3286

S-IVB WORKSHOP MOCKUP EXPERIMENT AREA

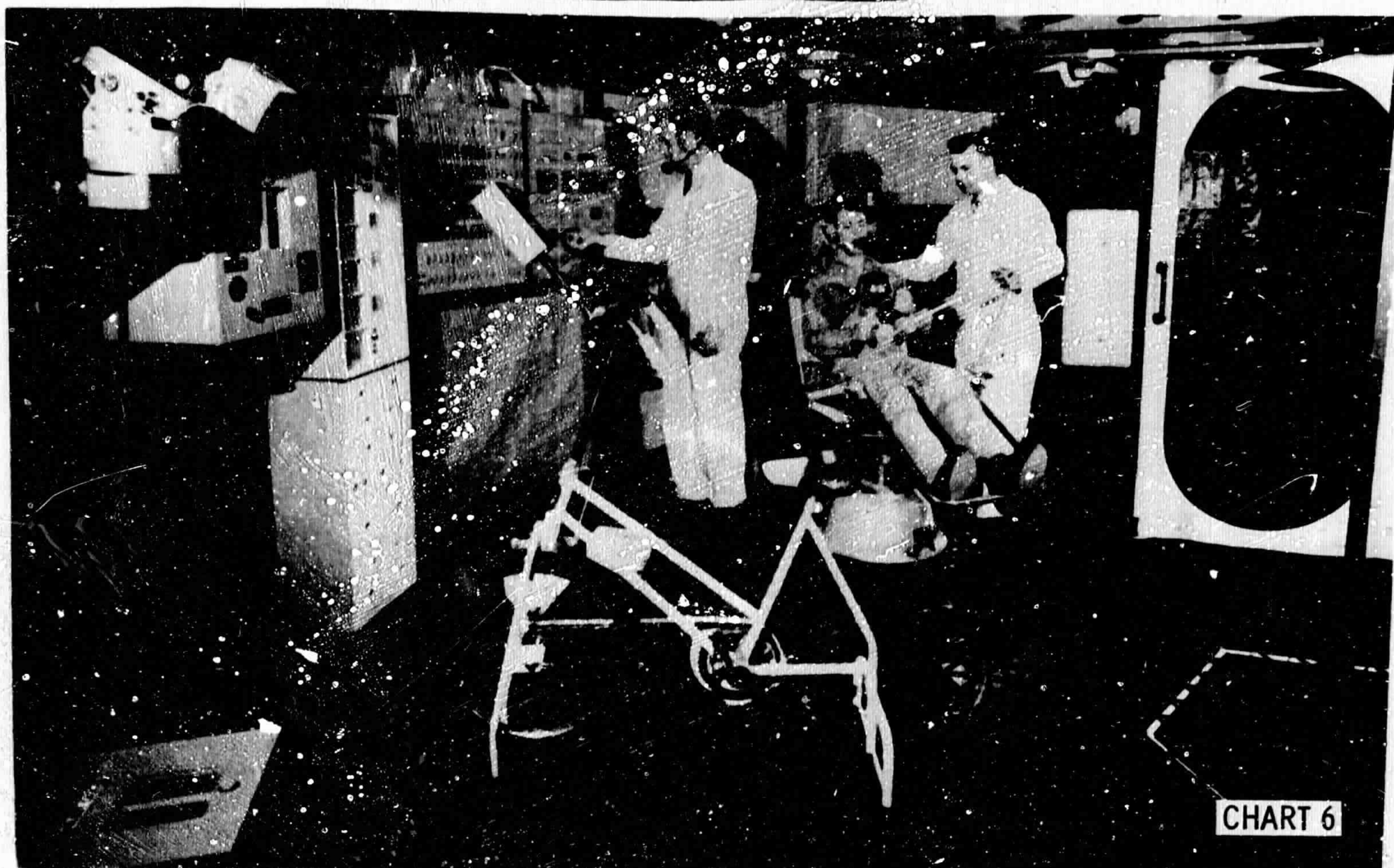
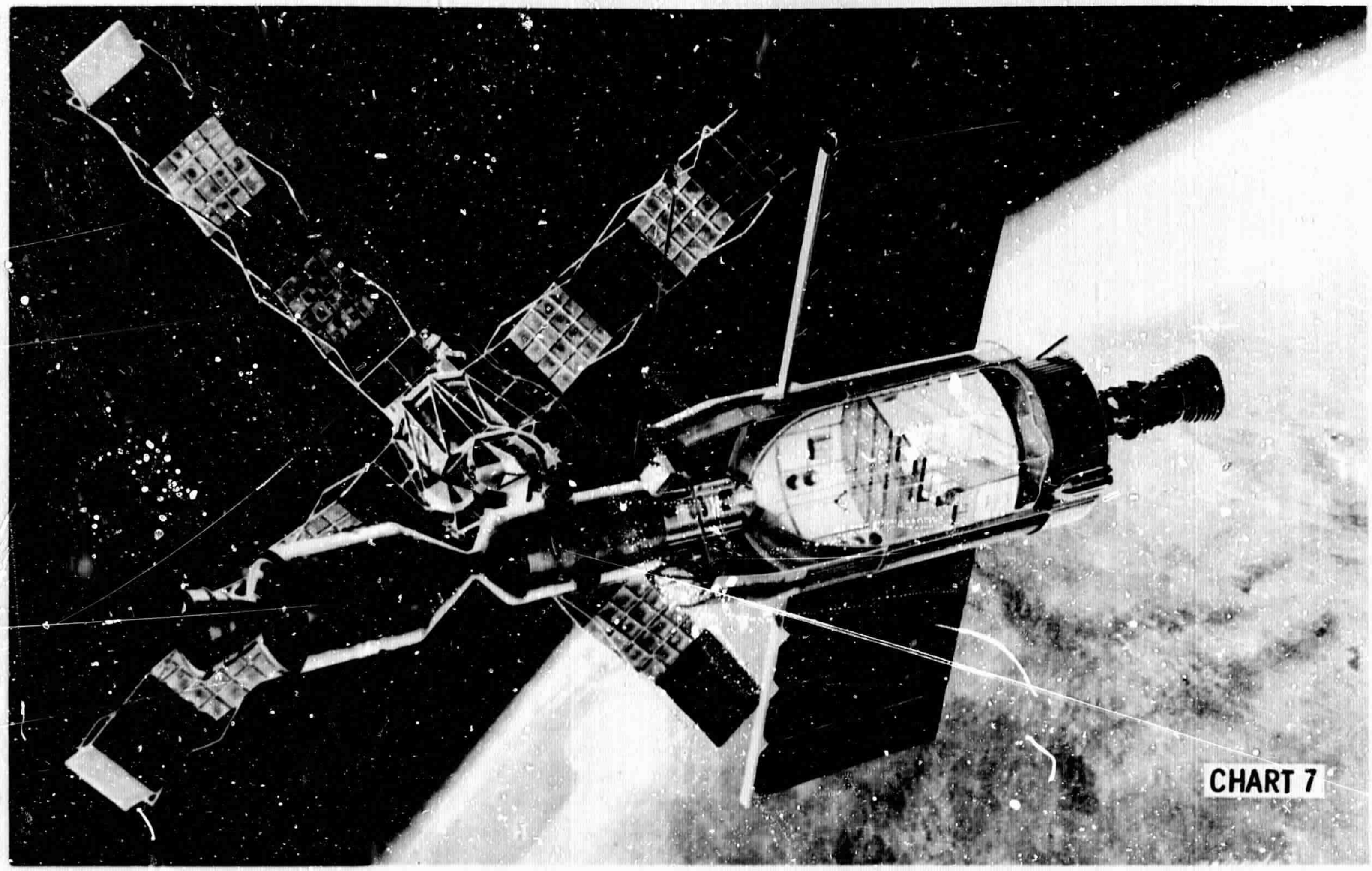


CHART 6

NASA-S-68-3289

AAP ORBITAL WORKSHOP WITH LM/ATM SOLAR EXPERIMENT ATTACHED



NASA-S-68-3295

ARTIFICIAL GRAVITY

- NORMALIZES ALL PROCESSES INVOLVING FLUIDS
  - WASHING AND PERSONAL HYGIENE
  - FOOD PREPARATION
  - CHEMISTRY
  - CLEANING
- NORMALIZES LOCOMOTION AND ORIENTATION
  - HANDS-FREE WALKING
- 'NORMAL' MAN/MACHINE INTERFACES
  - MINIMIZES SPECIAL TRAINING AND MAXIMIZES EFFECTS OF EARTH TRAINING
  - PERMITS USE OF 'STANDARD' EXPERIMENT AND OPERATIONAL EQUIPMENT

CHART 8

NASA-S-68-3296

ARTIFICIAL GRAVITY ENVELOPE

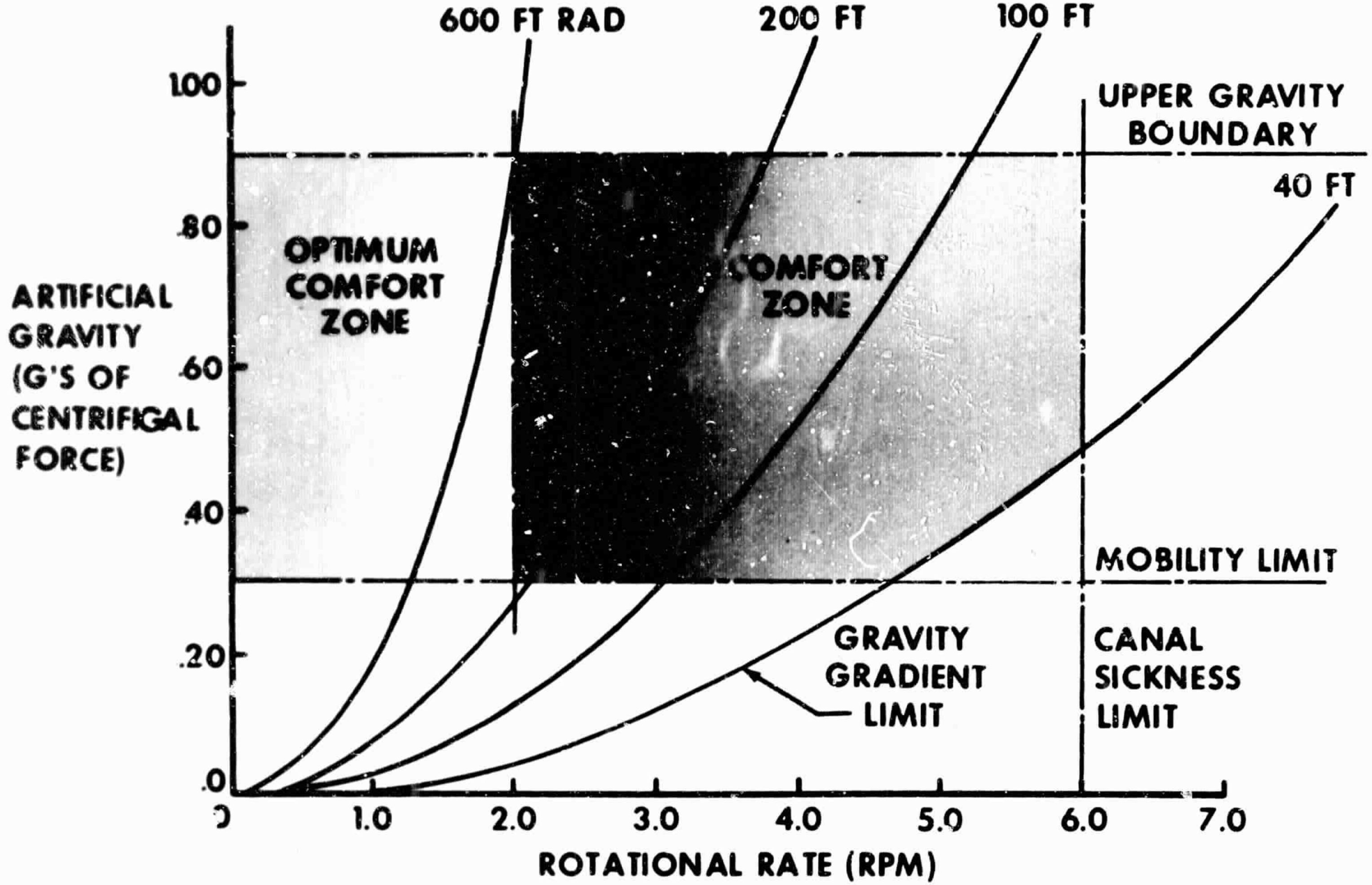


CHART 9

NASA-S-68-2882

ARTIFICIAL GRAVITY EXPERIMENT

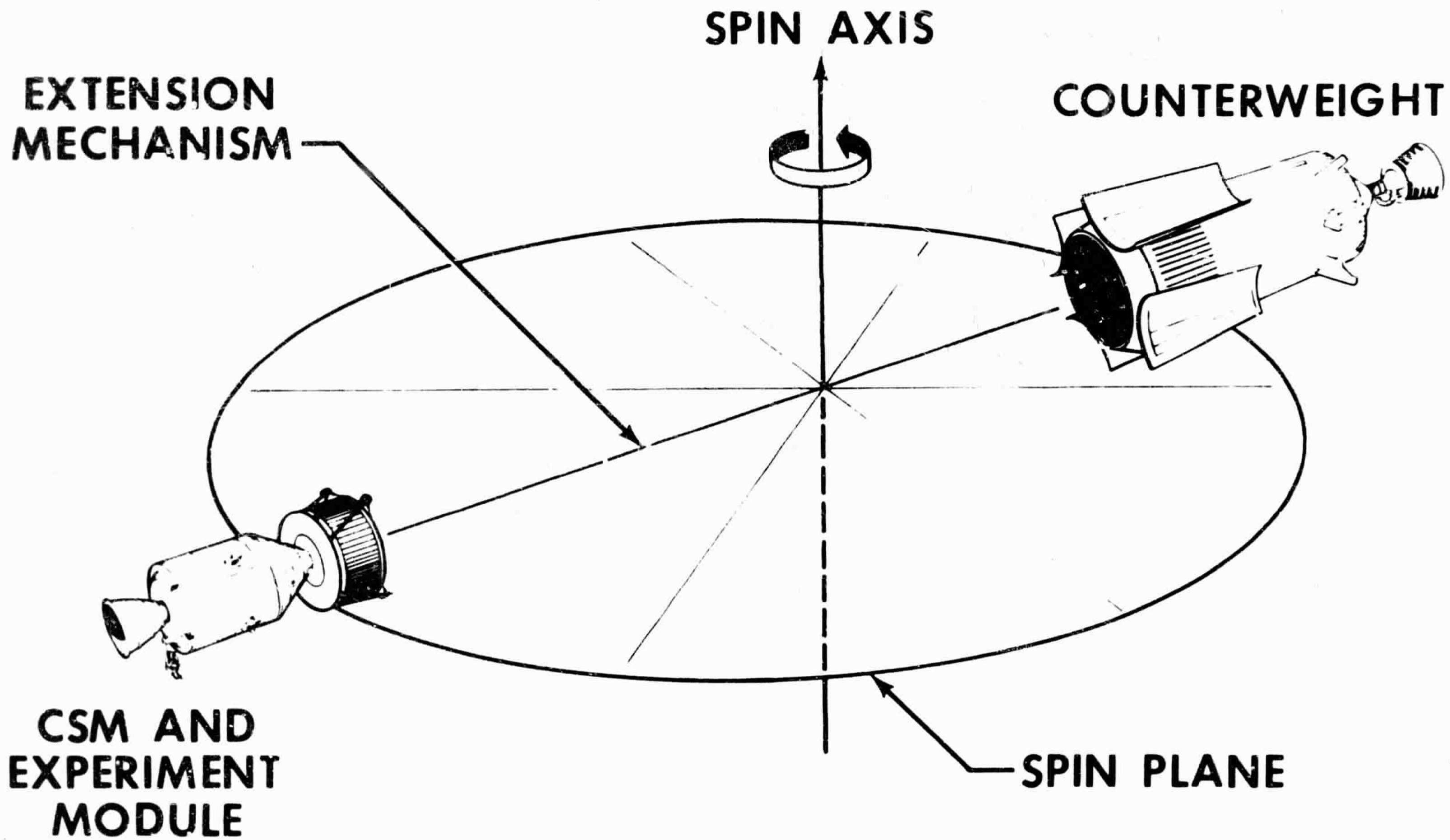


CHART 10

NASA-S-68-3294

FUTURE EXPERIMENT EXAMPLES

- OBSERVATIONAL EXPERIMENTS
  - ASTRONOMY
  - EARTH SENSING
- ON-BOARD EXPERIMENTS
  - BIO-MEDICAL
  - BIO-SCIENCE
  - PHYSICS

CHART 11

NASA-S-68-3283

ASTRONOMY

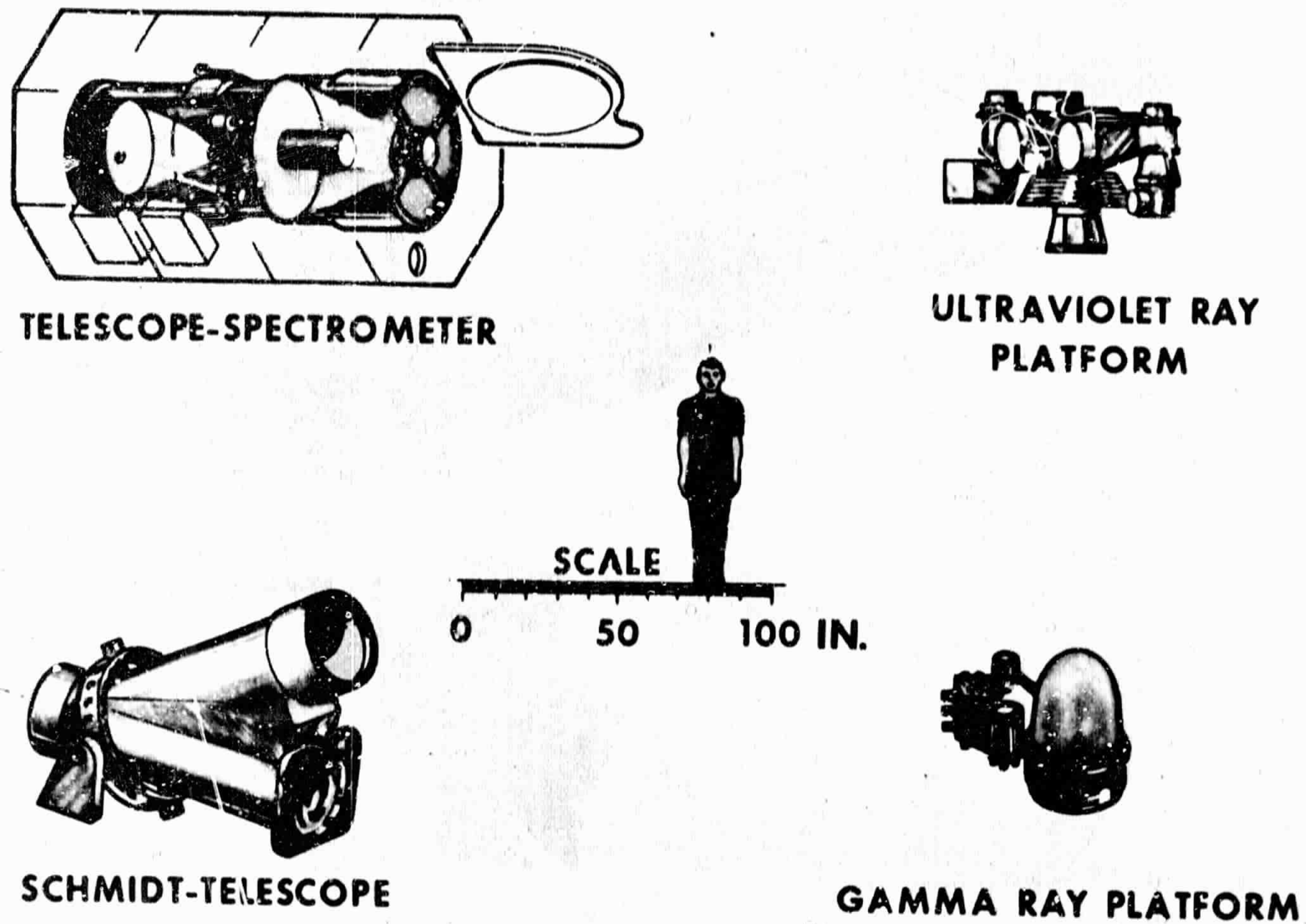


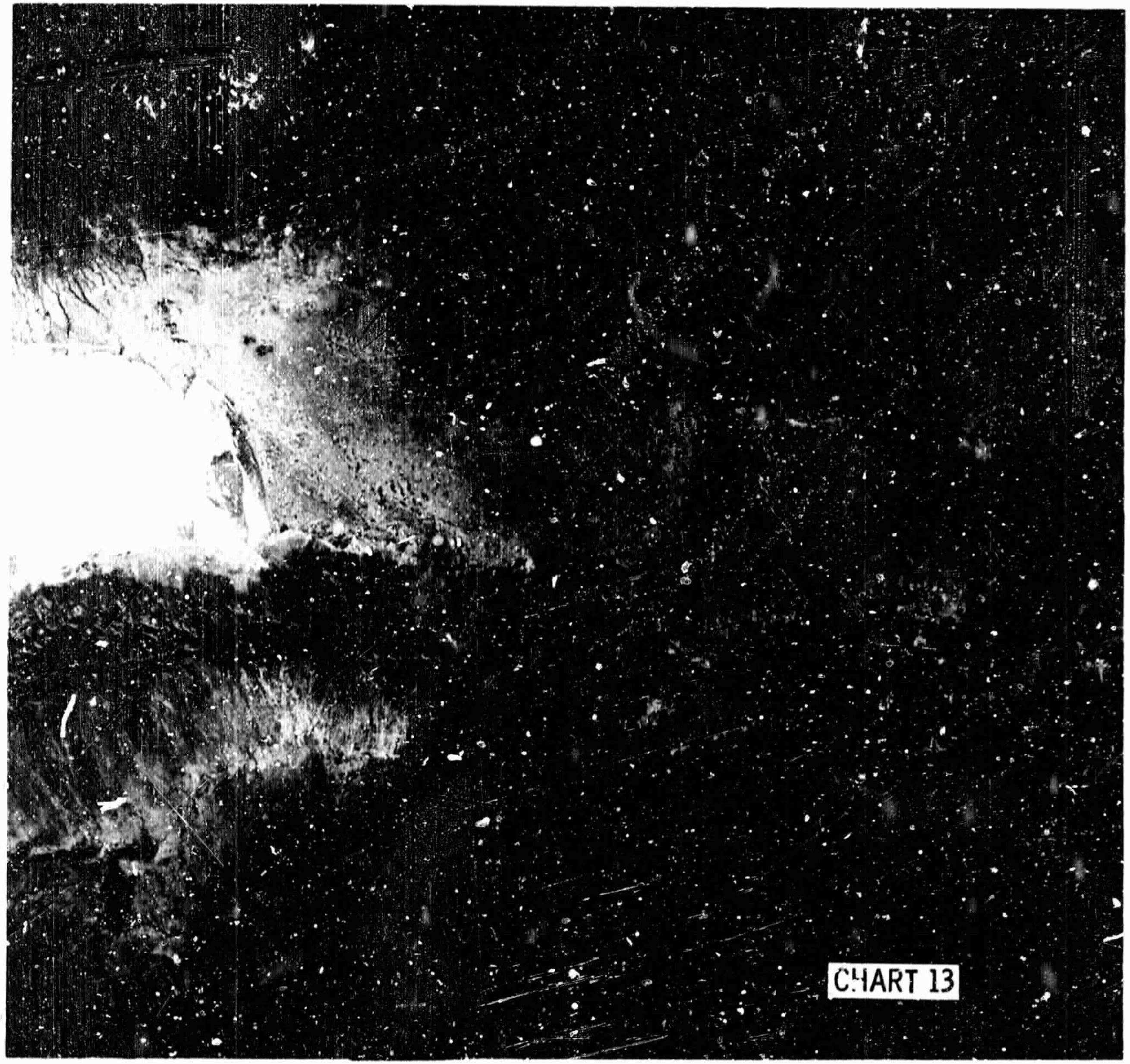
CHART 12

MSC
6-2-1448

NASA-S-68-3292

WHITE SANDS EL PASO AREA

APOLLO PHOTOGRAPHY

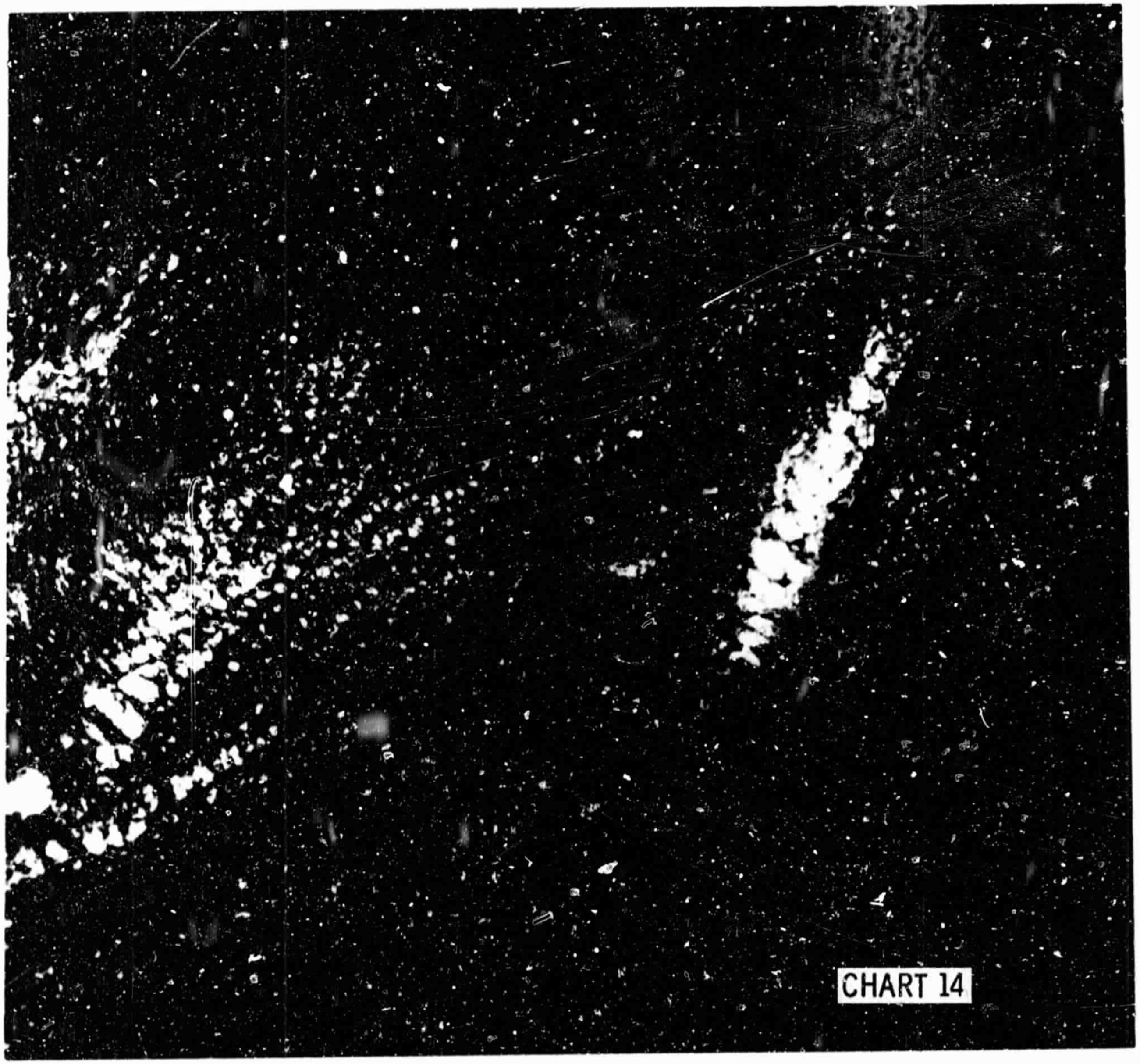


NASA-S-68-3281

GULF STREAM AND SEA STATE

APOLLO PHOTOGRAPHY

MSC
AS6-2-1495



NASA-S-68-2881

EARTH RESOURCES

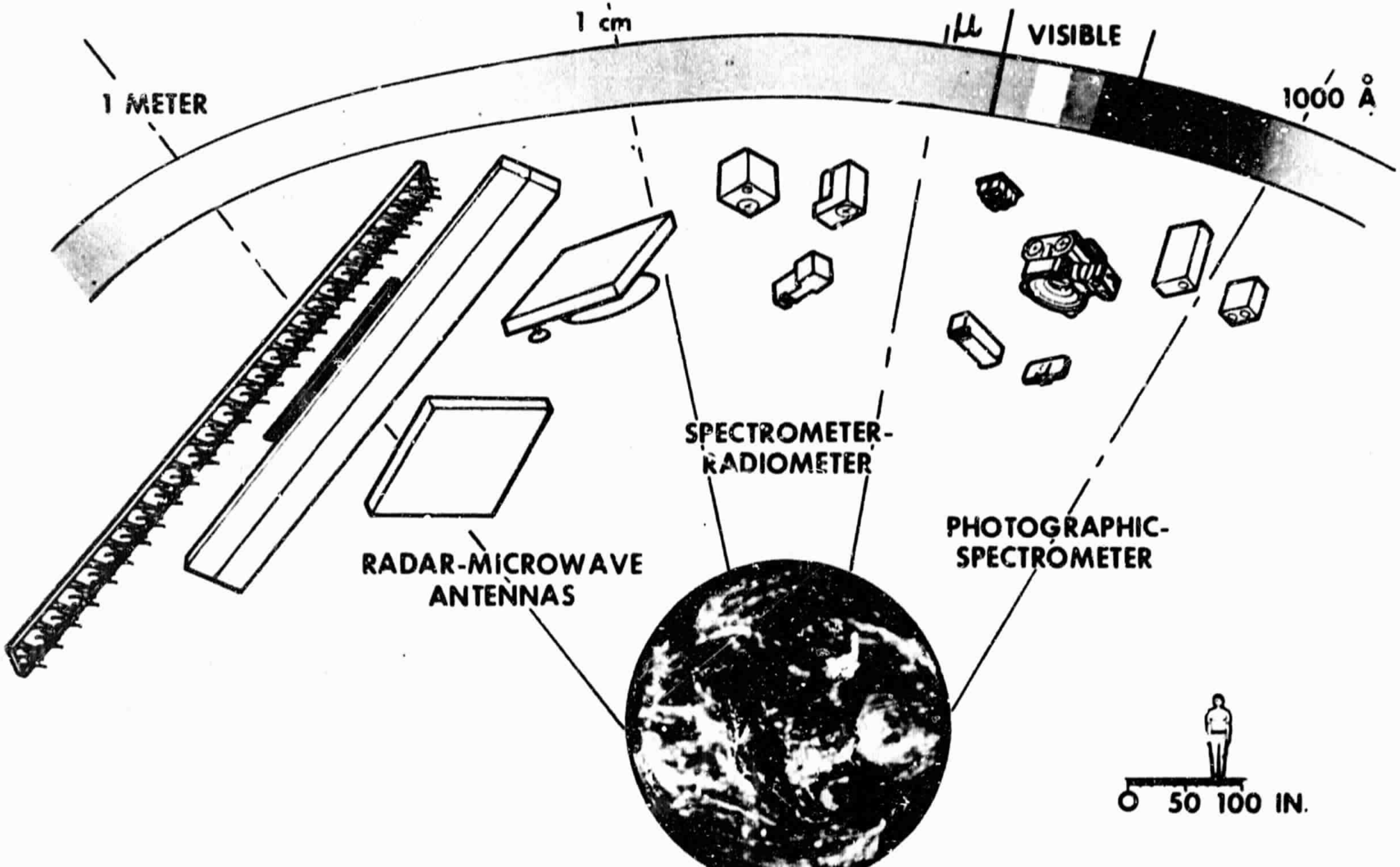


CHART 15

NASA-S-68-3282

BIOLOGY LABORATORY

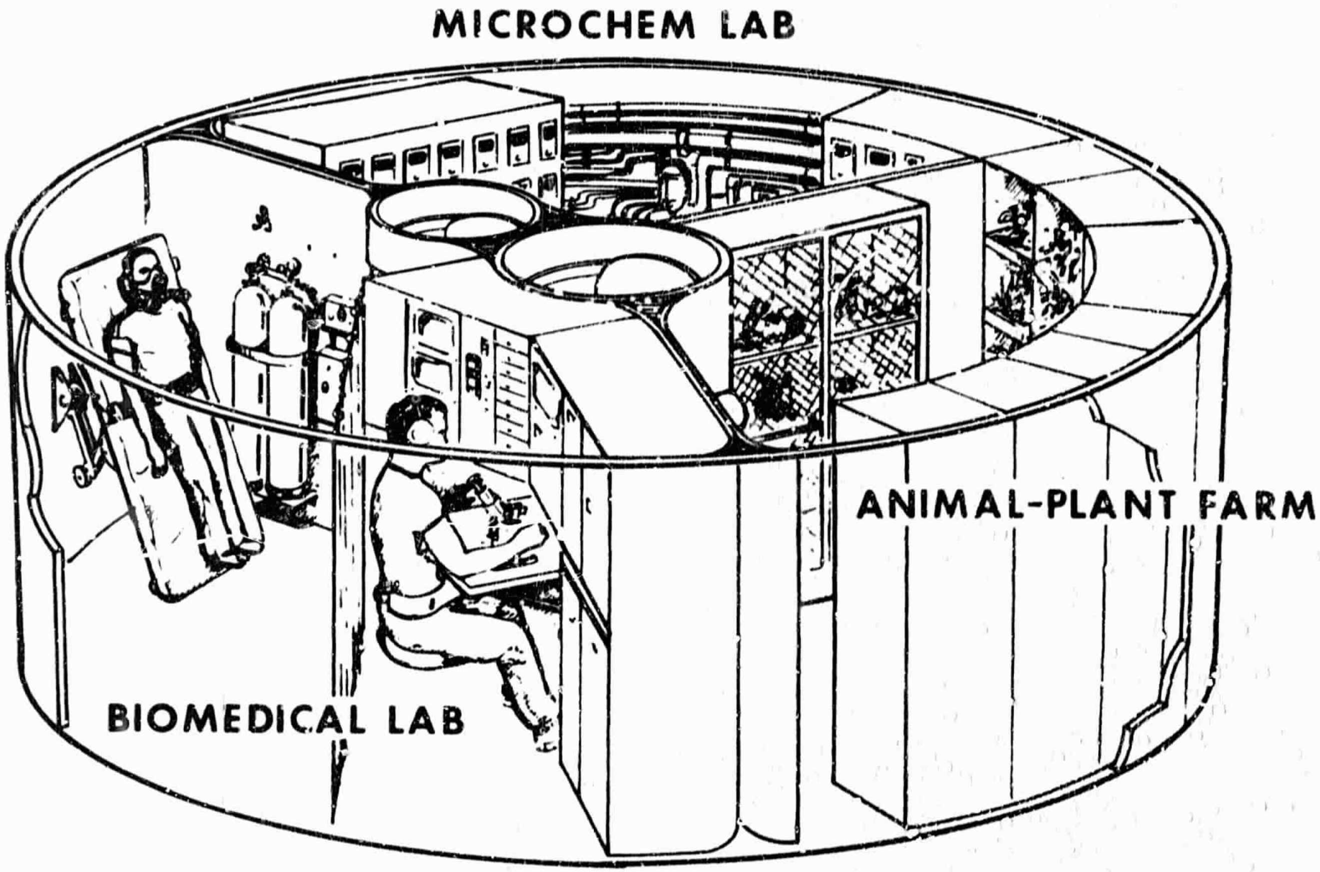


CHART 16

NASA-S-68-3285

HIGH ENERGY COSMIC RAY LAB

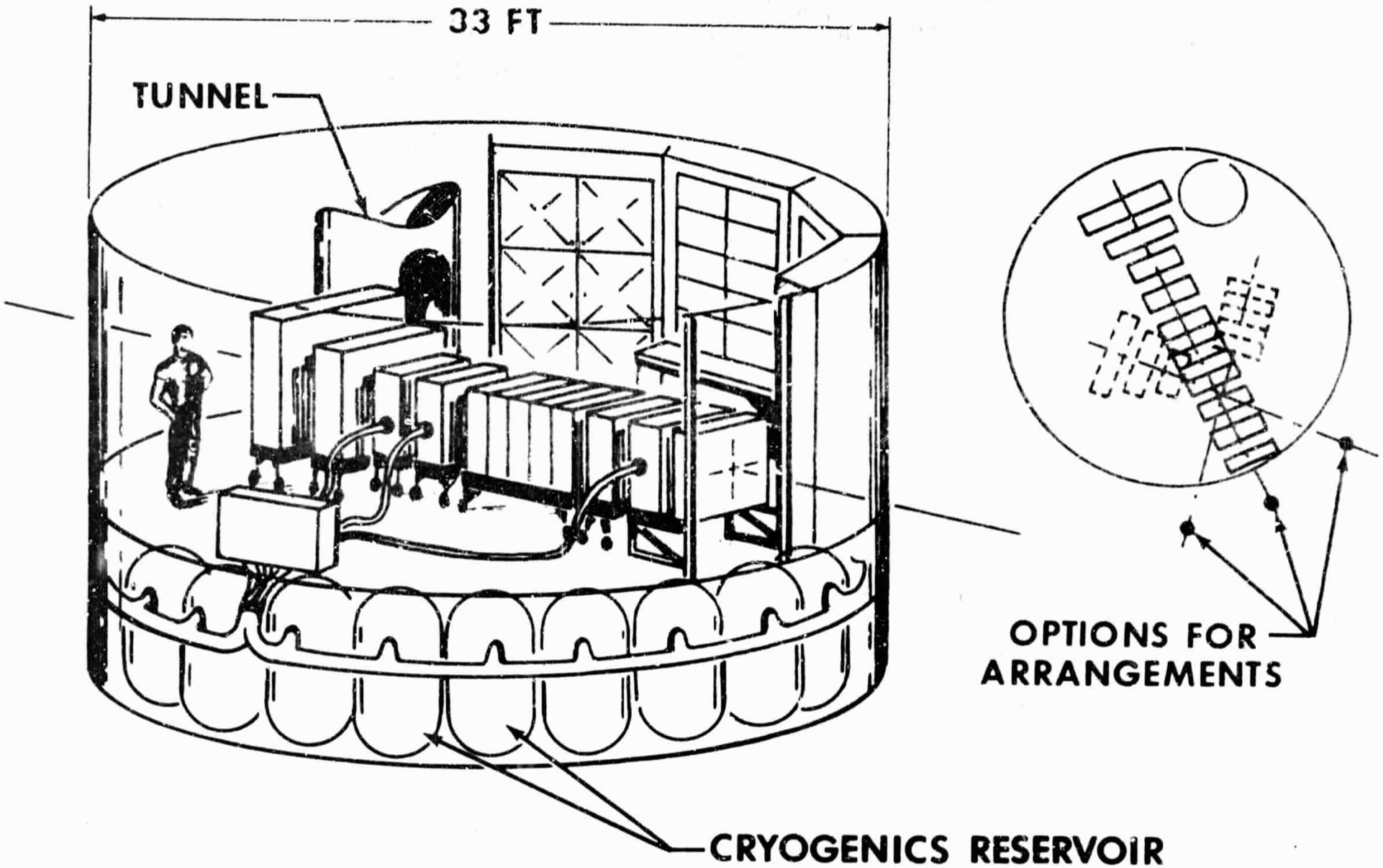


CHART 17

NASA-S-68-3288

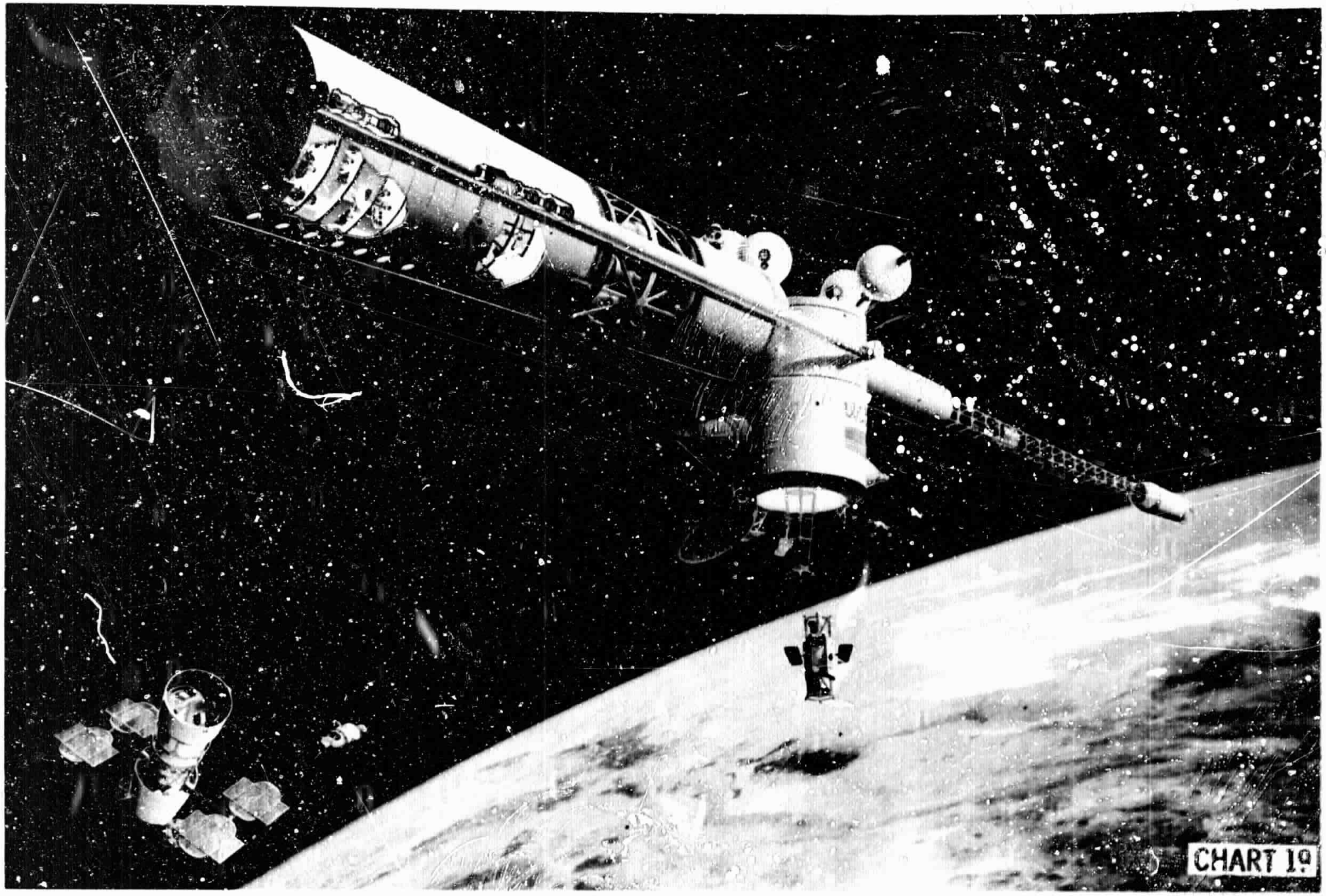
LARGE SPACE STATIONS- GENERAL CHARACTERISTICS

- EARTH-LIKE ENVIRONMENT
  - 10 - 14 PSI AIR LIFE SUPPORT SYSTEM
  - ½ TO 1 'g' ARTIFICIAL GRAVITY
- COUNTER ROTATING ZERO 'g' LABORATORY
- 50 MAN CREW - EXPANDABLE TO 100 BY ADDITIONAL LAUNCH
- HIGH INCLINATION $\geq 50°$
- ATTACHED AND STATION-KEEPING EXPERIMENT MODULES

CHART 18

NASA-S-66-3280

THE MILLION POUND SPACE STATION ROTATING NEAR A 120 IN TELESCOPE MODULE



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LARGE SPACE STATIONS-SPECIFIC CHARACTERISTICS

- SIZE
  - 240 FOOT RADIUS TO LIVING QUARTERS
  - 375 FOOT RADIUS TO POWER AND BALANCE SECTION
- WEIGHT
  - 1,000,000 POUNDS TOTAL WEIGHT
  - 100,000 POUNDS EXPERIMENT WEIGHT
- VOLUME
  - 50,000 CUBIC FEET LIVING AND OPERATIONAL QUARTERS (ROTATIONAL 'g')
  - 43,000 CUBIC FEET ZERO 'g' LABORATORY
- ROTATION
  - 3.5 RPM

CHART 20

NASA-S-68-3291

ORBITAL BUILD-UP

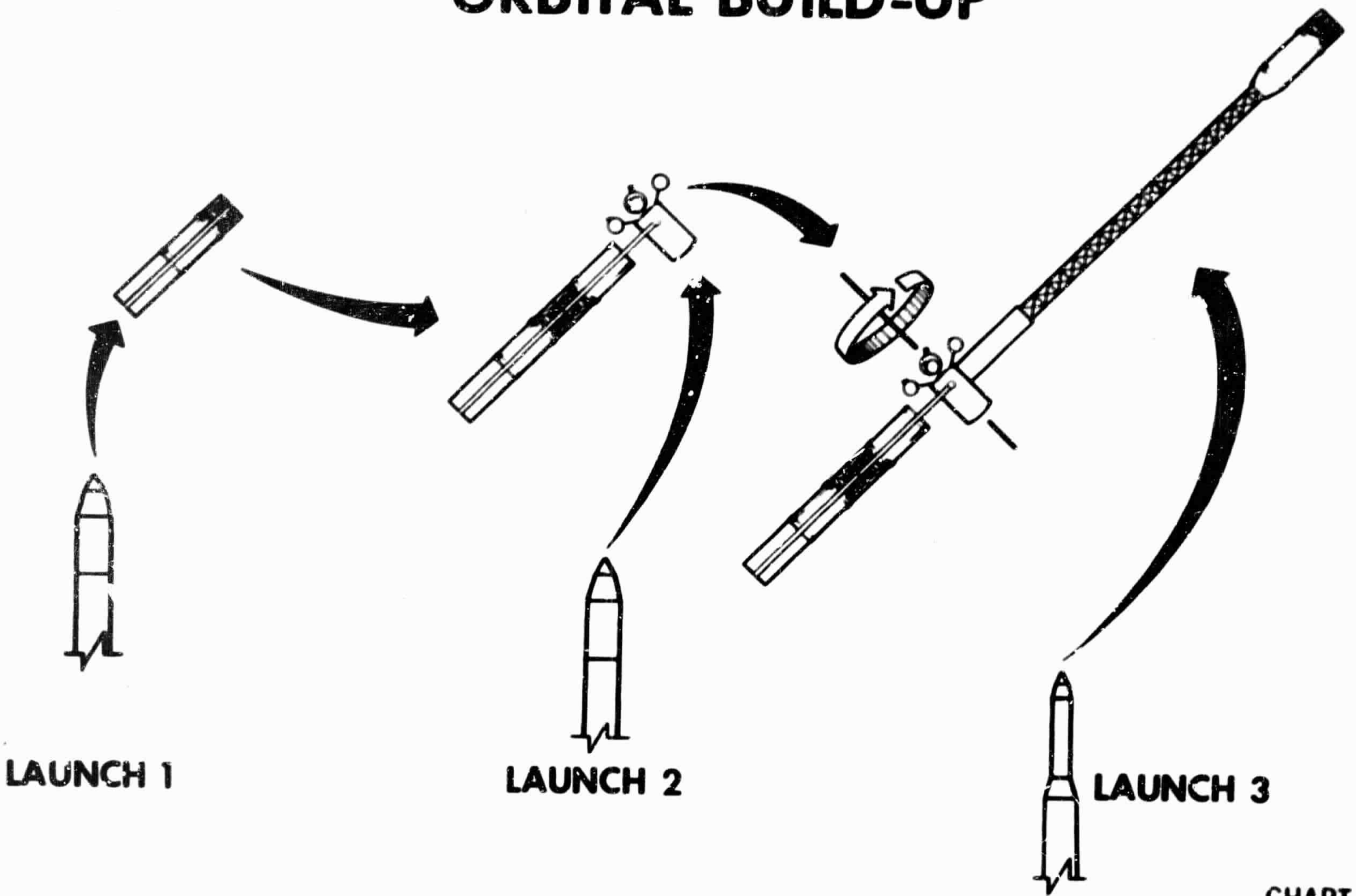

CHART 21

NASA-S-68-3290

ADD-ON CAPABILITY

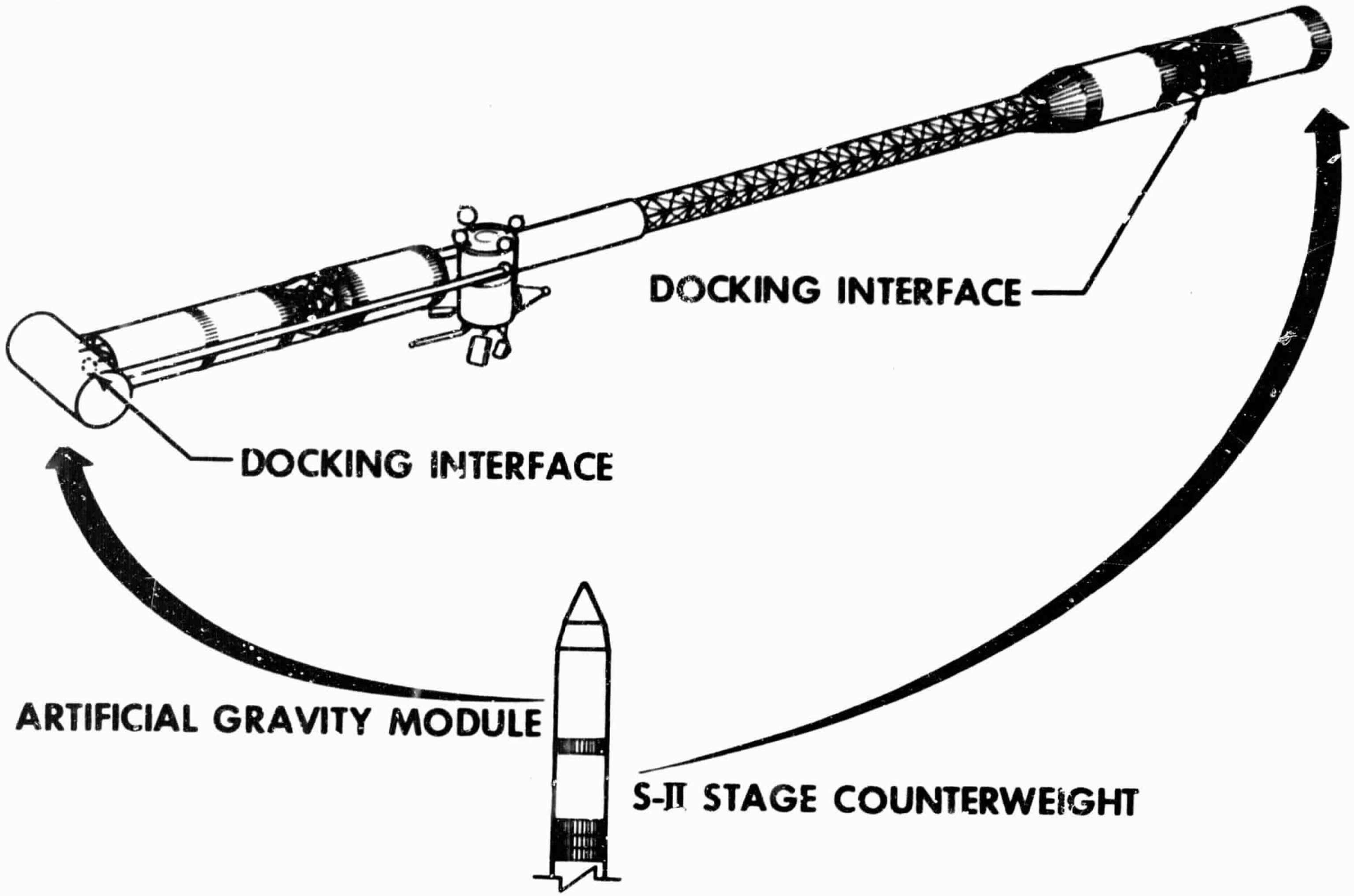

CHART 22