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LABORATORY IN SPACE

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Summary

The manned space station is growing in prominence as the potential next manned space flight project. The NASA plans and studies in the area of advanced manned earth orbital systems are discussed. The requirements for an Orbital Research Laboratory and its uses in the biomedical, scientific and engineering research areas are highlighted. Potential concepts of orbital laboratories ranging from minimum modifications of the Apollo spacecraft to a large 24-man space station are compared.

Background and Objectives

The earth orbital programs of the United States have been, and will continue to be, the foundation for accomplishing the utilization and exploration of space. We have learned from Mercury space flights that man has a potential usefulness in space which may be the basis of achieving new and important benefits in the national interest. As we progress from Mercury to Gemini and Apollo, the U. S. space team will bring us several steps closer to the development of manned space systems that will increase critical scientific and technological skills to ensure our continued growth and international relationships.

In the Apollo Program we will have a spacecraft, three-man crew and ground system that can operate safely and routinely for up to 14 days. NASA is studying the possibilities of an extended duration Apollo spacecraft for early experimentation and research. The Air Force is considering the possibility of extending Gemini with an experiment module to periods of up to 30 days. We believe, however, that the first truly operational Orbit Research Laboratory (ORL) will be a versatile multi-man space station whose flight duration may be as long as several years with periodic crew replacement and resupply. Such a laboratory appears to offer the best means of deriving direct benefit to the scientific community and the general public, and we are carefully investigating several approaches to accomplish this.

There are three promising avenues of approach to the Orbital Research Laboratory open to us:

1. A system based on the Apollo spacecraft with a laboratory section added (AORL) capable of supporting three to six men,
2. A medium sized Orbital Research Laboratory (MORL) with four to eight men, and
3. A large Orbital Research Laboratory (LORL) with 24 men or more.

The choice of which of these approaches or their various combinations is most suitable can only be established by careful study of the various objectives of manned earth orbital flight.
The specific goal of the NASA study effort of manned earth orbital missions is to determine the best methods that can be used to advance space exploration and exploitation through basic research and engineering experimentation in earth orbit. The scientific community at large is expressing a great interest and desire to participate in a sound manned earth orbital research program where one can utilize to the fullest man's ability to observe, discern relationships and exercise judgment. The space systems engineering community is also strongly supporting the establishment of a versatile orbital laboratory to further the development of advanced space flight systems. The early Orbital Research Laboratory would be the forerunner of an operational space platform that provides direct economic benefit to the public, for instance, through greatly improved weather forecasting or even control, earth viewing for agricultural applications, or communications. An orbital laboratory also would play a vital role as a stepping stone to more advanced space operations as a facility for the evaluation of prolonged weightlessness on man's ability to function and survive, and for the assembly and launching of large space ships from earth orbit. Thus the laboratory directly provides the basis for manned exploration of the planets.

There is no doubt that many of the objectives described above can be achieved by means of unmanned satellites; of course, with the exception of those where man himself is a subject. We believe, however, that the complexity required of automatic equipment to accomplish some of them will become rather overwhelming. The eventual earth orbital program will most likely consist of a balance between unmanned satellites and manned orbital space stations. This balance between machine and man depends on the fact that when the sophistication of the mission grows, the machine reliability diminishes, and a point is reached where a man in the system becomes necessary for its success. Besides being able to repair equipment man can be made a very necessary element in the operation of the experiment itself. He can monitor the experiments, calibrate and align equipment, and use his judgment to alter an experiment in progress to meet new objectives. Thus the inclusion of man in the system may be worth tons of electronic gear, which would be required to replace his capability to perform literally thousands of different tasks, accepting thousands of different commands, and providing a reliable on-board logic and memory system.

Because of the large variety of uses to which the ORL can be put it is necessary that it be a highly versatile system. It has to have the volume, weight, power, stabilization and crew capability to perform a large number of tasks and be flexible enough to respond to changing demands. To develop a better understanding of the various demands involved some of the potential uses of an ORL are discussed in the following pages.

Applications

Biomedical Research

One of the initial main uses of the Orbital Research Laboratory would be the study of man's physiological and psychological responses to the space environment and the determination of man's capability for performing useful missions in space over periods of months and years.

Ultimately we are interested in manned planetary missions which require flight times of over one year. The validation of man's active role in space cannot be accomplished by simulation on earth because of one particular factor peculiar to space:
Weightlessness may decondition man to such an extent that he would not be able to withstand the re-entry environment on return to earth or the normal gravitational environment after landing. In order to understand the effects of this phenomenon and to determine how to counteract the long-term effects of the space environment on man, all effects on man have to be closely evaluated and compared with earth-based simulation studies.

The space environment may affect the following systems:

Cardiovascular System. The maintenance of an adequate cardiac output with properly oxygenated blood to supply all areas of the body, is vitally important since this is the mechanical transport system for the cellular nutritional needs and waste product removal. The existing knowledge of the role of the gravitational force field, or its absence, on circulatory dynamics is limited. What is known however, points to the fact that cardiovascular dynamics may be altered significantly to the extent of causing symptoms which would lead to unconsciousness, upon return to a force field after a prolonged period of weightlessness.

Nutritional Functions. The role of a gravity field in the dynamics of food absorption, transport and utilization over prolonged periods of time is unknown at the present time.

Musculo-Skeletal System. The musculo-skeletal system has been subject to speculation as to the role of gravity in maintaining muscle mass, muscle function and strength, and decalcification of bones (mineral mobilization, deposition and balance). It is presently unknown whether these functions are gravity-dependent or primarily dependent upon maintenance of muscular contractions.

Pulmonary Functions. An area of vital importance are the long-term effects of partial pressures of oxygen in excess of sea level partial pressures. What kind of changes, if any, are initiated by an atmospheric composition dissimilar to earth's? How do these possible changes affect such pulmonary functions as ventilation, the mechanics of breathing, and pulmonary ventilation-perfusion ratios during weightlessness? The definition and estimation of the significance of these questions are yet to be determined. Some of these could be duplicated here on earth, but interaction of all multiple factors cannot be predicted.

Biochemical System. Any endeavor which produces stress in excess of measured experience may cause havoc to the endocrine organs. Much needs to be accomplished in understanding the significance of these fluctuations as they relate to the long-term functional usefulness of the individual and his well being after return from the mission.

Psychological Functions. Little is known in the area of psychological variations induced by small closed societies, isolation, and artificial environments, and what is known cannot yet be adequately correlated. Much work must be done so that some adequate measure of assurance can be had that long-term space missions will not pose undue problems in this area.

Vestibular System. This area is related uniquely to artificial gravity produced by rotation and is concerned with the study of the effects of Coriolis and angular acceleration gradients on vestibular functions. Questions which must be answered relate to the degree of interference with function, habituation and effects of changing magnitude of Coriolis and angular velocity as a function of space station configurations.
A biomedical facility in space will require flexibility so that any eventuality can be adequately measured and evaluated. This calls for a high degree of biomedical sophistication. Such sophistication recommends serious consideration of the use of properly trained medical personnel for flight missions.

The final evaluation of all biomedical parameters will lead to one of the key decisions in the future manned space flight program. It will answer the question whether or not an artificial gravity field is required in man’s life support environment.

There are three successive objectives in the biomedical experiments:

1. Determine whether man can operate successfully under weightlessness for long periods of time (of the order of one year) and subsequently survive in good condition the environment of re-entry and normal gravity conditions.

2. If there are indications of difficulty in the weightlessness state, determine whether on-board reconditioning measures, such as periodic rides on a low acceleration centrifuge or the occasional applications of pressure cuffs to the limbs, will enable the subject to operate successfully under prolonged weightlessness, followed by re-entry.

3. If there are conclusive indications that periodic reconditioning measures are insufficient, determine the best way of providing artificial gravity by means of rotation of the spacecraft and develop techniques for crew operations in the simulated gravity field.

Scientific Research

While the biomedical research is going on the Orbital Research Laboratory can be also utilized for scientific research. It should be pointed out that some scientific experiment, given high priority today, may be relegated to a lesser rating by the time a space station would become operational. This will depend largely on results of unmanned satellites as well as the military MOL program. However, several typical areas can be identified as being of considerable interest.

Astronomy. An orbiting space station could provide an astronomical observatory that would greatly increase the angular resolution and extend the wave length range beyond that possible in earth-based observatories. However, some experiments on an orbiting observatory might require pointing accuracies as stringent as 0.1 second of arc with photographic exposures for as long as one hour or more. Such stability may be difficult to achieve. A possible solution might be an astronomical mission module in close proximity to the space station with a radio command and an optical data link between the platform and the laboratory with periodic servicing of the platform by a laboratory crew member.

There exists a large range of astronomical observations that may be made from an orbiting observatory. Significant among these are:

1. Ultraviolet, visible and infrared studies of the planets, the solar disk, the solar corona, galaxies, nebulosites and interstellar gases.

2. Ultraviolet, visible and infrared studies at very high resolution of stellar systems and a search for planets of nearby stars.

4. Radio telescopes.

Only a few basic instruments would be required to do all the studies listed if man were present to align and calibrate the equipment, change attachments to the basic instruments and select the objects to be studied.

**Biology.** An ORL provides an opportunity for utilizing the unique aspects of the space environment to analyze the relationships that exist between an organism and its environment. Studies would be concerned with environmental effects on photosynthesis, biological rhythms, metabolism, and growth and development of organisms, such as:

1. Study of various physiological systems in the higher animals.
2. Study of embryology.
4. Plant physiology.

**Geophysics.** In this area many useful experiments could be performed. Photography from an orbiting laboratory covering several regions of the spectrum such as infrared and ultraviolet could be used to detect surface features not revealed by conventional photography. With a "multispectral" sensing device the spectral radiation and surface features could be identified and correlated. This would include correlation with known mineralogical composition and major geological features such as volcanoes and moisture patterns, thus developing the techniques for future planetary exploration. From the orbiting laboratory we could also perform panoramic photography of the earth for cartographic purposes with results that would be useful in many scientific fields, particularly meteorology.

Evaluation of the characteristics of electromagnetic matter from high altitudes will make it possible to determine the utility of radar and microwave emission detectors in predicting surface roughness and detailed topography; this may aid in better definition of the earth in oceanic areas by radar altimetry. Detailed definition of the advantages of spaceborne radar systems relative to geoscientific problems would be a major step in determining their future utility in planetary explorations.

**Meteorology.** With the ability to use high resolution cameras, radar, infrared sensors, and telescopes an orbiting laboratory could contribute significantly in determining meteorological phenomena affecting weather and weather prediction. Specifically the spaceborne laboratory could be used to observe systematically cloud systems as they approach, traverse and leave certain geographic areas with unknown thermal effects in each season. Man's presence would greatly contribute by his observation of peculiar patterns and features and relaying these directly to the ground observers in real time.

**Physics and Chemistry.** An Orbital Research Laboratory could contribute greatly to investigating the characteristics of space that cannot be measured from the earth. These characteristics, when studied with respect to the overall space environment, electromagnetic and particle activities, may lead to a much greatly increased understanding of materials, communications, relativity effects, artificial radiation belts and planetary system evolution.
The Orbital Research Laboratory has the potential of providing useful facilities for developing and qualifying the various systems, subsystems, structures, materials and operational techniques that will be required for future manned and unmanned space missions. In addition, an earth orbital space station which could evolve into an orbital launch facility would greatly improve the probability of success for planetary or advanced lunar missions. Launchings from orbit would ease the requirement for boosting large masses to escape velocities by assembling, refueling and checking out in earth orbit planetary exploration vehicles. However, orbital launching will require the solution of a variety of complex engineering development tasks such as assembly in space, checkout, launch procedures, fuel transfer, maintenance, repair, general operations and logistics.

Future systems and materials under development will require long-duration exposure to the space environment. Many parameters of this environment may be simulated in earth-based facilities; however, in many cases large volume and hard vacuum requirements favor in-space testing. Furthermore, ground-based tests obviously cannot provide the conditions of weightlessness or partial gravity for extended periods of time. One should bear in mind, however, that only tests which cannot be effectively carried out on the ground will be assigned to the space laboratory.

Some of the more significant potential engineering experiment groups for Orbital Research Laboratories are identified below.

**Crew Systems.** The study of advanced life support systems and crew equipment under space conditions would yield valuable information to support man on long-term space missions. The performance and reliability aspects of advanced environmental control systems to provide cooling, heating, pressurization, etc., for future spacecraft configurations can be evaluated. Particular tests would yield data on the effectiveness of leakage detection systems to pinpoint micrometeoroid penetration and failures in hermetic seals. This, in turn, would lead to an assessment of sealing techniques to correct these penetrations and failures.

**Extravehicular Operations.** For extended extravehicular operations man must be well versed in the capabilities and limitations of individual propulsion units, extravehicular suits and portable life support systems. The Orbital Research Laboratory would provide a test bed to train personnel for future lunar, earth orbital and planetary missions.

**Electrical and Electronic Systems.** The performance and/or endurance capability of various solar and chemical power generation systems operating in space environment can be evaluated. Various items of communication equipment, such as very high frequency devices, may be tested to develop improved space communications in terms of advanced components, optimum frequencies, bandwidths, transmission power, receiver sensitivity, reliability, etc. The performance characteristics of long lifetime advanced navigation and control systems can be studied and new guidance techniques evaluated.

**Propulsion Systems.** The effects of the space environment, especially weightlessness and long-time space exposure on ignition devices, re-start capability, fuel sloshing, vortexing and expulsion could be determined. Tests could be conducted on various fuels and oxidizers in different propellant tank configurations and with various insulation techniques and materials. Electric propulsion systems could be tested under true space conditions.
Structures and Materials. Many simultaneous effects of the space environment such as meteoroids, vacuum, radiation and temperature cycling on various characteristics of materials and structures are difficult to be meaningfully reproduced in ground tests. Ablative materials could be exposed to space vacuum and temperature extremes for long periods of time to evaluate their integrity. The zero gravity environment may be suitable for the manufacture of new materials. An effective meteoroid protection research program could be undertaken with the aid of trained experimenters who would help deploy large meteoroid bumper areas, examine penetrations and alter the materials to devise optimum protection schemes.

Development Flight Testing. Also of interest is flight testing of large unmanned satellites and space probes. Present satellite projects require a costly and time consuming development flight test program necessary to obtain reliable flight hardware. This is mainly due to the fact that we have not yet learned to build adequate ground simulators, and, thus, testing of final satellite configurations on the ground does not allow an isolation of all design deficiencies. By orbiting the test article as a "tag-along" near the orbital laboratory, such as a large deployable balloon or antenna system, thus allowing visual observation and a short command and telemetry link, diagnosis and repair of satellite malfunctions would be possible through extravehicular operations of the crew.

Laboratory Concepts

NASA, coordinating fully with DOD, has been studying the feasibility of manned Orbital Research Laboratories and the experimental requirements placed on such spacecraft. These study efforts, which are continuing, are conducted in-house NASA as well as through contract with the aerospace industry. The investigations have yielded to date a significant amount of data regarding many phases and aspects of potential advanced manned earth orbital systems. They have explored on a preliminary basis the modifications necessary to hardware presently under development within the Apollo program so that the same basic spacecraft could be utilized for the earth orbital missions, and the studies have looked at new vehicles that could accommodate from four to twenty-four men. Four different types of orbital systems are being considered:

1. Extended Apollo.
2. Apollo Orbital Research Laboratory (AORL).
3. Medium Orbital Research Laboratory (MORL).
4. Large Orbital Research Laboratory (LORL).

The first three are designed primarily for a Saturn IB launch vehicle. The large ORL utilizes the Saturn V capability. For initial missions these laboratories are all considered to be launched into circular earth orbits at altitudes of 200-260 miles and inclinations of about 28 degrees.

While examining the means by which a manned orbital laboratory capability could be realized, the studies also continue to investigate logistics systems that would support these orbital laboratories and explore the operational requirements of such systems. The Gemini B/MOL is being examined as a potential integral element of the ORL program. On the basis of these studies we will be able to compare the various alternatives and arrive at a choice of a system that is most suitable from the
technical as well as economical point of view. It is becoming increasingly clear, however, that Extended Apollo is an essential element of an expanding earth orbital program. In the initial stages it would be used as a laboratory, and later it could be converted to a logistics system. The AORL, MORL and LORL, on the other hand, are presently competitive systems, and a decision will have to be made which is the preferable first generation ORL system.

Some of the study results to date are highlighted below

Extended Apollo

Several methods for extending the capability of the Apollo spacecraft for longer earth orbital missions are being explored. Although currently designed for a fourteen-day mission to the moon and back, preliminary feasibility studies indicate that the mission lifetime capability of the spacecraft could be extended to periods of up to three months without major modifications.

In this version (Figure 1) only supplies such as life support stores and stabilization propellant are added, and some redundancy is provided in the subsystems. The basic Apollo subsystems are not replaced by more advanced equipment, thus allowing an uninterrupted growth of Apollo from its presently planned earth orbital tests. The environment control system is only changed to the extent of providing a two gas atmosphere (adding nitrogen), because pure oxygen may be harmful for periods of time over 30 days.

The major limitation of the Extended Apollo as a laboratory is its limited pressurized volume (360 cubic feet). By eliminating one crew member and his restraint system there can be made available for experimentation about 190 cubic feet of volume in the command module of a 45-day Extended Apollo. The removal of lunar mission propellant and tankage from the service module provides then an additional 1,000 cubic feet of volume for experimental payloads. With a Saturn IB launch the experimental payload available at an altitude of 150-200 nautical miles is about 5,000 pounds.

The Extended Apollo capability can grow to over 120 days when some subsystems are changed; for instance, one of the required changes would be the replacement of the present fuel cell power plant by a solar cell system.

Apollo Orbital Research Laboratory

The AORL is an outgrowth of the Extended Apollo, which incorporates a 5,600-cubic foot pressurized laboratory module in the adapter between the service module and the S-IVB booster stage made vacant by the removal of the Lunar Excursion Module (Figure 2). Such a laboratory would be launched initially with a crew of three in the Apollo command module. In orbit the Apollo would disengage from the laboratory, turn around and dock nose first to the airlock, thus allowing the crew to enter the laboratory. Another Apollo spacecraft could ferry up three additional crew members and supplies, which would dock at the opposite end of the laboratory. From then on for at least a year, on a three-month cycle, new Apollo ferries would deliver fresh crews and supplies or equipment. It is also possible that modified Gemini-B/MOL spacecraft may be used as ferries and modules carrying experimental gear.

Medium Orbital Research Laboratory

The MORL is directly comparable to the AORL, except that it is launched unmanned without the necessity of carrying the Apollo spacecraft; the Saturn IB can deliver a
heavier laboratory into the 200 nautical mile altitude circular orbit. Like the
AORL it accommodates a six-man crew which is launched on subsequent ferry flights. The additional weight margin over AORL allows for such things as carrying of more elaborate equipment, providing better radiation protection, and a hangar for docking, repair and unloading of ferry vehicles. Figure 3 shows a Gemini ferry in the hangar. Apollo or Gemini B/MOL ferries could be also accommodated.

The basic laboratory, as presently conceived, is a sphere, twenty-two feet in diameter surrounded by a cylinder to make its aerodynamic shape compatible with the Saturn IB launch vehicle. The pressurized living volume is 5700 cubic feet with 2,800 cubic feet devoted to experimental usage.

The design shown has two compartments, the upper equipped as living quarters and the lower as a laboratory. Between decks there is a centrifuge provided for crew reconditioning and biomedical research. Four kilowatts of electrical power are supplied to the laboratory by solar cell panels. The internal atmosphere is maintained by reprocessing the air to recover oxygen from carbon dioxide. Water is reclaimed from metabolic wastes.

Like the AORL the MORL is basically a zero gravity station, but could be conceived in such a way that it could be adapted to provide an artificial gravity field for the crew in the laboratory. The laboratory and the expended upper stage of the launch vehicle could be rotated about their common center of mass utilizing a connecting system of cables (Figure 4). Note the stored ferry vehicles on the side of the laboratory. These vehicles, of course, have to be stored at the station since the crew inside the laboratory must have means by which to abandon the laboratory in case of a disaster.

Large Orbital Research Laboratory

The LORL is characterized by a crew of twenty-four or more. It would be launched with a two-stage Saturn V vehicle into a 260 nautical mile orbit, and maintained there for a period of up to five years. Figure 5 shows one of the concepts presently under active consideration. It is a three-radial-module design with a diameter of about 150 feet. It includes a zero-gravity laboratory at the central hub and radial modules which can be rotated to provide artificial gravity. Various individual sub-laboratories can be accommodated in the radial modules at varying levels of gravity. The LORL has a total volume of about 67,000 cubic feet and weighs about 247,000 pounds.

The long mission duration of the LORL requires a very efficient life support system. Like in the smaller laboratories the atmosphere is provided by regenerating oxygen from carbon dioxide, and water is maintained by reclamation from urine and waste water. Thirty kilowatts of power are provided by approximately 7,000 square feet of solar cells. The crew and supplies are transferred between the earth and the space station by means of Apollo like six-or twelve-man ballistic or twelve-man lifting body ferries. Figure 5 shows a lifting body ferry docked at the station.

The LORL offers a flexibility of performance, manpower, space, and electrical power for a wide range of experiments which the smaller laboratories cannot provide. It could possibly be adaptable to operational growth into an orbital launch facility for planetary and advanced lunar missions. This great versatility may provide greatest cost effectiveness in spite of the initial high investment.
Operations and Logistics

The realization of any of the Orbital Research Laboratories discussed here will require an operational support system that will heavily tax our present capability in this area. Presently and in the foreseeable future space flight operations will utilize the launch facilities and global tracking networks on an intermittent basis with each manned launch receiving very special treatment. The gradual evolution of an orbital laboratory system will require these operations to be performed on a much more routine basis. To assure maximum utilization of the present facilities and those planned for the Apollo program the operations associated with the orbital laboratory will have to be conceived to be as simple and similar to other operations performed in connection with manned space flight as possible. Interactions with other programs will have to be defined precisely and flexibly in order to avoid delays due to coincident facility utilization at the launch site or the control center. Regardless of the method of ORL launch, ferry and resupply operations will be required for any extended duration missions. These operations will be necessary to replace the crew, provide life support and stabilization expendables, replace experiments, deliver spare parts and provide fuel for orbitkeeping or changing. The requirements on the ferry/logistics vehicle are that it must have a round trip capability and always be ready at the ORL for emergency evacuation. This in turn enforces severe requirements on the spacecraft in terms of long-term orbital storage capability as well as capability for rapid checkout and maintenance.

Crew replacement could be accomplished by a ferry spacecraft using launch, rendezvous, re-entry, landing procedures, operations and landing sites currently planned and being developed for the Gemini or Apollo program. The choice between Gemini, modified Gemini B/MOL, Apollo or a new generation of larger ballistics or lifting body ferry vehicles and their respective boosters is presently unresolved and will depend upon the operational requirements for crew replacement and resupply. Figure 6 shows the various ferry vehicles and laboratories presently being considered.

A great amount of study is still required to illuminate all of the systems possibilities to determine technological development requirements and to establish a coherent earth orbital program. Only through a concentrated effort on the part of both NASA and DOD to recognize each other's individual and our mutual goals can we arrive at an economic solution to the Laboratory in Space.
Figure 1. EXTENDED APOLLO

Figure 2. APOLLO ORBITAL RESEARCH LABORATORY
Figure 3. MEDIUM ORBITAL RESEARCH LABORATORY

Figure 4. ARTIFICIAL GRAVITY PRODUCED BY ROTATION
Figure 5. LARGE ORBITAL LABORATORY

Figure 6. LABORATORIES AND FERRY VEHICLES