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SAGE

The Spinning Artificial Gravity Environment
A design project for the:

United States Naval Academy
Aerospace Engineering Dept.
27 April 1987

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Midshipmen of the Class of 1987

(NASA-CR-184757) THE SPINNING ARTIFICIAL GRAVITY ENVIRONMENT: A DESIGN PROJECT (Naval Academy) 159 p CSCL 22B

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Abstract

The SAGE, or Spinning Artificial Gravity Environment, design was carried out to develop an artificial gravity space station which could be used as a platform for the performance of medical research to determine the benefits of various, fractional gravity levels for astronauts normally subject to zero gravity. Desirable both for its medical research mission and a mission for the study of closed loop life-support and other factors in prolonged space flight, SAGE was designed as a low Earth orbitting, solar powered, manned space station.

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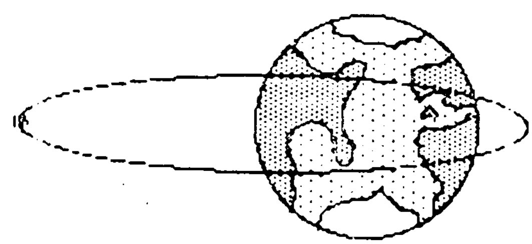

SAGE: SPINNING ARTIFICIAL GRAVITY ENVIRONMENT

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SAGE

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1.1 WHY DO WE NEED SAGE

The answer to this question is manyfold and can perhaps best be summarized by referring to Pioneering the Space Frontier, the report of the National Commission on Space. The report says that questions concerning the effects of variable gravity on humans need to be answered, specifically;

"In the longer term, more complex questions must be answered. What gravity level is needed to prevent the deleterious effects of less than Earth gravity? We suspect that the answer will turn out to be much less than 1g, but experiments are needed to establish how much less. If one-sixth gravity is adequate, then long term habitation on the Moon will be practicable; if one third gravity is adequate, then humans can inhabit the surface of Mars. What are the effects of return from low g to Earth gravity? Experiments to settle these questions will have to be carried out over long periods of time."

"For this work a variable gravity research facility is required. In addition to physiological studies, the Variable-g Research Facility should support basic research on the effects of low gravity in many scientific disciplines. Thus it will be available for studies of physics, chemistry, and biology in space. This facility will also be needed for long term testing of the synthetic biospheres that will support l [illegible] yages to Mars and on the surfaces of the Moon and Mars."

The commission also suggests guidelines for the construction of a variable-g research facility;

"The Variable-g Research Facility, like other space facilities, should be built using standard modules and previously developed utility subsystems. The facility must establish gravity level requirements in time to contribute to the definition and design of the orbital spaceports for the Moon, Mars, libration points, and the design of cycling spaceships for the Mars run."

In specific the Commission recommends: "Early availability of a dedicated Variable-g Research Facility in Earth orbit to establish design parameters for future long-duration space mission facilities."

The excerpts above from the report of the National Commission on Space contain the basic reasons for the conception and design of SAGE.

1.2 OVERVIEW OF SAGE

SAGE is the acronym for Spinning Artificial Gravity Environment. It is designed to provide a shirt-sleeve environment for comfortable habitation. All areas will be conditioned and pressurized for comfort.

The facility will be used for variable-g research on human health and for maintenance of human health in space for personell assigned to missions of long duration. The facility will be able to provide a bro d data base, obtained over a period of years, which will be extremely valuable for determining the feasability and requirements of future long duration space missions. Specifically, SAGE will help researchers to determine the minimum gravitational requirements versus the period of time spent in space as a general characteristic of extended mission duration. The development of such characteristic data would be very valuable in planning missions which are now being thought of. For instance, the long term effects of life at a lunar colony, or the need for artifical gravity on a manned mission to Mars, may be predicted much more accurately after data obtained from SAGE is analyzed. A much more thorough discussion of the medical benefits to be derived from SAGE follows in section 9. In addition to medical care and research facilities, SAGE will be equipped with data reception equipment which will allow data from other space based research systems to be brought on board and analyzed by crew members during their stay at the station. This capability will allow the personnel assigned to SAGE to continue productive research on board the station. In order to facilitate this research, SAGE will be equipped with on board computer systems for use in data analysis, limited programming, and computation.

The station will be of modular construction with each module sized to fit securely in the space shuttle cargo bay, thereby making transportation needs during the station construction closely conform to the capability of the U.S. ogram. There are to be four modules, comprising the habitation, research, and work spaces for the station. Each module will be connected to it's adjacent modules by relatively small two force members (trusses) to prevent excessive oscillations and to distribute the shear forces on the crosspieces evenly. The modules will be 14.6 foot diameter cylinders 44.5 feet long and of aluminum construction. The 3/16 inch pressure shell will be covered by Mylar and Kevlar insulation, and will be protected by a meteroid shield. The internal framework housing the equipment racks will provide additional support and will also help distribute the axial forces and moments evenly. The modules are to be connected to a central hub module of the same type of construction and size. The seventy five inch diameter cross pieces will be constructed from two 39 foot (approximately 44 ft. with connectors) sections. Their construction will be similar to that of the modules, and each cross piece will house all fluid, gas, electrical, and other necessary connections from that module to the central hub. Externally, each cross piece will support a solar cell array forty feet long. A docking adapter will also be connected to the central hub module and equipped with a de-spin system to allow docking with the station without de-spinning the station itself. Althoug it is improbable that the Space Shuttle will be allowed to dock with the station in this manner until the technology is proven over a long period of time. A basic drawing of the SAGE station is presented in figures 1.2-1 through 1.2-4. It is estimated that approximately nine shuttle launches will be necessary to loft all assembly equipment and parts of SAGE into orbit. In order for SAGE to be assembled in orbit, extra vehicu ity as well as

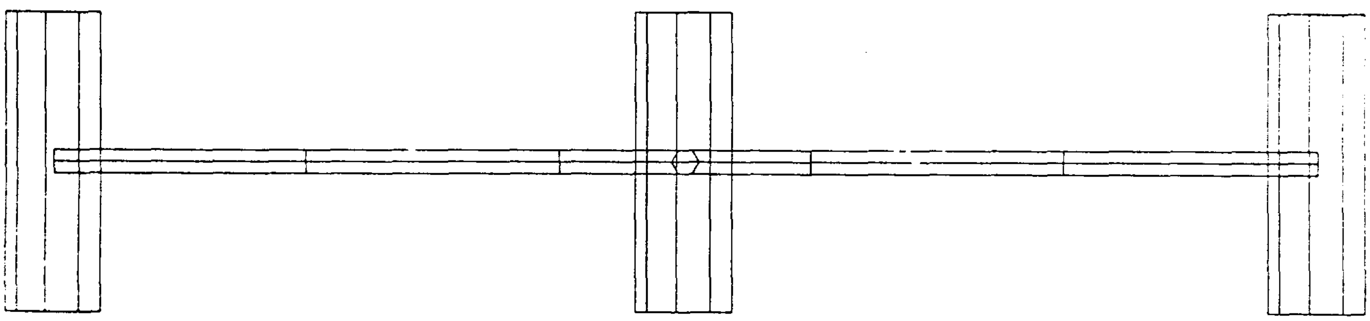

Figure 1.2-1 Basic side view of SAGE before additions.

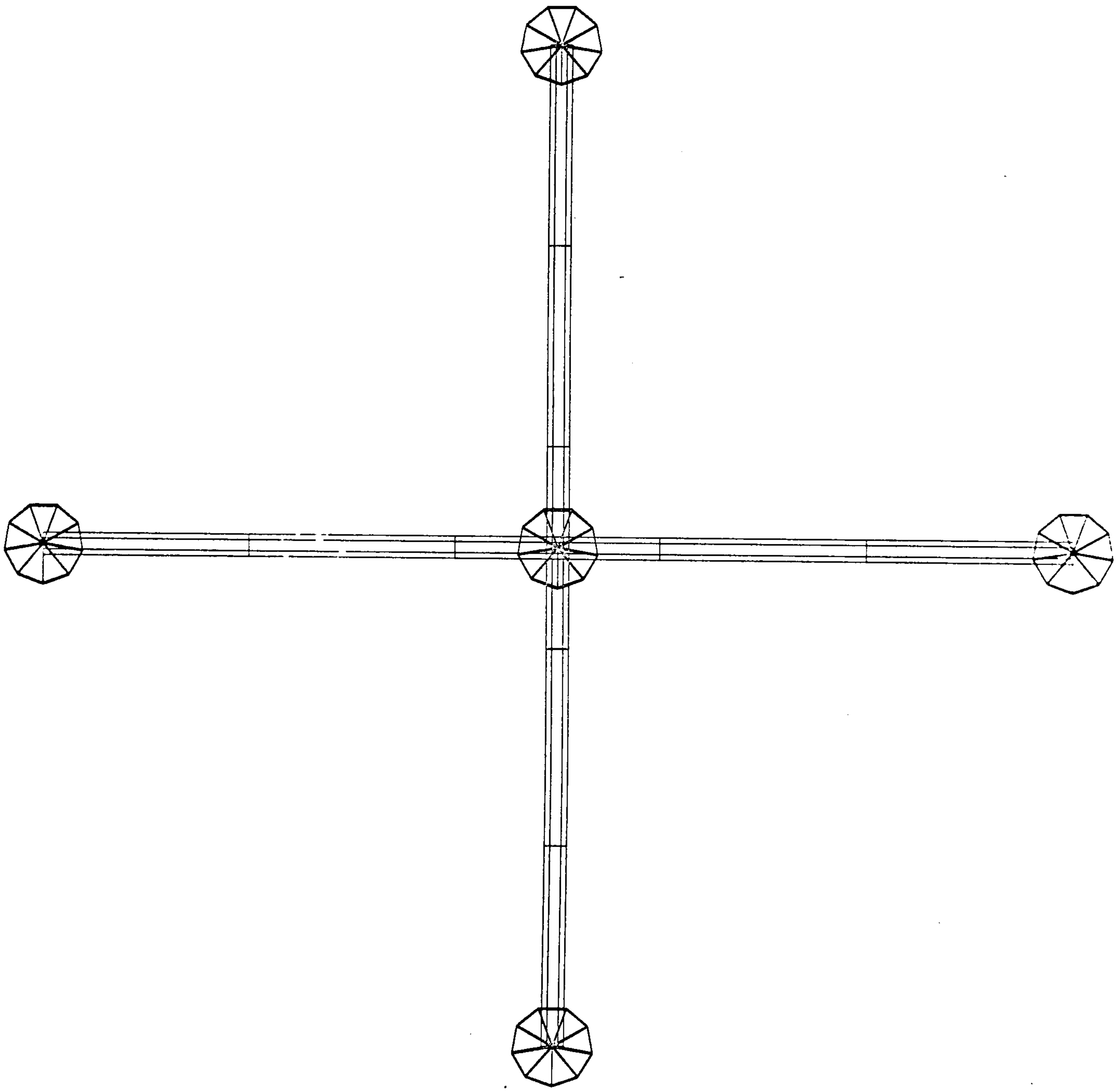

Figure 1.2-2 Top view of SAGE

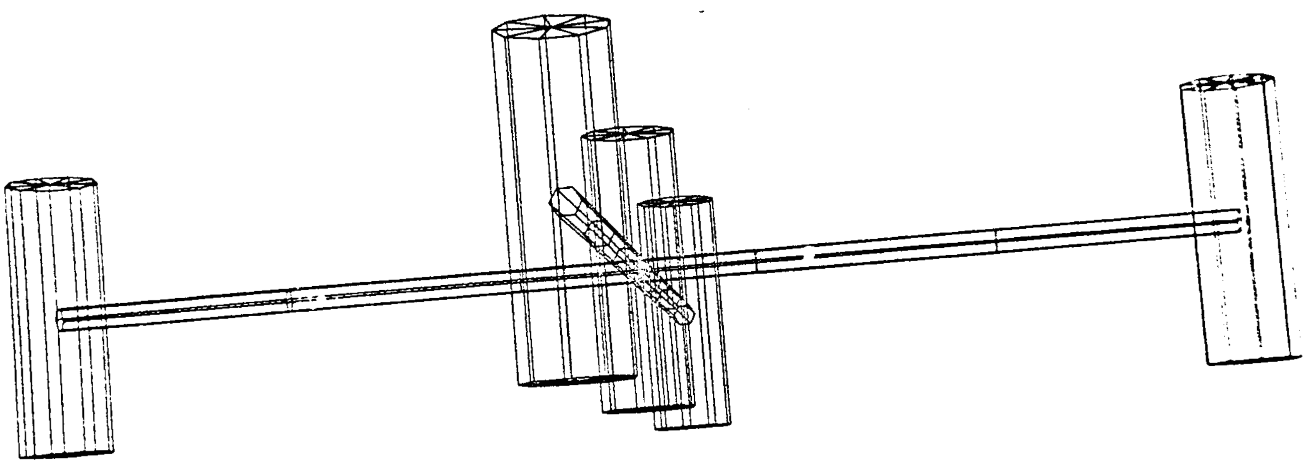

Figure 1.2-3   Basic three dimension view of SAGE (without additions or solar dynamic arrays)

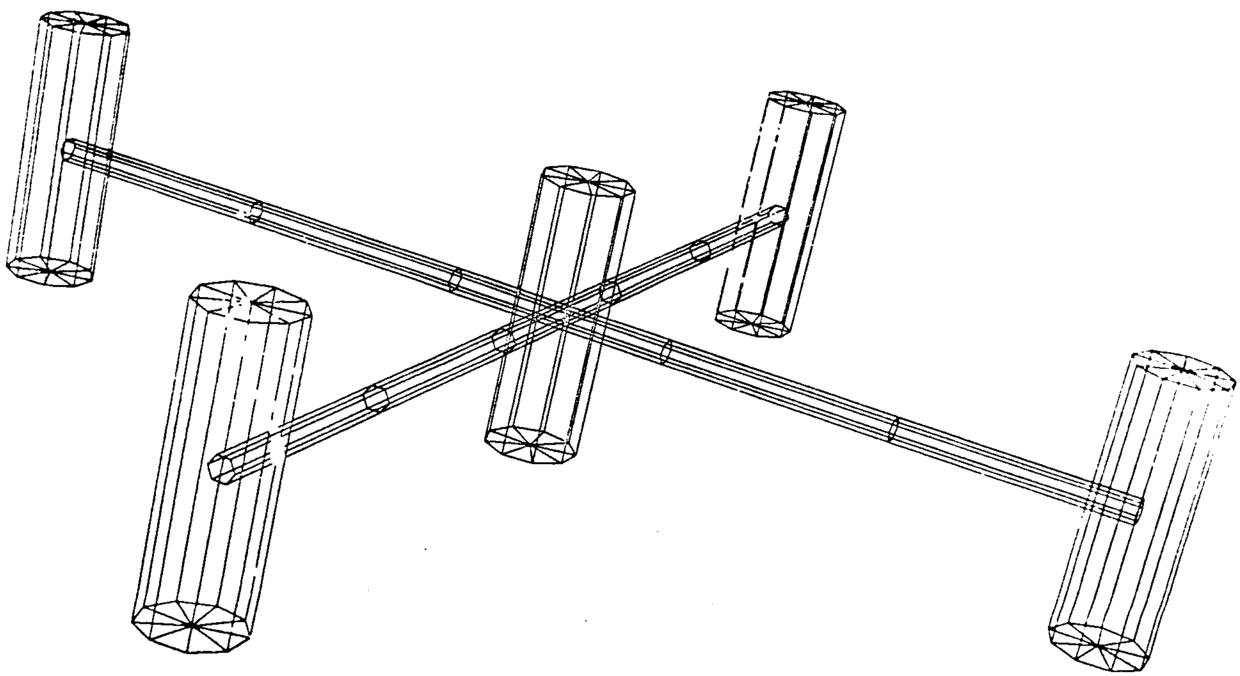

Figure 1.2-4 The basic SAGE configuration.

operations using the shuttle remote manipulator arm will be required. For these reasons the solar panels will be included in one of the earliest launches in order to supply power during the construction phase. The parts of SAGE will be designed in an almost prefabricated manner to facilitate on orbit construction.

SAGE will be equipped with living quarters for eight people, each with their own room equipped with a rack, a closet, and a personal workspace. The living quarters will be divided into two habitation modules. Each of the two habitation modules will contain personal quarters for four people along with a shower and a toilet. The station will also be equipped with hygeine facilities designed to function in zero gravity in case of accidental de-spin. Limited but adequate lounge facilities will also be included in the habitation modules. Module layout will be discussed more thoroughly in section 2.

The SAGE power system is designed to provide power to the station continuously throuhgout the sixteen eclipses of approximately thirty-six minutes each every day. SAGE will be powered by two solar dynamic converters attached to opposing modules of the station. The solar dynamics, later described in more detail in section 3, will provide approximately 50 KW each of power to the the station. SAGE will also have photovoltaic (solar cell) collectors mounted externally which will provide approximately 25KW of power each. In case of emergency SAGE is to be equipped with batteries which will provide power. In determir type of power

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system to use on the station, both photovoltaic and solar dynamic systems were considered. The primary advantages of photovoltaic systems considered were the existing manufacturing technology and fabrication industry and the body of performance data resulting in high reliability and low cost for such systems. The disadvantages of photovoltaic systems include low efficiencies of eleven to sixteen percent, large array size (20,000 square feet to generate 75 KW) which introduces atmospheric drag problems, and susceptibility to thermal cycling effects. The solar dynamic system has the disadvantage of being an as yet unproven concept which would result in large research and development costs. Despite this disadvantage, solar dynamics have been considered for use on board Space Station. Solar dynamics does, however, have it's advantages, which made it worthy of serious consideration and eventual incorporation into the SAGE design. These advantages include higher efficiencies of eighteen to thirty percent, an array size one third that of photovoltaic systems providing equal power, and reducing atmospheric drag considerably, along with the possibility of thermal energy storage. TRW and Rocketdyne are presently evaluating the solar dynamic system and are ths source of most of the solar dynamic data used in designing SAGE power systems and presented within this technical report. A basic view of what the solar dynamic arrays to be used on SAGE look like is presented in figure 1.2-5. The power distribution system on SAGE is designed to be fully compatible with the Space Station providing 400 Hz, 208/220 v, three phase power. The primary generators of the solar dynamics use a turbine driven alternator while the backup/emergency generator uses a DC to AC converter. The weight and cost of all power generation systems on SAGE s greatly reduced by the sun pc +titude of the station which will be discussed in greater detail in section 6.

Passive thermal control will be used on board SAGE to reflect heat, and an active one-phase H_2O system will carry waste heat to the dark side of the station for rejection into space. The solar pointing side of the station will be painted with white paint having an absorbtivity of 0.04-0.05 and part of the dark side will bve painted with black paint having an emissivity of 0.90 or higher. In the event of a loss of pointing ability, heat pipes or the H_2O system would be used to transmit excess heat to the solar dynamics or to the H_2O storage tanks throughout the casualty.

Electrical resistojets along with gaseous H_2/O_2 thrusters will provide the total attitude control, spin-up, spin-down, and orbit maintenance capability. Three axis control will be provided by redundant, variable thrust resistojets located at the maximum radius for control, found on the outer sides of the modules. Attitude will be determined by digital N-slit sun sensors, horizon sensors, and use of Global Positioning System (GPS). Atmospheric drag makeup will be continuously provided using waste gases produced from the life support system. Storage will be provided for spin-up, spin-down needs and orbit reboost based on 180 day resupply missions of the Shuttle. If necessary, H_2O can be electrolyzed to provide fuel for emergency purposes or any unplanned rendezvous with Space Station. The phase angle can easily be adjusted for a rendezvous with Space Station, and orbit decay to 200 nautical miles will be allo resupply from the Space Shuttle.

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For communications, which will be covered in greater detail in section 4, SAGE will be outfitted with a space to space and a space to ground communications system. Two UHF transmitters for voice communications to Space Station and one long range transmitter will accomplish these functions. A backup transmitter connected to the emergency power supply system will also be on board in case of major failure of the primary long range communication system. Two multichannel satellite receivers for Earth based news and television broadcasts, as well as electronic mail reception will be included on board. Internally, SAGE will be equipped with an intercom system, as well as multiple color monitors and cameras for experiment monitoring and internal communications with visual as well as sound capability. Also, SAGE will be cabable of using the GPS system for orbital tracking and determination.

1.3 MAJOR DESIGN CONSIDERATIONS

The major consideration in designing SAGE was the human factor. Human beings are subjected to unusual conditions in ordinary spaceflight, but to try and simulate the Earth's gravity further complicates the matter greatly. The radius and rate of rotation of the station have great influence on the human factors. If a good approximation to linear gravity is to be achieved, a longer radius is desired. In the early conceptual design stages of SAGE, the human factors as well as the cost, structural considerations, and ease of construction were c [illegible] in developing the ultimate configuration pictured in figure 1.2-4.

Unfortunately, artificial gravity generated by rotation involves a number of undesirable phenomena (Dole, 1960; Faget and Olling, 1967; Loret, 1961). Because of the unusual forces operating in such an environment, astronauts may anticipate considerable degree of locomotor difficulty, spatial disorientation, and perhaps motion sickness. The degree to which these adverse effects will be experienced varies greatly with the radius, angular velocity, and gravity level.(Ramsey 1971) Because the artificial gravity vector at any point in a rotating space station is radial, It was decided early in the design of SAGE to have an effective radius of the same length in all working and living spaces on board the station. A normal perceptual-motor adaptation, for example, might well be highly radius specific so that an astronaut completely adapted to rotation at a radius of 33 ft. might be unable to perform well at 16 ft., where different responses are appropriate because of changes in radius and gravity level.(Ramsey 1971) For this reason the idea of a "tomato can" type design originated. In this type of design the long axis of each module is parallel to the axis about which the station spins. This design prevents the problem of having a gravity gradient on any of the walking surfaces of the modules.

In order to relate all of the factors being considered together in a unified way, the graph of figure 1.3-1 was constructed. The graph relates the radius, rotational speed, and gravity created in a series of curves. The initial capability desired for SAGE was from 0-.5 Gs. T[illegible] [illegible]s was

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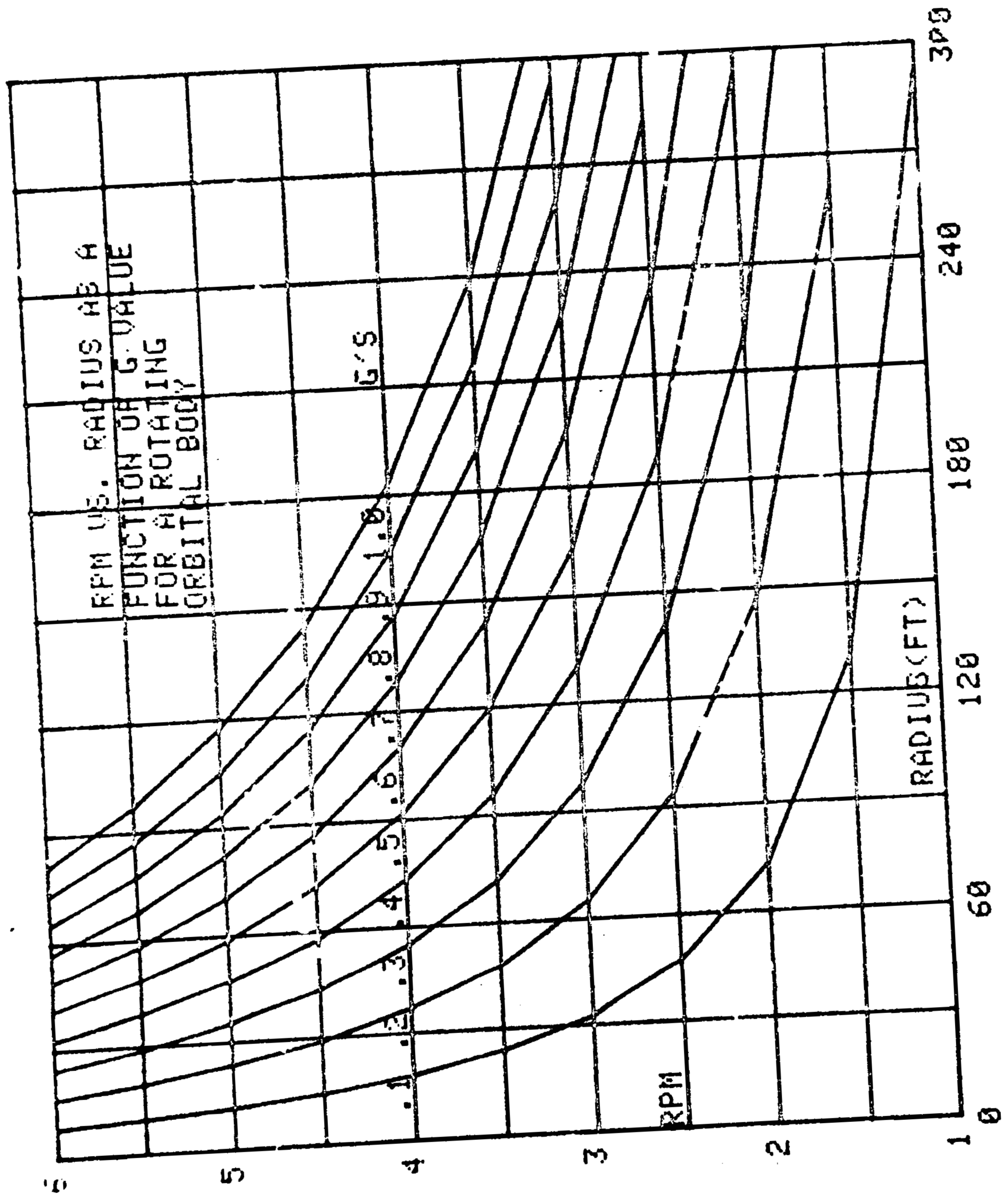

figure 1.3-1

desired to be minimal to reduce costs, construction difficulty, and number of launches necessary to lift the station. It was also noted that a longer radius, while providing many benefits such as more linear gravity and a lower rotational speed, would also create a more difficult transition between modules for crew members. The rotational speed of the station was desired to be minimal in order to reduce disorientation ofd crew members due to coriolis effects. From Soviet studies of the rotating environment, two parameters have been determined. The maximum rate of rotation has been determined as 6 RPM and the minimum level of gravity to prevent atrophic muscular alterations has been determined as .3 Gs. Combining all of these parameters, the radius of SAGE was determined to be ninety five feet providing an effective gravity of 0 to .5 Gs at 0 to 4 rotations per minute .

1.4 ORBITAL PARAMETERS

SAGE is to be placed into an orbit that will shadow the Space Station to allow ease of transport between the two stations. This close orbital relationship could prove very worthwhile if a major problem should occur at either SAGE or Space station. While transport and exchange of personel between the two stations will be kept at a minimum, so as not to disturb the experimentation routine on board SAGE or cause the necessary de-spin if the Space Shuttle is involved, the ease with which data may be exchanged between the two facilities will contribute greatly to making the close orbital proximity worthwhile. A basic orbital sketch and ground track of the SAGE orbit is shown in figure 1.4-1 while the orbit itself characteristics is discussed in more detail in section 6.

a=6786Km

e=0.0 (effectively)

i=28.5

j=188 deg

w=0.00

M=90.00 deg

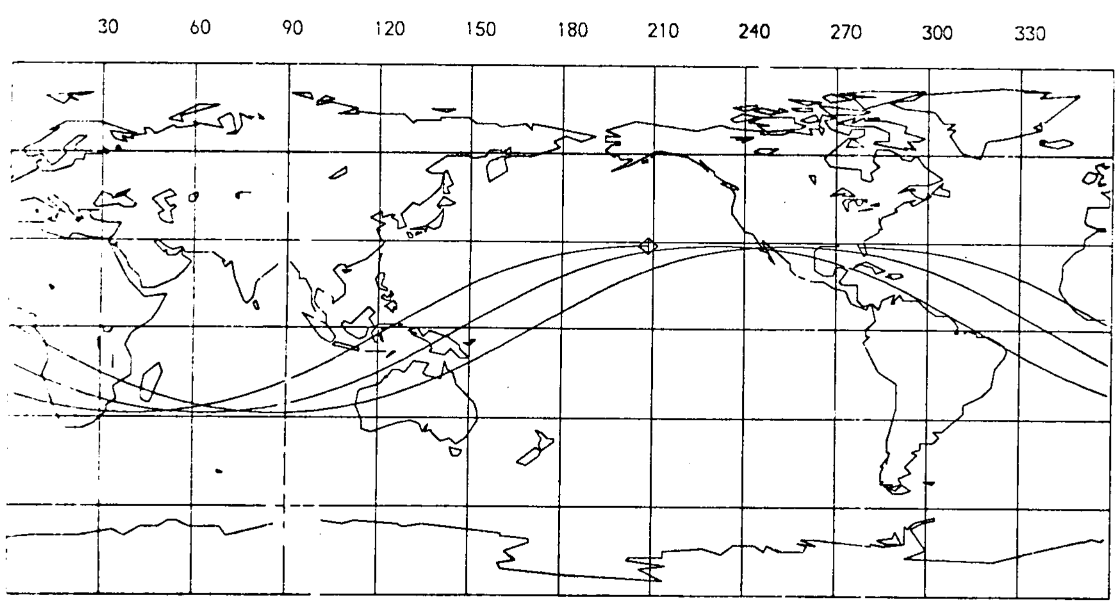

Figure 1.4-1 SAGE Orbit and parameters

The environmental control and life support system (ECLSS) on SAGE is designed with a focus on creating and maintaining a safe and comfortable environment conducive to high crew productivity. Due to the extended periods of time to be spent on station, the ECLSS incorporates closed loop, regenerative processes to reduce on board storage. The ECLSS will be responsible for many functions. It will monitor atmospheric composition at all times and generate O_2 and reduce CO_2. The ECLSS will use circulation fans and heat exchangers for humidity control. Potable water will be recovered from the humidity control an CO_2 reduction processes. Before consumption the water will be treated with a multifiltration device. Water for use in personal hygeine (not to include potable water) will be recovered from wash water, wasted potable water, dishwasher, shower, and laundry water as wel as from the urine recovery system. Human wastes will be collected, treated, and stored, until they can be taken from the station and disposed of. A fire detection and supression system will also be operational on board SAGE. As suggested in the report of the National Commission on Space and stated previously, SAGE will incorporate previously developed systems using existing technology for life support and these systems will be almost identical to those on board Space Station.

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2 SAGE STRUCTURE

2.0 SAGE Structural Design

With the NASA Space Station technology well at hand, SAGE will use this existing hardware, but will modify specific aspects due to mission requirements. This will greatly decrease the assembly cost, and ensure reliability. Modifications due to operational experience, will further increase safety. The main structural members include the HAB and LAB modules, the Core Module(CM), the Logistics module(LOG), the four crosspieces(XP), resupply nodes, airlock, despin mechanism, berthing mechanism, Mobile Service Center(MSC), and truss structure. A mass summary is contained in table 2.0-1.

2.1 HAB/LAB modules

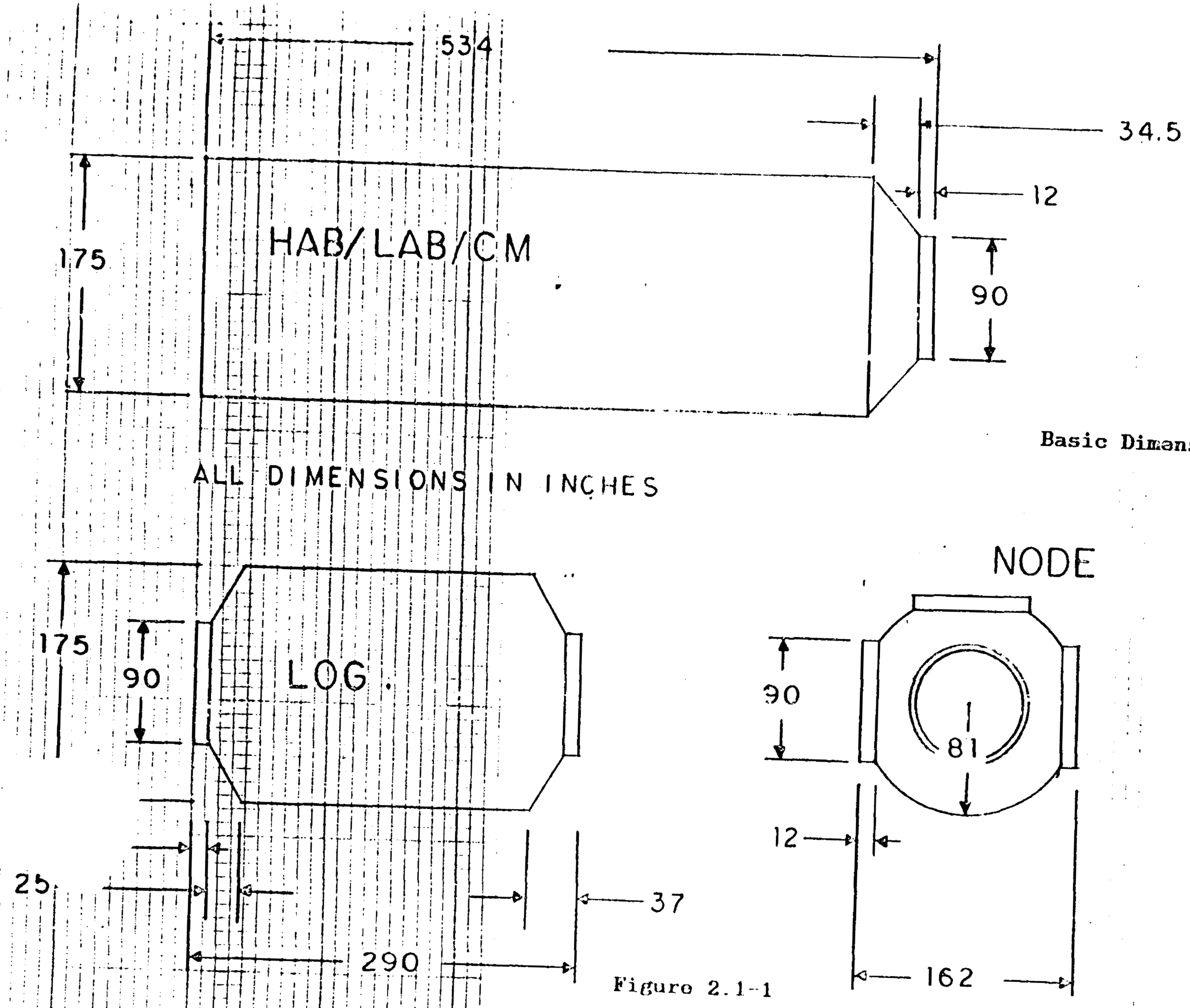
These four modules form the working and living compartments of SAGE. The dimensions are given in figure 2.2-1. Taken apart, these modules begin with four cylindrical shells .188 in thick, welded together and reinforced by three main hoops(see figure 2.1-2). Their inside diameter is 166 in, and the pressure shell is fabricated from a 2219 aluminum alloy. One end is capped off by a closed, slightly rounded dome, while the other end has a berthing mechanism. This is a standard berthing mechanism with common utility interconnects and a standard 50 in hatch. Internally, a truss network exists to support the instrument racks spread the spin loads evenly. This internal truss network o the three main rings which also form the STS keel and sic ment

MASS SUMMARY

Item	X(in)	Y(in)	Z(in)	mass(lbm)
Hab1	-1036	0	8	42000
Hab2	1036	0	8	42000
Lab1	0	-1036	62	36000
Lab2	0	1036	62	36000
CM	0	0	-70	32000
Node L1	0	-1036	-280	8000
Node L2	0	1036	-280	8000
Node H1	-1036	0	-334	8000
Node H2	1036	0	-334	8000
LOG	0	0	-470	24000
Despin mechanism	0	0	-340	4000
Solar Dynamics H1	-1036	0	130	6264
Solar Dynamics H2	1036	0	130	6264
Crosspiece H1	-570	0	0	21000
Crosspiece H2	570	0	0	21000
Crosspiece L1	0	-570	0	21000
Crosspiece L2	0	570	0	21000
Reaction Control System H1	-1155	0	0	3000
RCS H2	1155	0	0	3000
RCS L1	0	-1155	0	3000
RCS L2	0	1155	0	3000
MSC(main) H1	-570	0	-70	3500
MSC(secondary) H2	570	0	-70	3000
MSC L1	0	-570	-70	1500
Manual Service Center L2	0	570	-70	1500
Photovoltaic H1	-305	0	50	2505
PV H2	305	0	50	2505
PV L1	0	-305	50	2505
PV L2	0	305	50	2505
Truss H1-L1	-570	-570	0	500
Truss L1-H2	570	-570	0	500
Truss H2-L2	570	570	0	500
Truss L2-H1	-570	570	0	500
				378048 lbm

Izz=5.7x10^7 Iyy=3.35x10^7 Ixx=2.75x10^7 slug-ft^2

Table 2.0-1



Basic Dimensions

Figure 2.1-1

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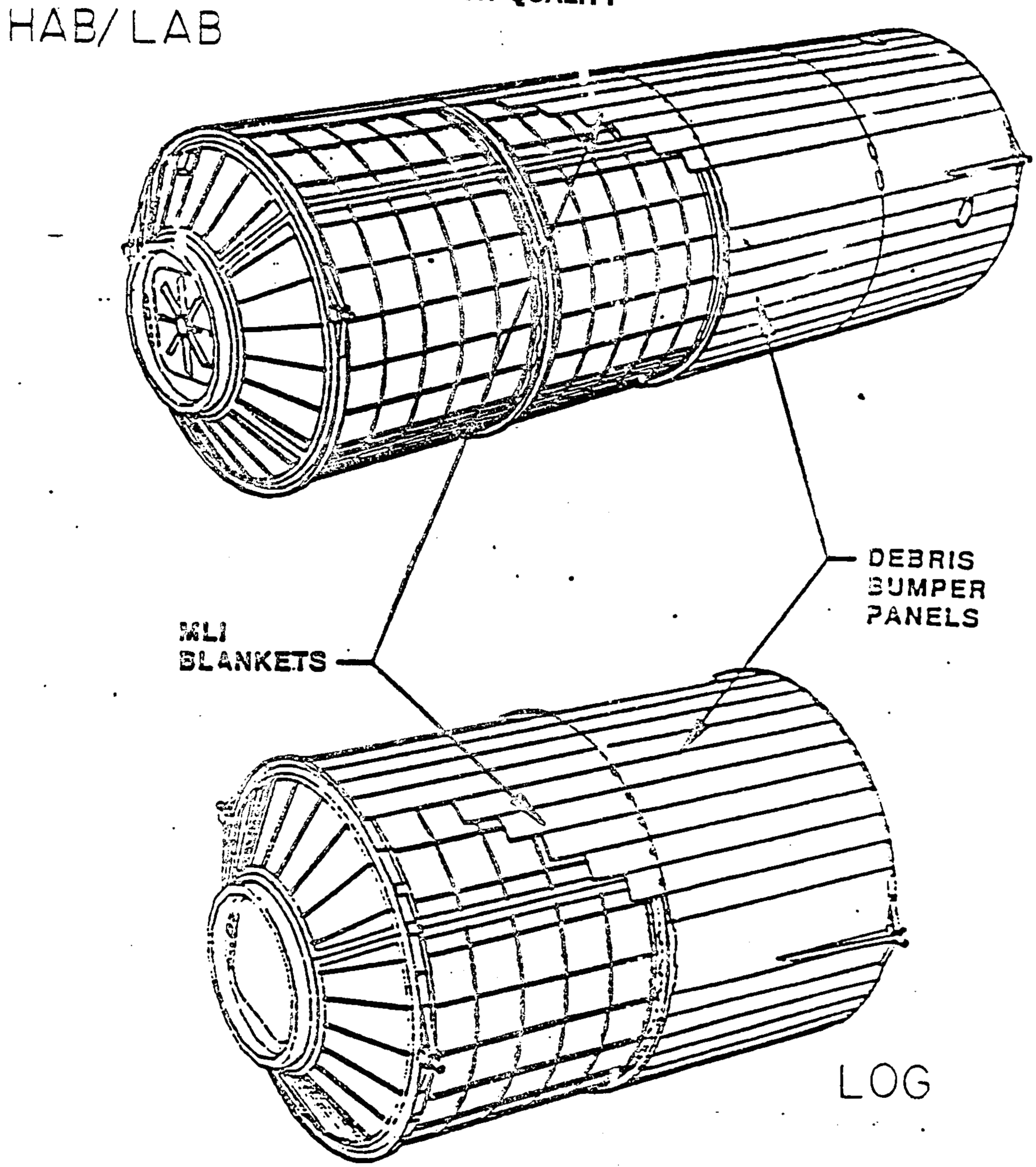

HAB/LAB Modules

Figure 2.1-2

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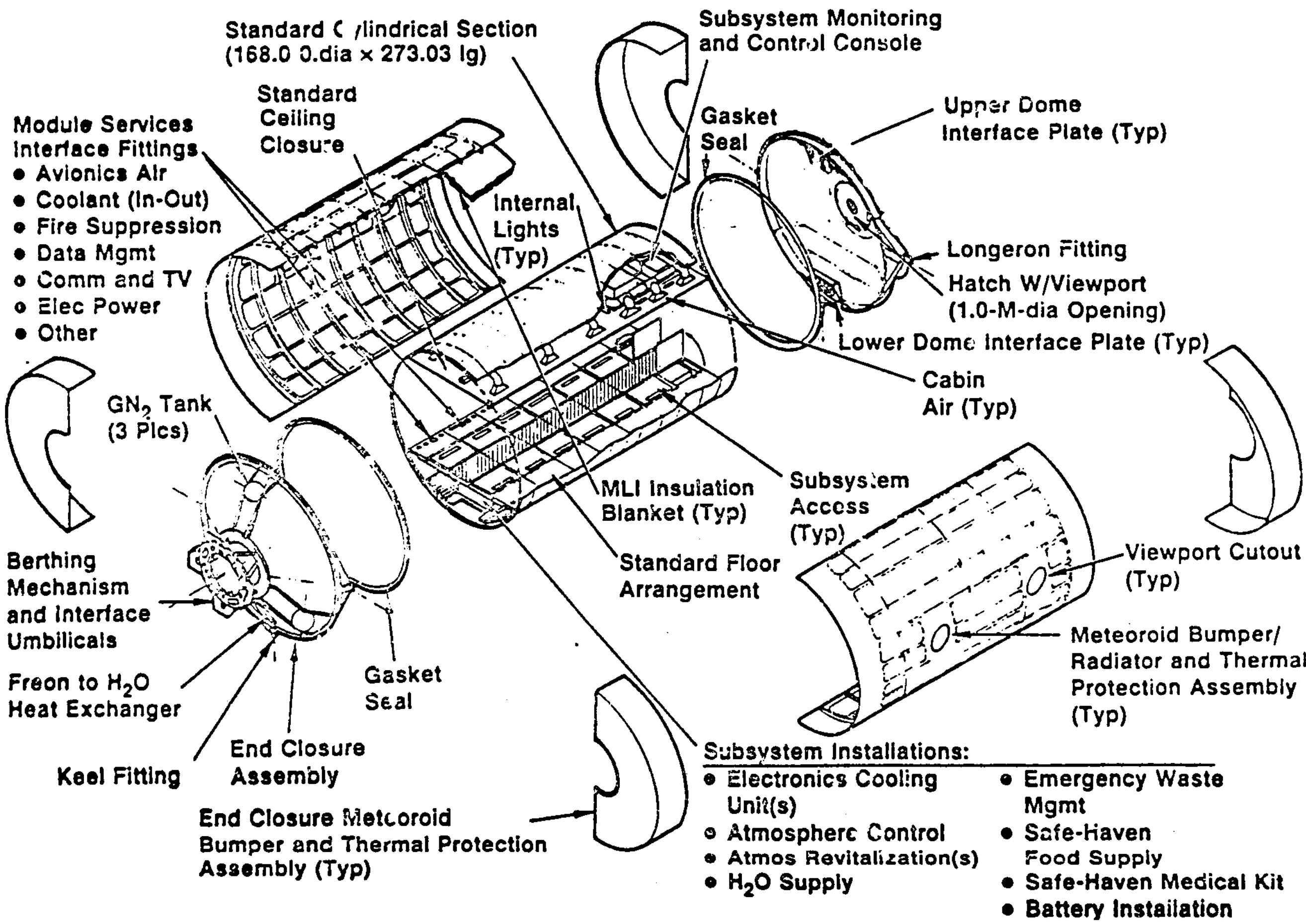

Pressure Vessel Concept

Figure 2.1-3

Courtesy of McDonnell Douglas Corp.

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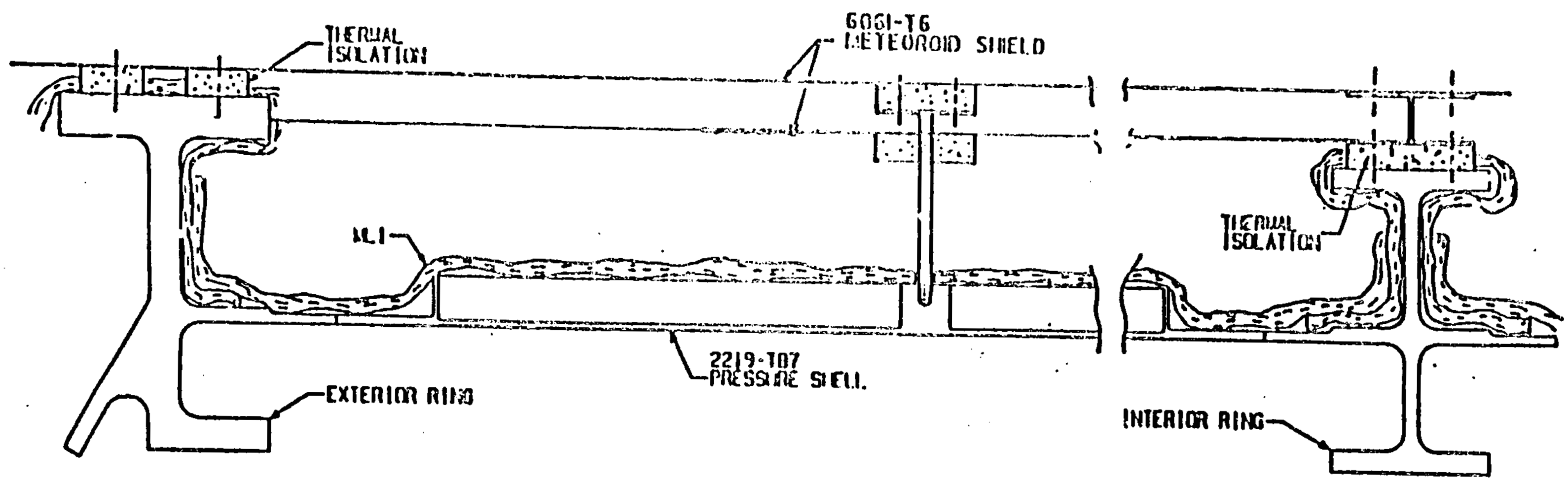

Meteoroid/Debris, Radiation, and Thermal Protection

Figure 2.1-4

Courtesy of Martin Marietta

fittings. A series of additional rings supports the pressure shell, and longitudinal stiffeners connect the individual rings. Multi-layer insulation, and mylar/kevlar meteoroid shielding are formed over the surface of this pressure shell. Finally, two .02 in 6061-T6 aluminum micro-meteoroid shields cover the outside of the insulation(see figure 2.1-4). These shields are spaced 1 in apart, and are formed in separate sections for ease of replaceability. EVA handholds will exist on these modules.

At the point where the crosspieces pierce the pressure shell, a hatch exists to maintain module integrity in case of a cross piece failure. The extension of the XP extends to the floor of the module in order to distribute the spin loads to the internal instrument framework. This area is also stiffened to ensure fatigue failures do not occur in the 30 year lifetime.

The .188 in pressure shell can easily withstand 15 psi and the framework will absorb the spin stresses, but radiation effects can be excessive with just this arrangement. Typically, 75 Rem is the whole body limit for one year of exposure. For a 180 day stay, an astronaut must receive less than 38 Rem. With the existing shielding on the HAB/LAB modules(a 2 g/cm^2 equivalent), an astronaut would be exposed to 75 Rem in 180 days. Increasing this cross-sectional density to approximately 5 g/cm^2 decreases exposure to 32 Rem per year, and allows for multi-year missions. This increase will be achieved by integrating the Thermal Control System(TCS), with the radiation shielding. Water w... ...rry heat away from the sun... side of SAGE, reradiate the h... darkside, and offer radiation protection since H a... ...rate high energy particles very well.

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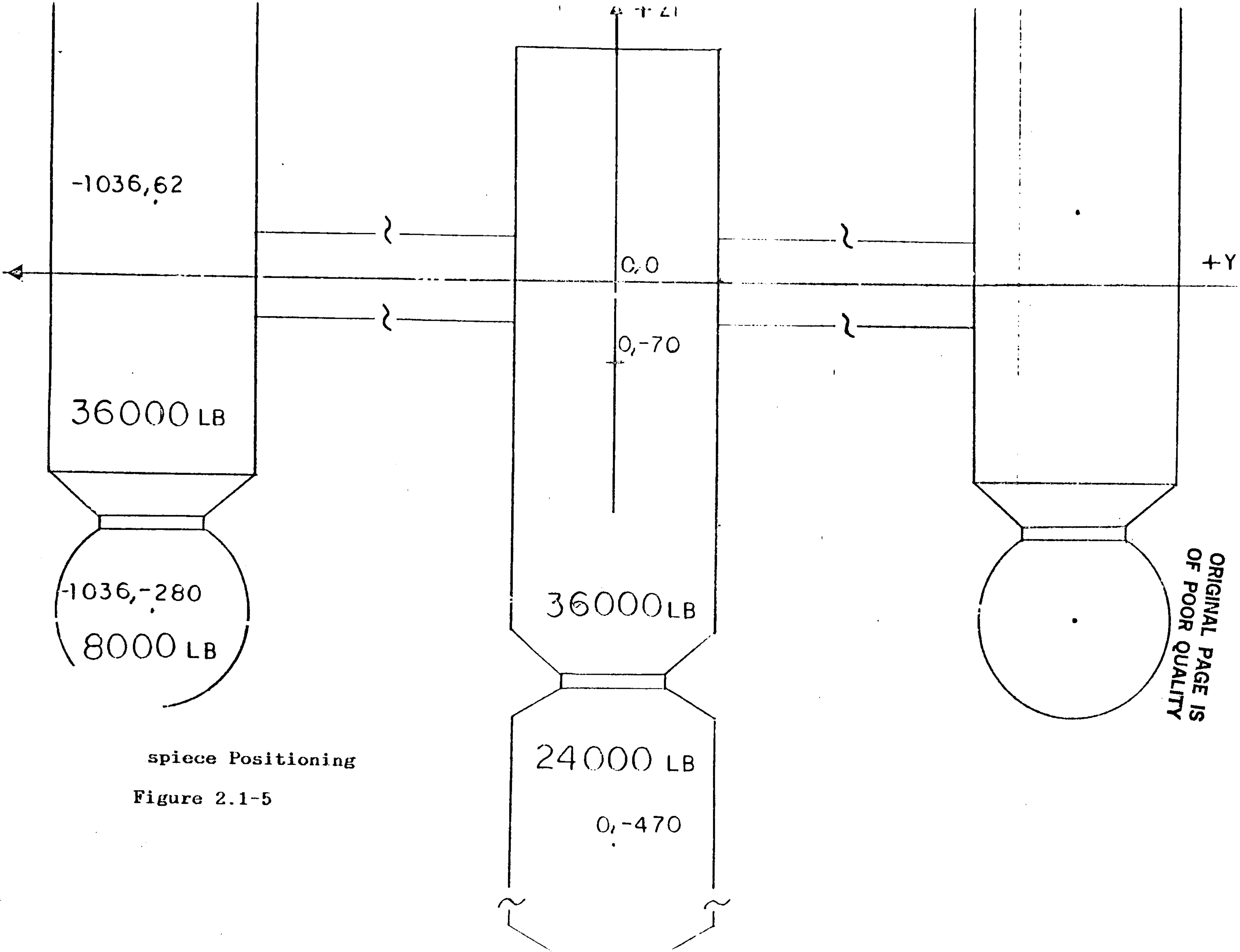
The double micrometeoroid shields, kevlar/mylar insulation, and pressure shell are estimated to prevent a pressure shell puncture, by up to a 1 g meteorite, with a 95% probability over 15 years. The first shell serves to break up the micrometeor, while the second absorbs any residual energy. These shields are replaceable on orbit.

2.2 Core Module

The CM will be constructed similarily to the HAB/LAB modules. Its stucture will not absorb any spin stresses since the internal crosspiece adaptors will transmit the axial stress to the opposing crosspiece. To enter the CM, a single hatch in the center of this internal XP adaptor must be opened. This reduces the required hatches from four to one, and maintains all forces along the cross pieces. The crosspieces enter the CM near the top of its closed end in order to provide clearance for orbiter berthing when SAGE is spinning.

2.3 LOG Module

The LOG module will be attached to the bottom of the CM(see figure 2.1-5). It will be constructed similarily to the HAB/LAB modules, but will not normally be occupied. It will serve as supply storage. At the STS berthing portion of the LOG module, an ai separate from the docking port will exit from the side of th le in order to provide EVA capability when the orbiter i . This



spiece Positioning

Figure 2.1-5

airlock will also serve as a hyperbaric chamber which can be pressurized to 5 atm, in case bends occurs in the lower pressure EVA suit. Control stations for orbiter berthing with portholes will exist in the LOG module to facilitate orbiter docking, and the teleoperator arms will have their primary controls housed here. The other docking port will consist of a despinning mechanism. This mechanism will rotate the LOG module at speeds up to 4.7 rpm. The atmosphere leakage will be kept to a minimum by pressurized, rotating seals. When the orbiter berths, the LOG module will be despun for the entire visit.

The docking adaptor on the LOG module will be a passive berthing adaptor(see figure 2.3-1). The MSC arms will berth the orbiter, and no impact energy needs to be absorbed. This will not disturb spin dynamics or cause unnecessary wear on the despin mechanism.

2.4 Crosspieces

These members absorb the spin stresses and motion dynamics due to thruster firings, and must be built to exacting tolerances and specifications(see figure 2.4-1). Each XP has a 38 ft length, 65 in inside diameter, and 75 inch outside diameter. These crosspieces have a similar structure as the HAB/LAB modules--a .25 in pressure shell(welded in cylindrical sections), longitudinal and hoop stiffeners, and double .02 in meteoroid shields. Additionally, each crosspiece will have a rail upon which the MSC can move from the LOG module to a node. Figure 2.1-5 shows the relative [illegible]on of the crosspieces to the LAB modules. This offset was r[illegible] to balance out moments caused by the nodes. Since th[illegible]ers form

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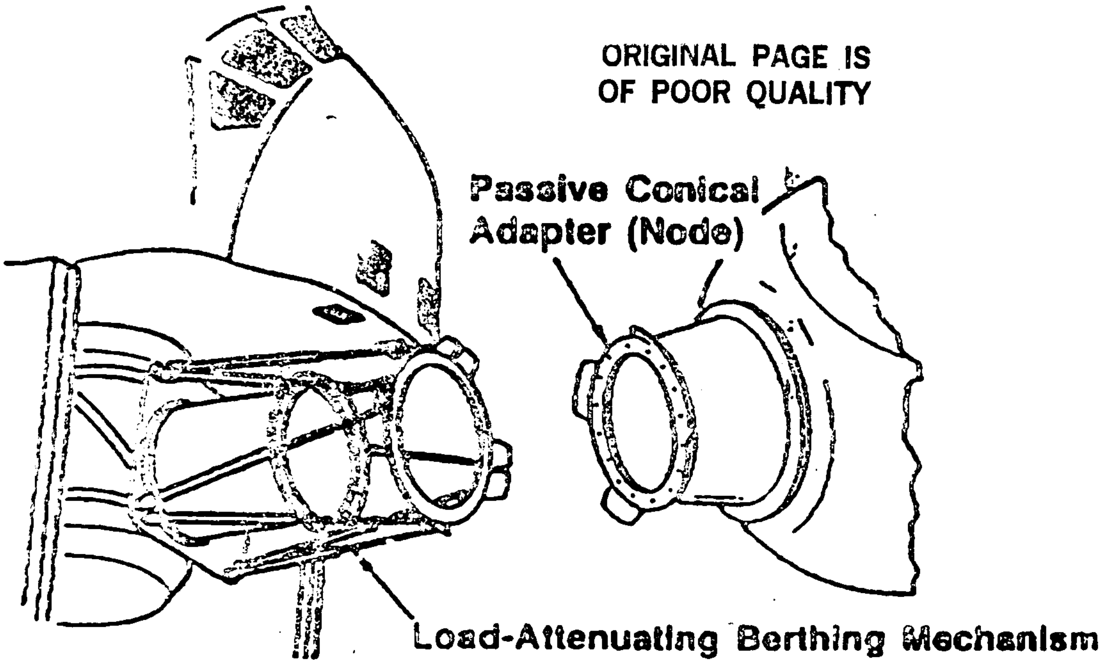

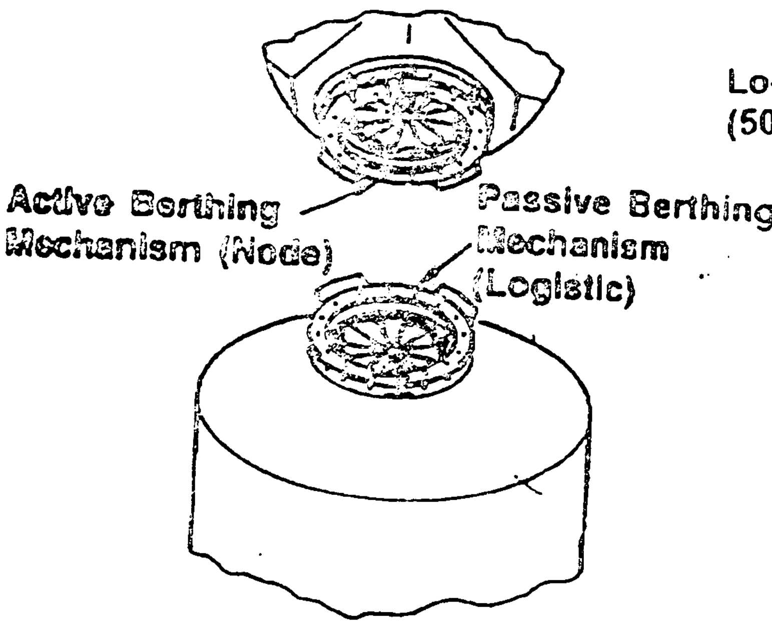

Logistic Module Berthing System
(50-Inch Square Hatch)

Berthing System

Figure 2.3-1

Courtesy of McDonnell Douglas Corp.

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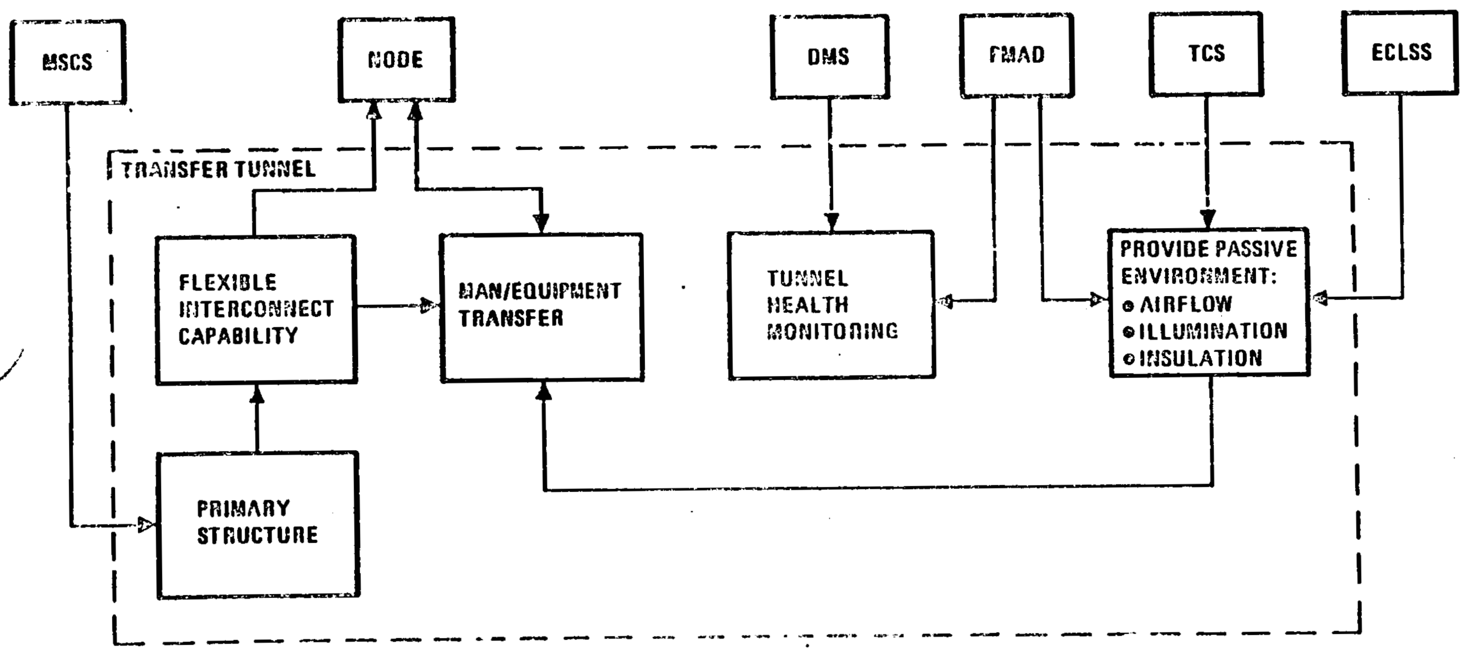

Crosspiece Schematics

Figure 2.4-1

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ourtesy of Rockwell International

the interface between the modules, gas, fluid, electrical, and fiber optic piping run outside their pressure shells. Twelve evenly spaced stiffeners with an area of 3 in^2 provide primary longitudinal support by forming the connections between the crosspieces themselves, and the adaptors in the modules. During on orbit construction, two crosspieces will slide approximately 20 in into each other and pins will join the longitudinal beams. With IVA, bolts will be tightened on the pressure seal, designed to work in spin and no spin conditions. This joint is critical because it can not transmit stresses to the XP pressure shell. The seal is designed to allow for play in all directions, without incurring significant leakage. The longitudinal stiffeners are designed for low elongation over the 30 year lifetime;therefore, this joint must absorb any possible damaging stresses from thruster operation. Hazardous materials must run outside the pressure shell, but the ECLSS can be contained internally. All piping and hoses will be self-sealing, have periodic quick-disconnects, and the seals between the piping at the oint must be available for maintenance during operation. Internally, each crosspiece will have a ladder in the pro and anti spin direction for up and down traffic. A manual elevator running along the ladder rails will also be provided for transport of equipment racks. The 65 in internal diameter allows a standard rack to undergo a 90 degree turn.

2.5 Nodes

At the bottom of each HAB/LAB module, will be a per ly docked storage node. Each node is an 81 in diameter weld with six berthing ports attached at 90 degree positions. I ave

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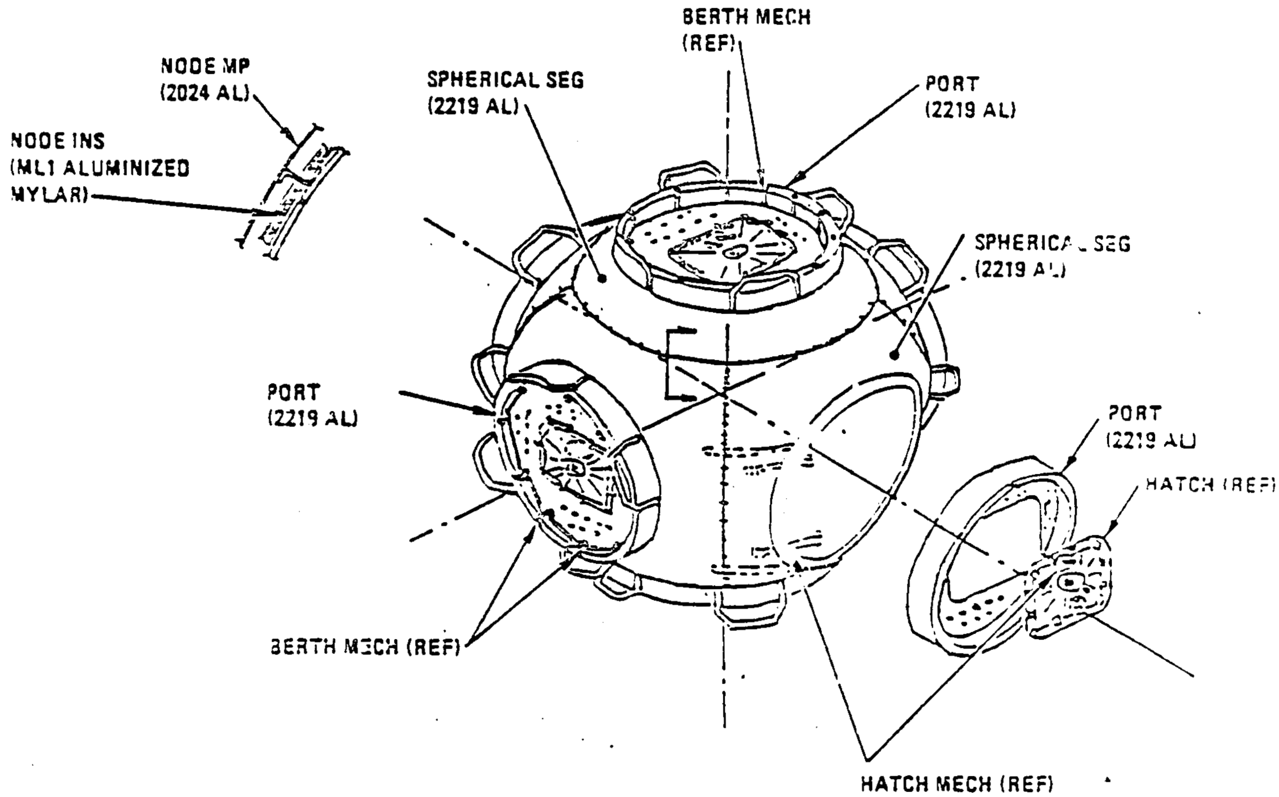

Node Showing Segments and Materials

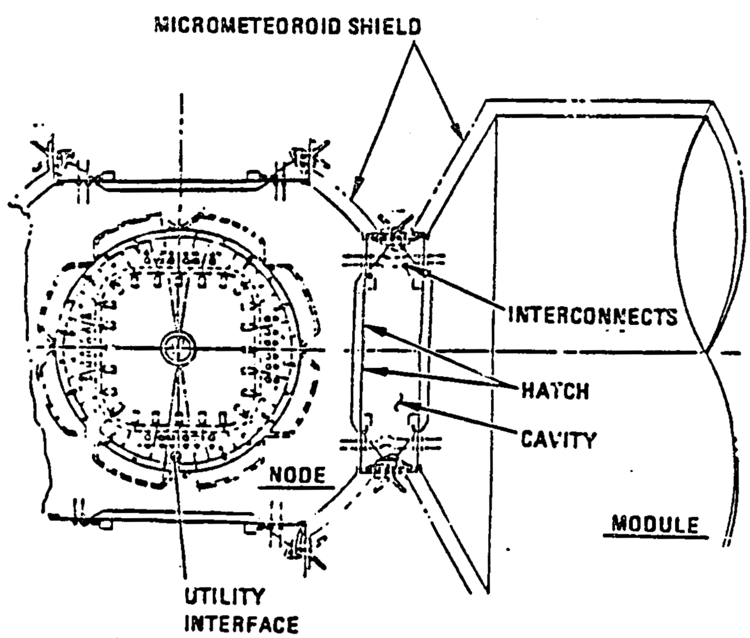

Figure 2.5-1

Utilities Interconnect

Courtesy of Rockwell International

standard 50 in hatches and internal utility connections. The pressure shell will be .18 in thick, and the single meteoroid shield will be .03 in thick, with insulation in between. The nodes will have external supports for EVA and changeout.

2.6 Robotics

Under each crosspiece, a Mobile Service Center(MSC) teleoperated arm will be used for supply transport, EVA support, and berthing assist. The entire arm assembly(see figure 2.6-1)will move along rails on the crosspieces. Only the main MSC with two arms as seen in the figure, and the secondary MSC with one long arm will be used for orbiter berthing. The other two will have shorter arms for EVA support and node transfer. The primary and secondary MSC's will have a reach of 65 ft in order to grab the orbiter well before misalignment could cause a collision and to transfer stores to the two smaller arms directly from the orbiter bay. After the orbiter has been berthed, the arms will transfer supplies, and exchange nodes and propulsion packets. Several end piece adaptors will exist to alow the arms to handle a variety of cargo, including an attachment for moving an EVA astronaut around the SAGE structure to do maintenance. Finally, the each MSC can be moved in and out on a crosspiece to compensate for mass inbalances.

2.7 Trusses

Between each HAB/LAB module, triangular space frame [illegible]es will provide structural support to the crosspieces duri[illegible] and despin, by balancing thruster torques. They are s[illegible]

Mobile Service Center

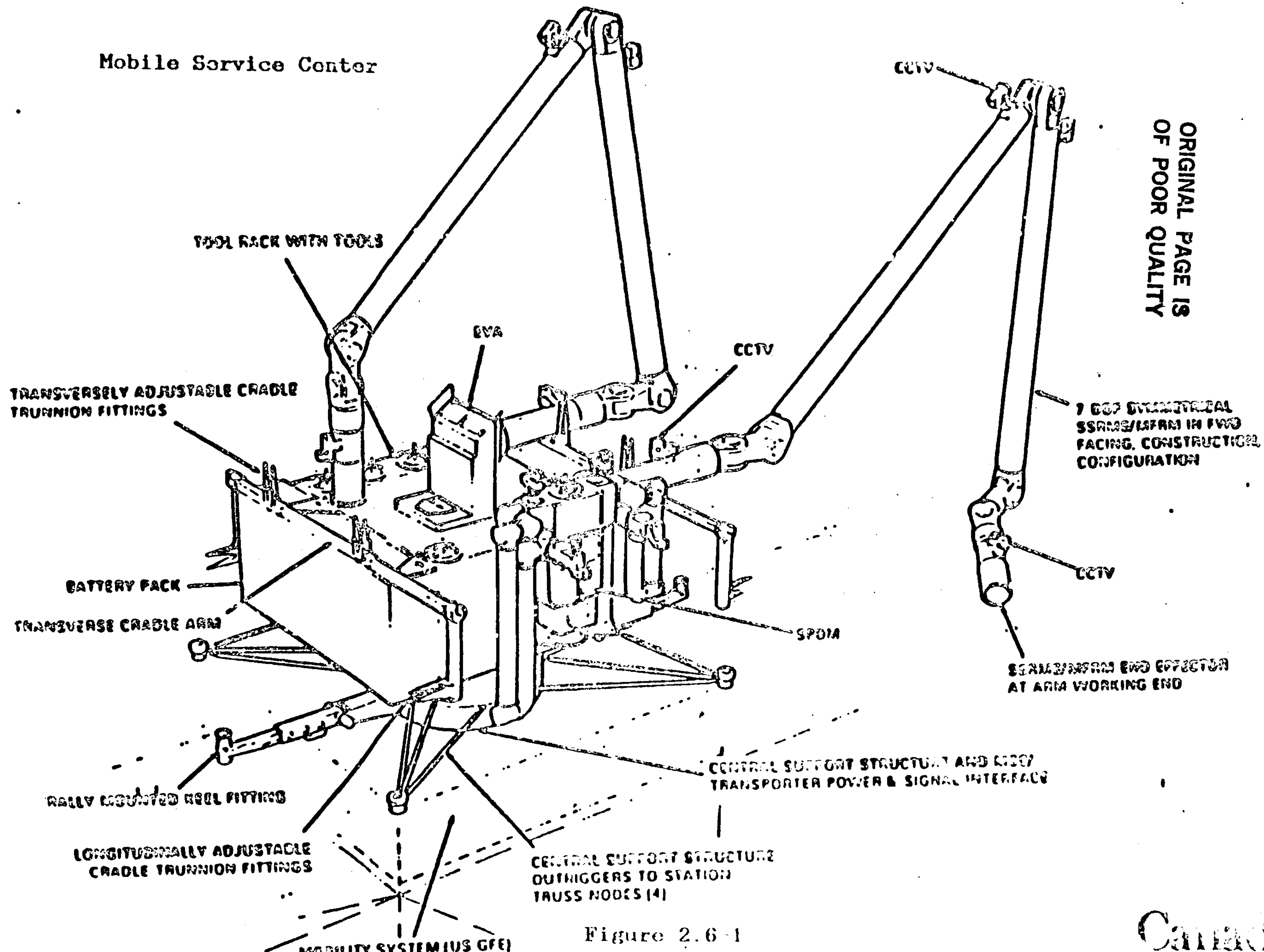

Figure 2.6-1

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Canada

Courtesy of NASA

lightweight, and easily constructed by EVA(see figure 2.7-1). Each box is 38 in long, forming an equilateral triangle with a 20 in side. The end pieces are made from aluminum while each member is composed of graphite. Initially, they will be attached to the modules at the crosspiece interface, but provisions will be made to have attachment points on either ends of the modules if needed. These frames will also house the magnetic coils for pitch control.

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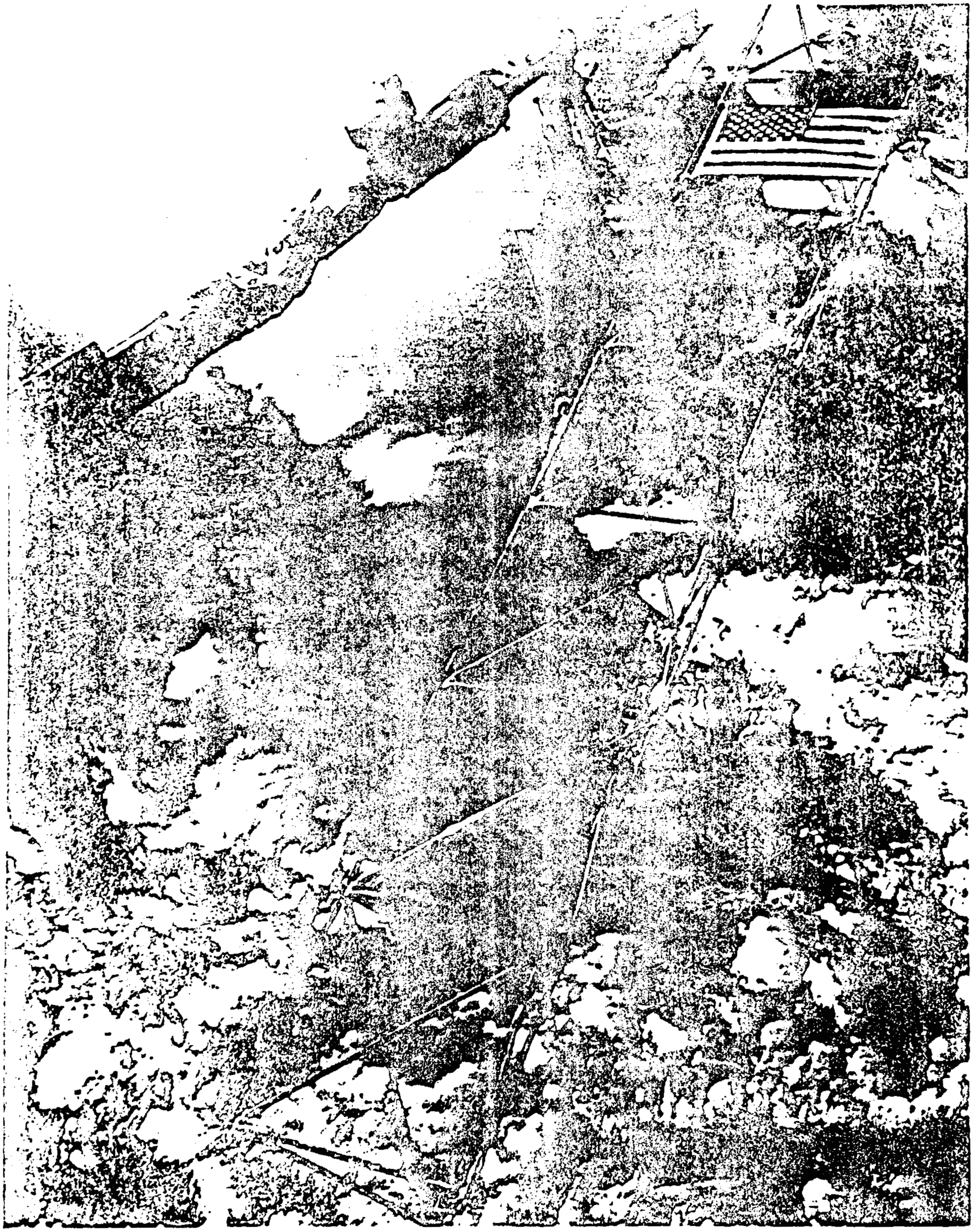

Truss Structure

Figure 2.7-1

Courtesy of NASA

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[illegible]
MARZEC
PIGNATARO
SEIBERT
WALKER

SAGE Power Systems

CONTENTS

FIGURES

3.0 Power Systems

The SAGE design holds, as a primary objective, compatibility with the Space Station presently being developed by NASA. The reason for this has been that the use of compatible systems is expected to reduce research and development costs for SAGE. An equally important reason for using such compatible systems is the simplification and economization of the stocking of spares, which will make possible the sharing of common spares between Space Station and SAGE. The sharing of spares also makes possible the cannibalization of one platform to save the other in the event of catastrophic, life-threatening failure of a system. Cannibalization of this sort would, of course, only be performed if such action did not threaten the cannibalized platform, and only if absolutely necessary.

The Space Station power system design, although not complete nor thoroughly specified in every detail, has progressed quite far. Through contracts and subcontracts to various aerospace firms, the Space Station Work Package Four (WP-04), has been used to first narrow, then begin the specification of the design. One of the first options to be discarded was the S-100, and all other radioactive power generation methods. The problems, which are also bars to use aboard SAGE, include the necessity of shielding or separating the radioactive source from the living quarters. The weight of shielding and the difficulties of placing the reactor on a boom while maintaining repair capability si[illegible]y limited.

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usefulness. The deciding factor was that, in light of the dangers of accidental reentry from low Earth orbit, and the undependable record of U.S. launches in recent history, political pressures would prevent the appropriation of funds to develop such a design.

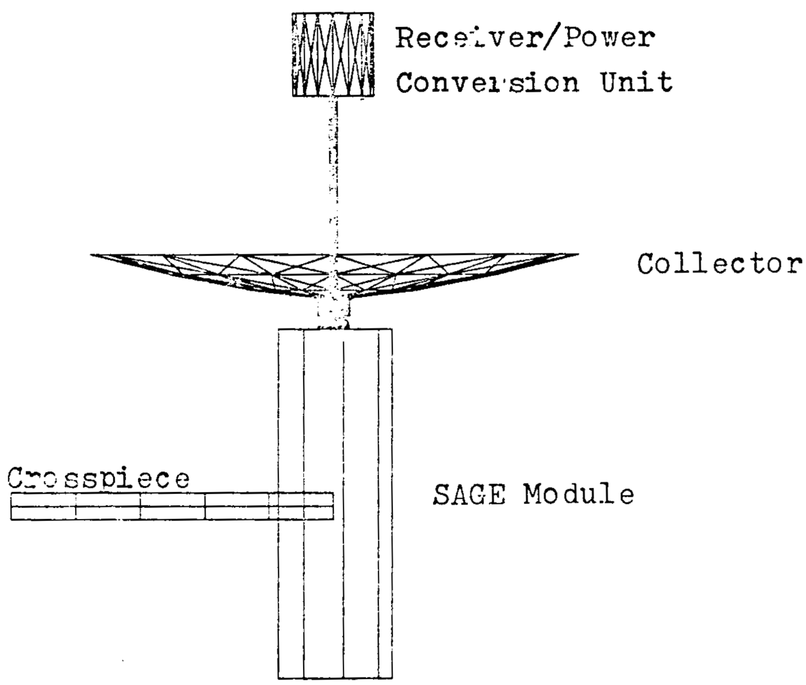
The next power system concept to be explored was solar power. Solar power has several strong advantages and several limitations. The primary advantage of photovoltaic systems is that the technology has been thoroughly tested and is therefore highly reliable and presents no design obstacles of major proportions. Additionally, solar power systems require no consumable fuels. The limitations of photovoltaics are primarily a result of their low efficiencies. Photovoltaic power generation schemes can achieve efficiencies of only 11% to 16%. The result of this is that with the solar constant a mere $1353 mW/m^2$, the required area of photovoltaic cells to generate large power supplies is approximately $24.77 m^2$ per kilowatt. This means $1362.6 m^2$ for 55kWe, which would induce unacceptable atmospheric drag forces. The cost of drag make up would be so high as to suggest exploration of other power generation schemes. Further limitations include plasma effects which limit the maximum voltage to about 200V, and atomic oxygen degradation of solar cell arrays and connections. Gallium Arsenide wafers have been suggested as a substitute for the typical Silicon Dioxide wafers, due to their higher efficiency, but their cost is prohibitively high.

The result of these problems has been a search for a solar power system which has a low specific area, reasonably low cost, Space Station compatibility, and two other factors which are of particular importance to SAGE. The first factor is that, since SAGE will be a man-rated platform, the power system must be highly reliable. This will be achieved through redundancy and simplicity of repair. The second factor is that, because SAGE will generate a gravity of up to 0.7g(during testing). the power system must be of low weight to lessen the bending and vibration of the crosspieces. These many considerations have been synthesized into the very promising power system design which we have developed.

3.1 Primary Power Generation

The power generation problem received a great deal of attention with a quite exciting result. The many problems of radioactive and photovoltaic power generation schemes lead to the exploration of solar dynamics as a method of power generation. Solar dynamics is the concept of using either a large parabolic reflecting surface or a large Fresnel lense to collect and focus the Sun's rays onto the lense of a receiver. See Figure 3.1-1, which illustrates the concept of solar dynamics in the form of a solar dynamics system mounted on one SAGE module. Acting as a black body, the receiver absorbs the thermal energy from the Sun's rays and uses this to heat a working substanc enon

Figure 3.1-1 Conceptual Solar Dynamics Generation



mixture @MW=40)[1] to 1034K and uses it to drive a turbine which then drives an alternator. Solar dynamic systems offer power generation efficiencies of 18% to 30% and the possibility of thermal energy storage, which will be discussed in the next section. The second and perhaps most important advantage of solar dynamics over photovoltaics is a 50% reduction in surface area for a given power requirement.[2] The difficulty lies in that solar dynamics have not yet flown in space and the [illegible] ground based prototypes will be extensive. Fortunately, solar dynamics, due to its promise, has been chosen as part of the [illegible] (solar dynamic and photovoltaic) power system being designed for Space Station. This is fortunate because the costs of R&D for solar dynamics will be borne by Space Station, not SAGE, and the SAGE power modules will be almost identical to those on Space Station.

The SAGE design was found to require 55kWe of electrical power in order to supply all its loads Figure 3.1-2 enumerates those loads. In order to achieve this with high reliability, the power system was designed to employ two 25kWe power modules and a 5kWe photovoltaic system. These are best illustrated by the SAGE model. The Primary Power Generation system provides only the 50kWe of power from the two solar dynamics power modules. Each module will consist of the collector and receiver units mounted together and rigidly attached to the top of a SAGE module. The desire for simplicity has led to the removal of Space Station's

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Figure 3.1-2 SAGE Power Budget

Item or System	Power (Watts)
Module Structure (5X30000)	0
Crosspiece Structure (4X6167.2)	0
Waste Management	184.0
Water Recovery & Management	447.2
Fire Detection & Suppression	109.4
Atmosphere Control & Supply	212.1
Temperature & Humidity Control	1428.0
Atmosphere Revitalization	2360.0
Laundry, Showers, Handwashers	183.6
Cooking, Refrigerator, Freezer	1500.0
Miscellaneous Lights, Tools, Heaters	5500.0
Module Instruments & Controls	13200.0
Life Sciences Lab	9000.0
Science Payloads (3 max.)	15000.0
Communications & Tracking	6800.0
Photovoltaic Arrays	0
Solar Dynamics	0
Batteries	0
Power Distribution (95% eff.)	2750.0
Attitude, Spin, and Orbit Control	3000.0
Thermal Control	?
Totals Of Known Data	61674.3 Watts
Total Emergency Loads	7500.0 Watts

Note that power requirements will be lessened to 55kWe through power management techniques. This 12% reduction in power demand will be eased during those periods of operation in which the solar dynamics performance is above the nominal level of 25kWe each. Power management techniques will also be used to lessen emergency loads (7.5kWe) by 33%, to 5kWe. The emergency power requirement is based on minimal life support, thermal, and attitude control needs. These loads need not be operated all at the same time.

preferred aimability of the power modules in favor of solar pointing the entire SAGE spacecraft, to avoid [illegible] complexity of the aiming equipment. The [illegible] of processing the spacecraft one degree per day is well [illegible] SAGE capabilities. These requirements were met and many others [illegible] introduced in the sections discussing the equipment which [illegible]

The largest components of the primary power generation system are the collectors. Each collector is, in effect, a parabolic mirror with a diameter of 57.1 feet or 17.[illegible], as shown in the Power Appendix, accounts for the shadowing of the collector surface by the receiver/power conversion unit while maintaining the same effective projected area as the Space Station design for a nominal power production of 25 [illegible] per power module. The necessity to account for the shadowing [illegible] decision that SAGE, in order to simplify the design, will not be using the offset Newtonian reflector chosen [illegible] Space Station. The SAGE collector configuration is demonstrated in Figure 3.1-3. The simple parabolic surface of each collector will be made up of twenty-one hexagonal mirrors, each of which has been formed to the specific shape of its assigned portion of the parabola.[3] The hexagonal mirror sections will be made up of glass, backed by a reflective coating of Magnesium flouride, Alumina, and Silver.[4] The two layers will then be epoxied to a rigid substrate as shown in Figure 3.1-4.[5]

Figure 3.1-3 SAGE Solar Collectors (Topview)

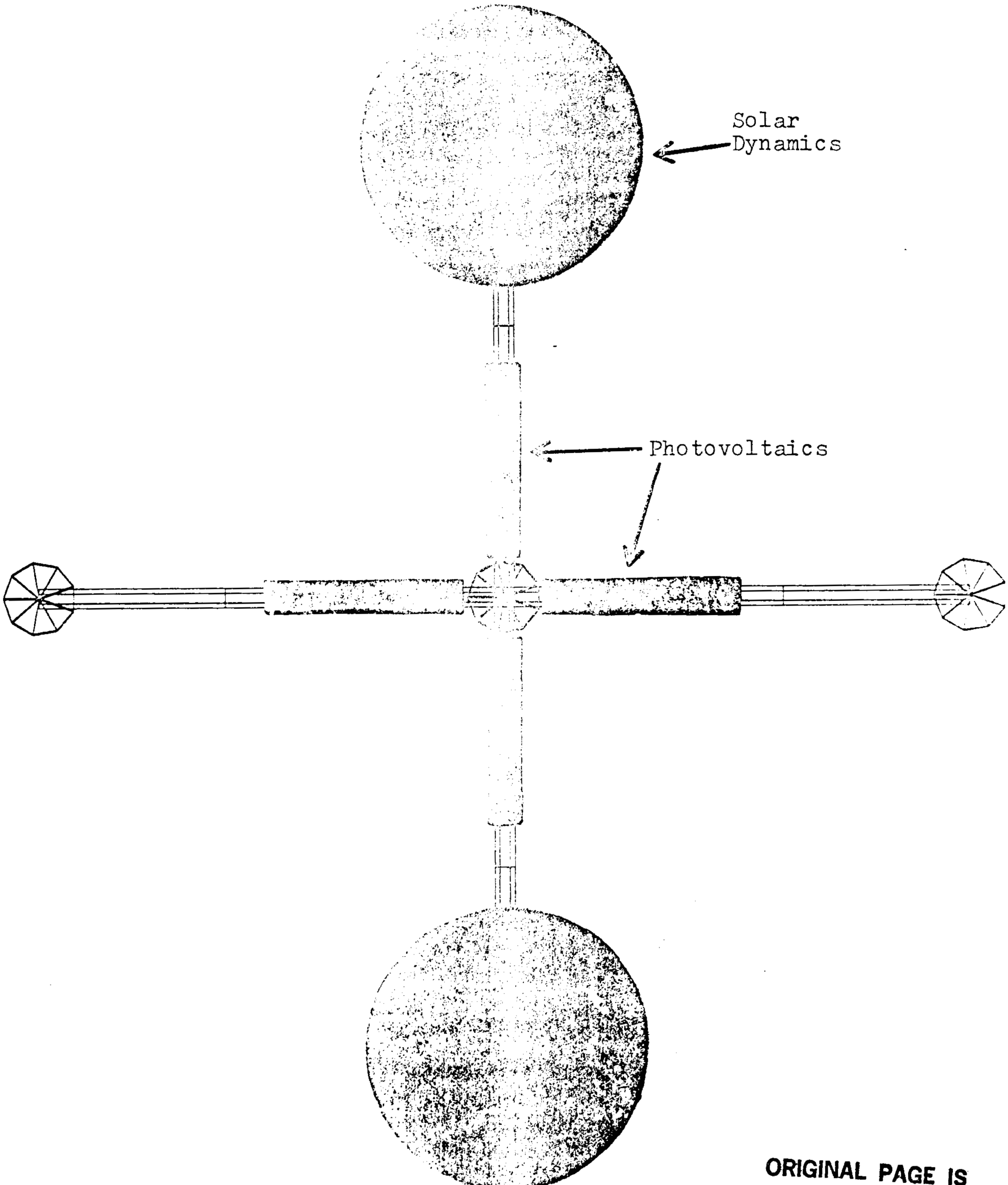

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Figure 3.1-4 SAGE Reflector Design

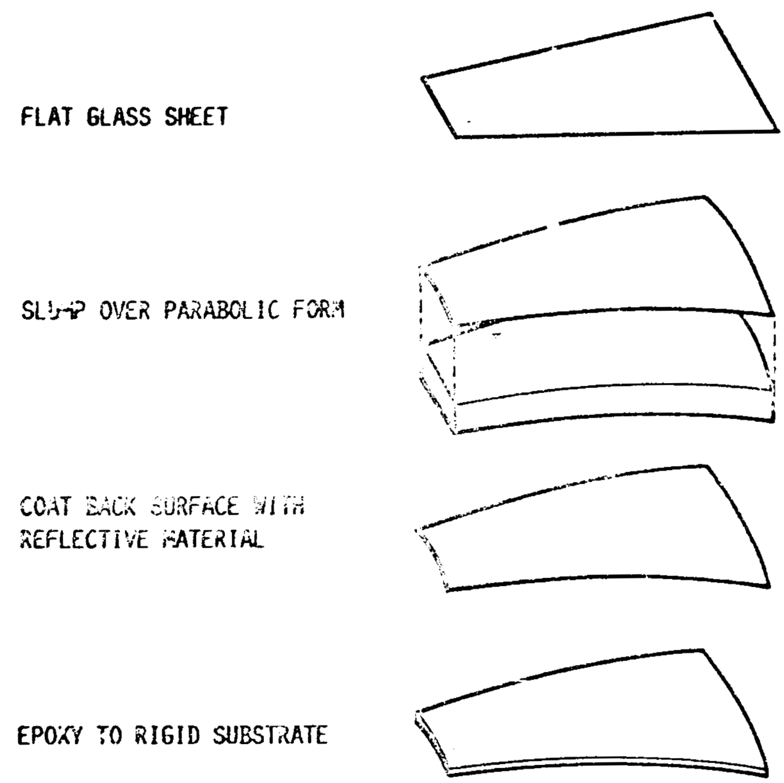

FIGURE 18.- FABRICATION OF MICRO SHEET GLASS REFLECTIVE SURFACE. Copied from NASA TM 88884

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The collectors will each be supported by a box truss which will provide the structural integrity necessary to maintain the required microradian slope tolerances and to prevent structural failures from excessive bending and vibration of the collector. The design of the support trusses is detailed in Figure 3.1-5.

The receiver/power conversion unit (R/PCU) is located at the focus of, and in coaxial allignment with, the collector. The design of the R/PCU is dependent upon the thermodynamic cycle selection. The cycle chosen for SAGE was the Brayton cycle, which, with its 1034K maximum cycle temperature, offers Sun-to-bus efficiency of 20.8%.[6] The Brayton cycle efficiency is higher than the other option, the Rankine cycle. This fact was the deciding element in the cycle selection. Figure 3.1-6 shows the components of a Brayton cycle. The outward appearance and dimensions of the R/PCU are shown in Figure 3.1-7.[7] The receiver is an assembly consisting of a high temperature rated lense which allows the insolation to heat a working fluid contained within the receiver. The working fluid for this design is a MW = 40 mixture of Helium and Xenon.[8] The working fluid serves to transport heat around the thermodynamic cycle, and to charge the thermal energy storage system, which will be discussed in the next section. The working fluid evaporates and expands through a turbine which drives the shaft of the alternator to generate electrical power.

Figure 3.1-5 SAGE Solar Power Generation (Side-view)

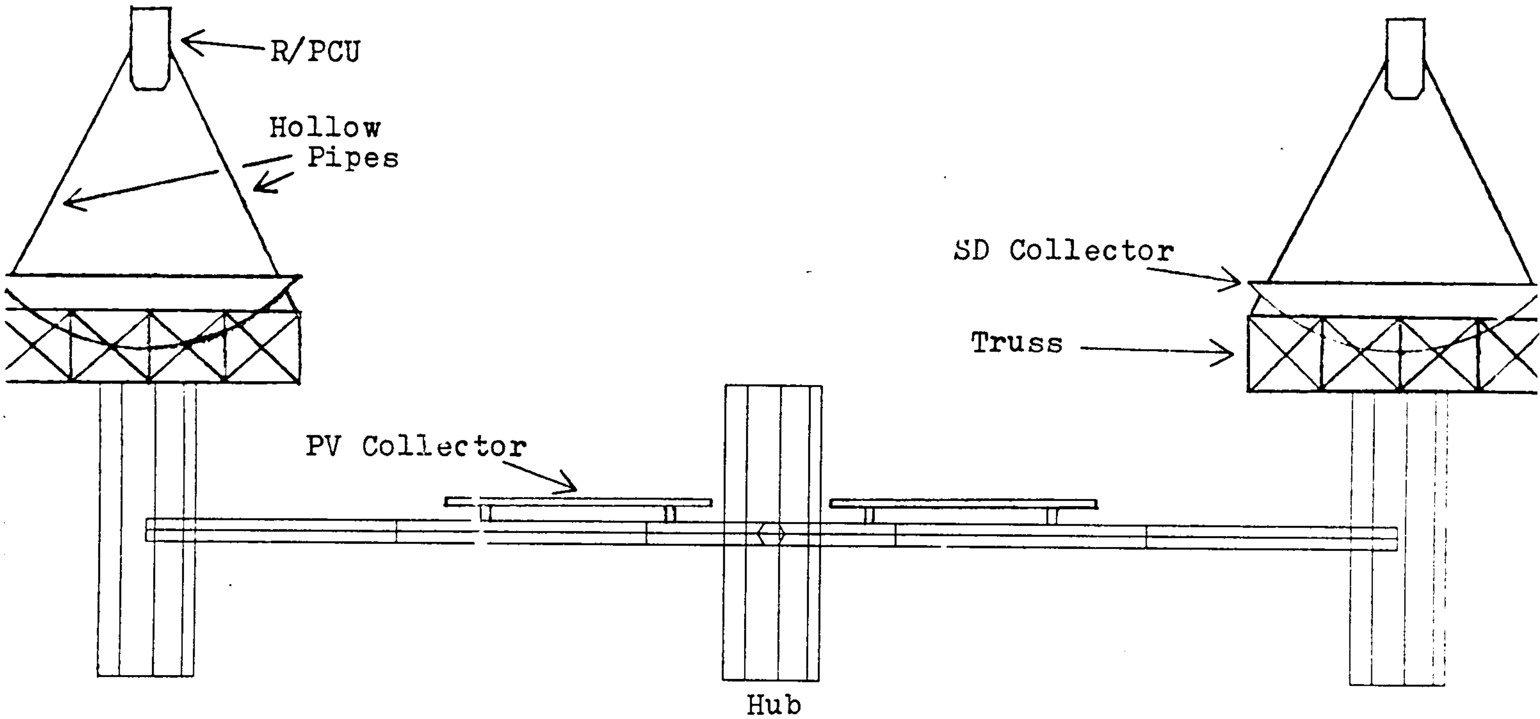

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FIGURE 3.1-6 SAGE BRAYTON CYCLE R/PCU COMPONENTS

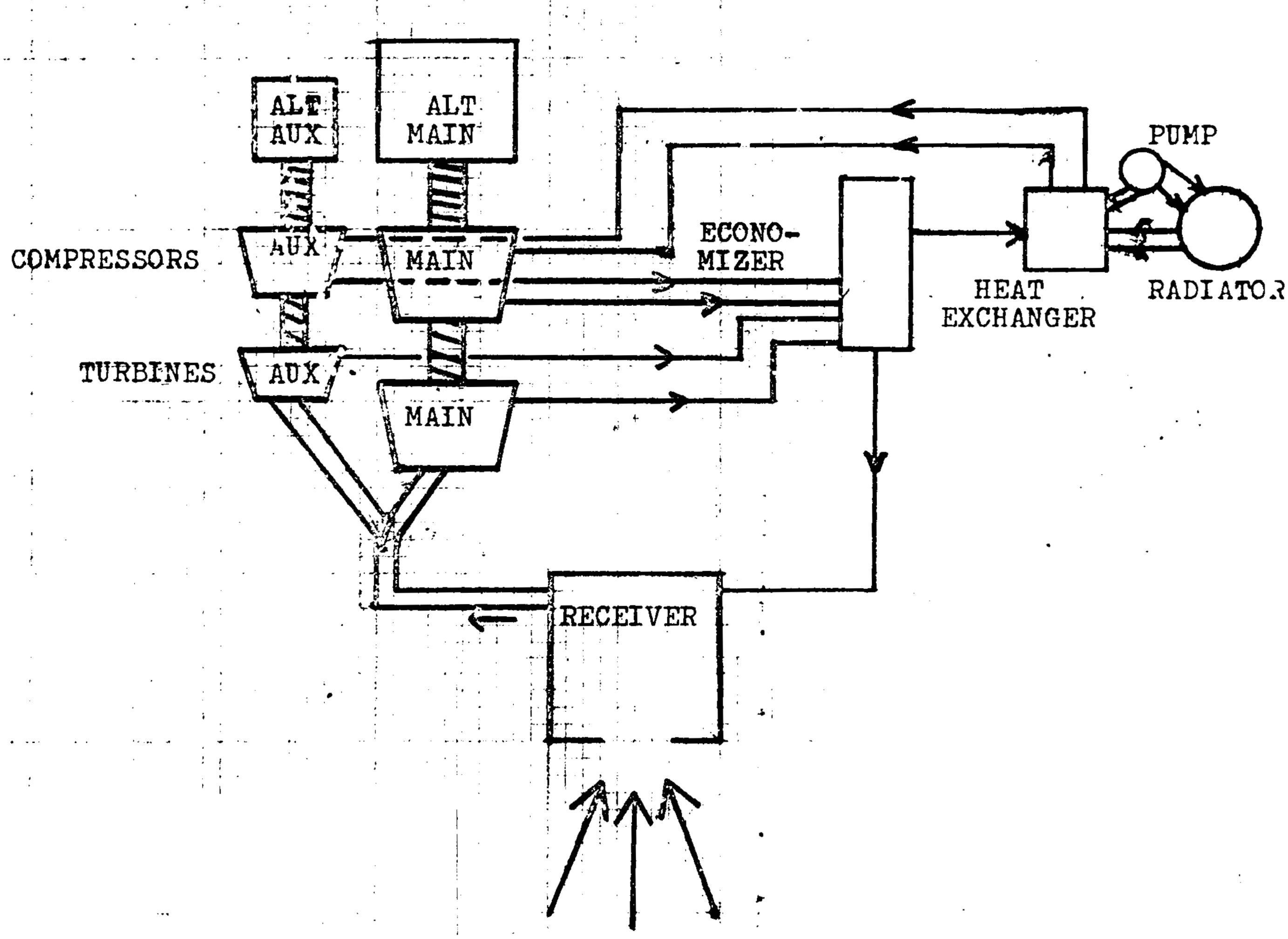

Figure 3.1-7 Receiver/PCU Concept

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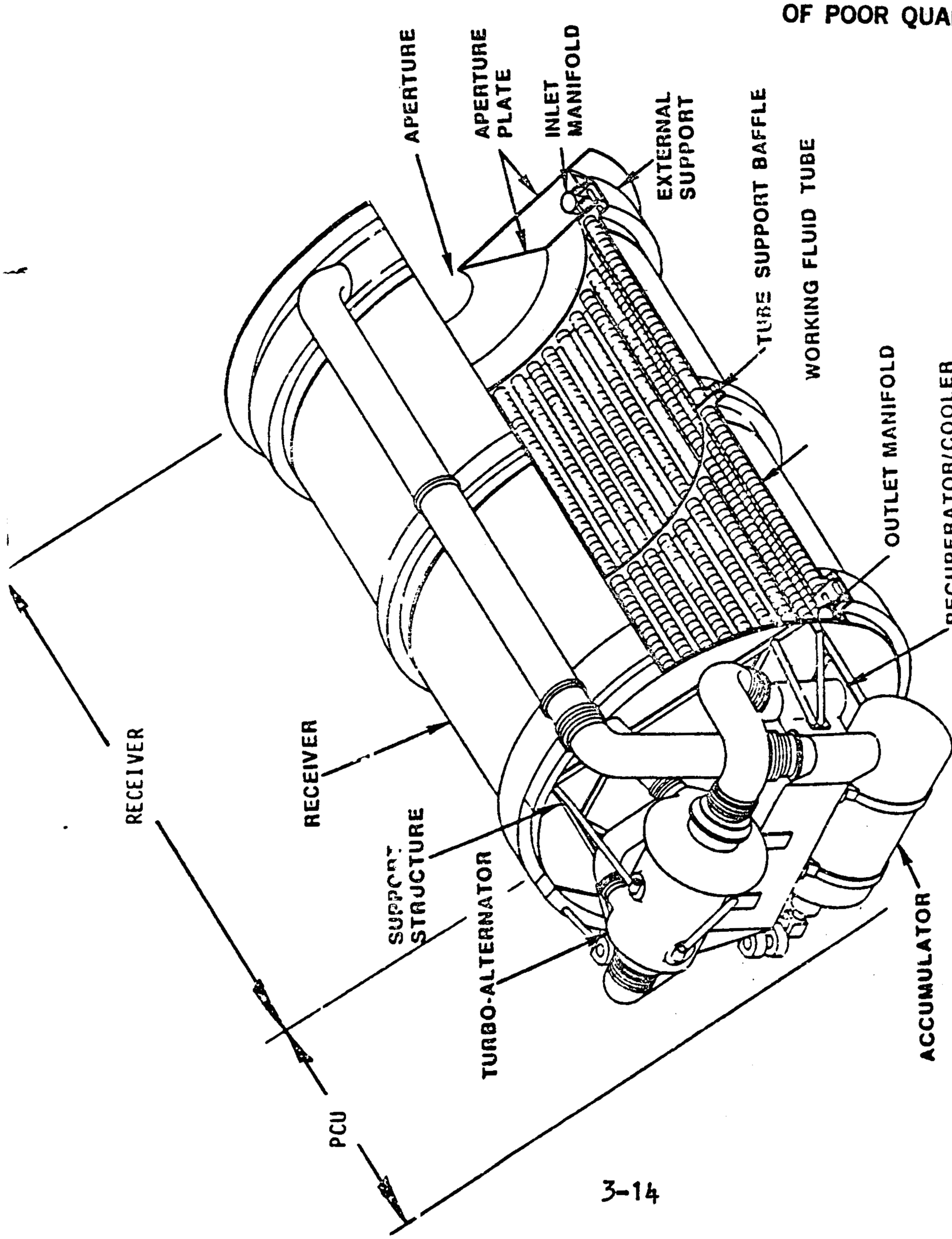

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The next requirement of the thermodynamic cycle is the rejection of excess heat to space in order to maintain high cycle efficiency. SAGE will employ circular radiators, which will be located coaxially with, and in the shadow of, the collectors. The radiators will use an ammonia filled heat exchanger within the PCU to remove heat from the working fluid, pipe it through the hollow R/PCU supports, then reject it to space through the radiators, which will be coated with Z93 White Paint for high emissivity. Radiator and piping configuration is shown in Figure 3.1-5. The radiators will be mounted to the trusses of the collectors for support: expansion joints will be incorporated into the design to prevent excessive thermally induced shear forces on the mounting connections.

The Primary Power Generation System is quite intricate in its design and will require careful assembly in space to ensure optimum performance. The collector hexagons will be hinged and stacked in a deployable configuration. Upon rigidly mounting the stack to its assigned SAGE module, the collector will be deployed to its full dimensions. Following this, and prior to any spinning or orbital maneuvering, the support trusses and radiators will be assembled in place and rigidly connected to both the SAGE module and the collector's rigid substrate. The next step in the assembly is the addition of the R/PCU which will be supported by four slender, hollow poles which will provide structural support, conduit for heat transportation fluid(ammonia), and harness points for the electrical supply cables from the PCU to SAGE. A period of system tests and spin-testing up to 0.7g will prepare the system for its final certification for full capacity operation.

3.2 Primary Energy Storage

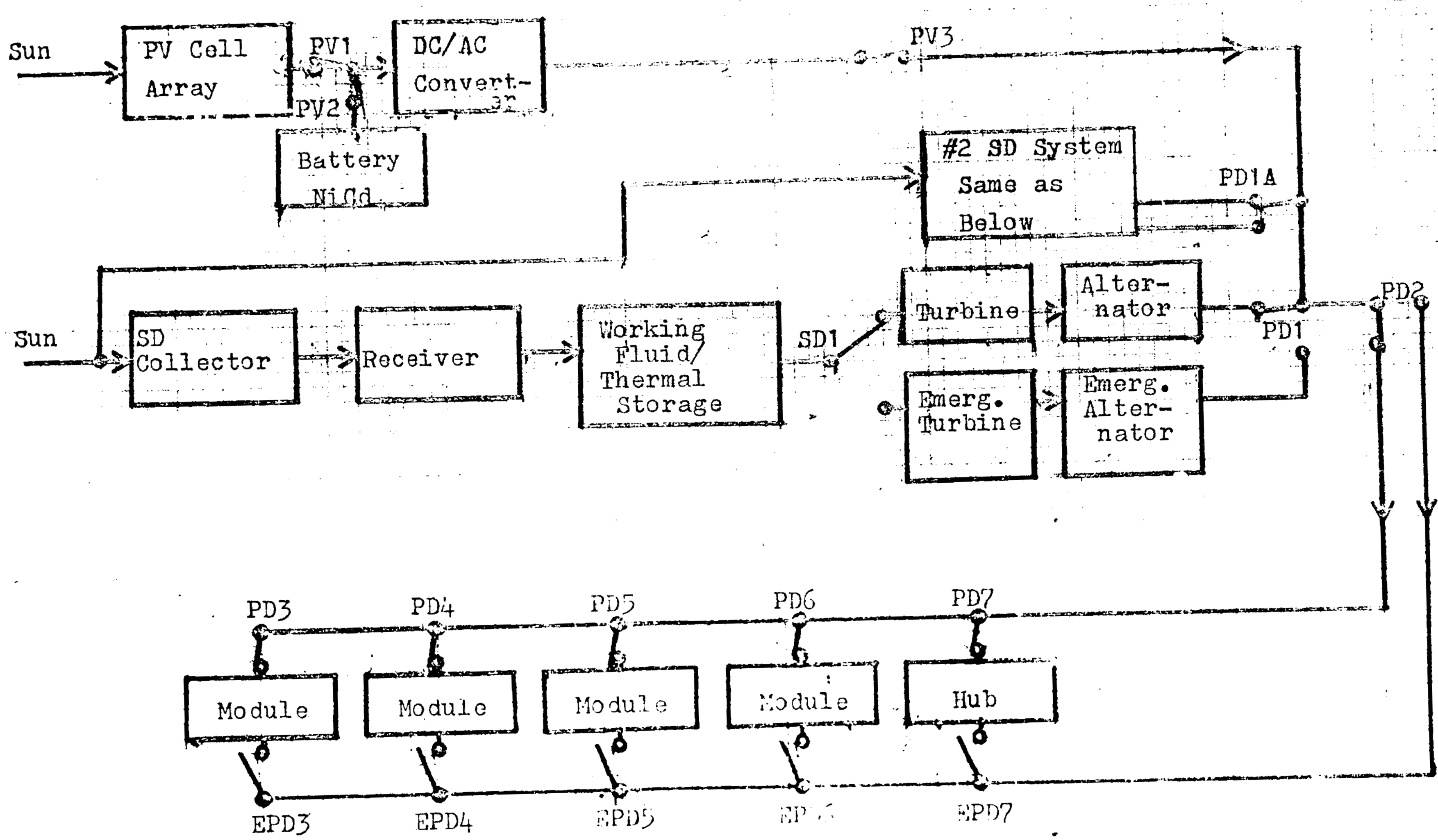
One of the most promising prospects introduced by solar dynamics was the concept of thermal energy storage. The advantage of this concept is that it promises storage efficiencies of up to 90% as compared to the 55% to 65% offered by battery storage systems. Fortunately, this concept has been found to be feasible. The thermal energy storage(TES) material is required to be a eutectic composition with its melting/solidifying temperature near 1034K. A mixture of Lithium flouride and Calcium diflouride was chosen for the job, and has been shown to work well in prototype TES systems.[9] Figure 3.1-7 shows the receiver, which contains the TES system. The TES material will be encased in ceramic or glass tubes which will be surrounded by the working fluid. The heat in the working fluid will melt the TES material. When SAGE enters the eclipse, the TES material will resolidify, giving off heat which will continue heating the working fluid throughout the 36.01 minutes of darkness.

3.3 Make-up and Emergency Power

The total power requirement of SAGE, as shown in Figure 3.1-2, is 55kWe. Obviously, the solar dynamics will provide, nominally, only 50kWe of that requirement. Furthermore, the emergency loads, amounting to 5kWe, must be supplied in the event of catastrophic failure of both solar dynamics systems. Although the actual power produced by each solar dynamics system is 26kWe to 30kWe, the desire for safety even under less than ideal conditions requires that the system be designed with the expectation of nominal power production. The result of the safety, reliability, and redundancy requirements for SAGE is a combination of photovoltaics, Nickel-Cadmium batteries, and slow bleed operation of the TES system. An important point to note is that, under nominal(55kWe) power production conditions, SAGE requires a 12% reduction in total power consumption through the use of power management techniques. Likewise, the emergency power requirements of 7.5kWe will be subject to 33% reduction through power management to decrease the requirement to 5kWe.

The three elements of the SAGE Make-up and Emergency Power system can be seen in Figure 3.3-1. This block diagram will be extremely useful throughout this and the following sections on power systems. The first two components, photovoltaics and batteries, are used for make-up of the extra 5kWe and for emergency supply of 5kWe. The photovoltaics will consist of four arrays situated on the solar-pointing sides of the crosspieces. Each array will be 40ft long by 6.39ft wide(12.2 meters by 1.95 meters) which w ide a steady power production of 5kWe while perpendicular t

Figure 3.3-1 SAGE Power System Block Diagram



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See the Power Appendix for calculations. The photovoltaics' lower sensitivity to pointing errors provides a degree of safety during emergency operation which is not present in the solar dynamics.

The batteries are NiCd, which provides a reliable and easily manufactured energy storage system. 176 cells, of 1.25V each, will be used to provide 220V output at 5kWe. The discharge will be limited to 25% during the 36.1 minute eclipse time, and the system capacity will be 60.12 Amp-hours at a maximum current of 25Amps. The batteries will be located in the central hub along with the DC/AC converter for both the photovoltaics and the batteries. The maximum duration of 5kWe production by the batteries, from a full charge, is 2 hours, 24 minutes. This is the emergency mode, which results in 100% discharge. All calculations are enclosed in the Power Appendix.

The third component is the slow bleed of the thermal energy storage system. The R/PCU will contain, in addition to the main turbine and alternator, an auxiliary turbine and alternator which will have a maximum output of 2.5kWe. The result of this will be a much slower solidification of the TES material, which will increase the length of time during which SAGE can provide its emergency loads of 5kWe. The two solar dynamics systems, each contributing 2.5kWe, will have approximately 10 times the normal eclipse duration because of the reduction to one-tenth of normal eclipse power production. The resulting duration is six hours, 1 minute. This calculation is shown in the Power Appendix. The batteries would be held in fully charged reserve during this time, and would be used after the exhaustion of the TES to extend the duration to 8hours, 25minutes. This is the maximum length of time, by a conservative estimate, that SAGE can be supplied with emergency power without any insolation. This could only happen in the event of either catastrophic destruction of all photovoltaic and solar dynamic systems, or the catastrophic failure of the attitude control system with SAGE pointed far off the Sun. The first scenario would almost certainly result in the destruction of the entire satellite, which would preclude the need for emergency power. The second scenario is very unlikely for this spin-stabilized spacecraft, and even in the event of its unlikely occurrence, the astronauts could manually operate the thruster valves to despin and then solar-point the spacecraft, thus restoring insolation.

Nearly any imaginable scenario can be handled by the combination of the solar dynamics, thermal energy storage, photovoltaics, and batteries. The section which follows, after explaining the Power Distribution system, will examine several emergency scenarios and the power switching necessary to control each situation.

3.4 Power Distribution

The power system, like all SAGE systems, is designed with a goal of Space Station compatibility. In addition, reliability, low cost, and low weight are major considerations. As a result of these design objectives, the power distribution chosen was the 400Hz, 208/220V, 3 phase distribution being considered for Space Station. The solar dynamics will generate this specified power directly, using the turbine-driven alternators. The photovoltaics and batteries will use a DC/AC converter to generate the desired power distribution. The conversion and transportation of this power is expected to experience 95% efficiency, which is typical. The costs of power distribution are considered to be components of the respective power generation systems' costs and are not listed separately in this design. Figure 3.3-1, the SAGE Power System Block Diagram, shows the major switches and the functional connections of the power system. The suffix "A" in the diagram refers to the components of the second solar dynamics power module. The "E" prefix refers to emergency distribution switches.

The block diagram is the ideal perspective from which to illustrate the normal operation and emergency response of the power system. All switches are operable both locally and remotely from any module. The normal distribution system(PD) has a completely redundant emergency back-up system(EPD). In addition, the entire distribution (PD,EPD) system can be supplemented by jump cables which can be used to replace any damaged section of distribution wiring. The PD and EPD switches allow the supply or isolation of any m - group of

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modules, and can be switched from within each module or remotely from any other module. PD1 and PD1A are the cut-outs for the solar dynamic power systems. PD2 is the PD/EPD distribution selector switch. PV1 is the photovoltaic array cut-out, and PV2 is the battery cut-out. PV3 is the emergency cut-out for both photovoltaics and batteries, used to prevent backflow of current from the solar dynamics when the aforementioned systems are not functioning. SD1 and SD1A(not shown) are the wye valves which are used to switch from the main to the auxiliary turbine and alternator.

Emergency scenarios can never provide for every contingency; thus it is crucial that the automatic switching be monitored, and perhaps corrected by the astronauts, when operating under unforeseen circumstances. The various scenarios foreseen, the changes from normal operation, and the power generation capability and duration are summarized in Figure 3.4-1.

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Figure 3.4-1 SAGE Emergency Power Distribution

Scenario	PV1	PV2	PV3	SD1	SD1A	PD1	PD1A	PD2	Power (kWe)	Duration (min)
	Main Switches									
1. Normal	1	1	1	M	M	M	M	M	55	unlimited
2. Main Dist. Failure	1	1	1	M	M	M	M	E	55	unlimited
3. PV Failure battery not needed	0	0	0	M	M	M	M	M	50	unlimited
4. PV Failure battery needed	0	1	1	M	M	M	M	M	55	144 then #3
5. Batt. Failure	1	0	1	M	M	M	M	M	55	until eclipse, then 50kWe
6. Single SD 100% failure	1	1	1	M/O	O/M	M/O	O/M	M	30	unlimited
7. Two SD 100% failure	1	1	1	O	O	O	O	M	5	unlimited
8. Attitude control failure 180 deg out from Sun	0	0,1	0,1	1	1	1	1	M	5	505

KEY

0= open circuit or off
1= closed circuit or on
M= main
A= auxiliary
E= emergency
,= left, then right

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3.5 Weight and Cost

The SAGE power system provides numerous services with wide latitude for the handling of contingencies. The power generation system provides a nominal 55kWe power to load, and an actual capacity of up to 65kWe. The energy storage systems provide that same 55kWe capability during 36.1 minute per orbit eclipses. The emergency power systems, in addition, provide for 5kWe emergency requirements for various durations, depending on the cause of the emergency. All this capability certainly does not come without its costs. These costs include weight and dollars, which are balanced by 57% lower 30 year lifecycle costs over entirely photovoltaic systems.[11] The weight and cost of SAGE power system components are summarized in Figure 3.5-1.

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Figure 3.5-1 SAGE Power System Weight and Cost Budget

Item or System	Weight(Lb)	Cost($ million)
Solar Dynamics	6264.2	800.0
Photovoltaics	2505.8	48.0
NiCd Batteries	1319.7	25.3
Totals	10089.7 Lb.	$873.3 million

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SAGE Power System Endnotes

[1]G.J. Hallinan, Space Station WP-04 Power System Final Study Report (Rocketdyne Division, Rockwell International, 1987), p. 2-17.

[2]Ibid., pp. all.

[3]Ibid., p. 2-32.

[4]Ibid., p. 2-17.

[5]NASA, Advanced Solar Dynamic Space Power Systems Perspectives, Requirements, and Technology Needs, (Cleveland, Ohio: Lewis Research Center, 1987), Figure 18 copied, all credit to NASA.

[6]Hallinan, p. 2-17.

[7]Ibid., p. 2-16.

[8]Ibid., p. 2-17.

[9]Ibid., p. 2-17.

[10]Ibid., p. 2-11.

[11]Ibid., p. 3-7.

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SAGE Power System Appendix

1.) Required Collector Area

Given: 56.8ft dia. Space Station SD collector and 67.8inch dia receiver/power conversion unit.

Find: Collector dia to allow for receiver shadow while maintaining same useful area.

Solution:

dia= 67.8inchesxft/12inches=5.65ft.

area= .25xPIx(dia)^2=.25xPIx(56.8ft^2 + 5.65ft^2)x (.3048m/ft)^2

= 237.7m^2

collector dia.=SQ Root(4xarea/PI)= 17.4 meters or 57.1 feet.

2.) PV Array sizing

Given: 5kWe req'd. PV requires 19m^2/kWe

Find: Array size to fit on crosspieces

Solution: 5kWex19m^2/kWe= 95m^2= 1022.6ft^2 = 4 each at 255.6ft^2
The resulting size is 40 ft long by 6.39 ft wide or 12.2 meters long by 1.95 meters wide.

3.) Emergency Power Duration

Given: Normal thermal energy storage operation is 50kWe for 36.1 minutes. Emergency power requirements are 5kWe. Batteries last 36.1 minutes when discharged to 25%.

Find: How long can 5kWe be generated with no input of solar energy?

Solution:

Battery: 36.1 minutes / 0.25 depth of discharge= 2hrs, 24min.

Thermal: 50kWex36.1 minutes per eclipse/5kWe= 6hrs, 1 min.

Total= Battery + Thermal= 8hrs, 25 minutes.

4.) Battery Design

Given: Eclipse time is 36.1 minutes (maximum). Batteries operate at 1.25V/cell when combined in series. Desired depth of discharge is 25%. Operating voltage is 220V. Power to load is 5kWe.

Find: Number of cells required.
Operating current for purely resistive load.
Capacity.

Solution: #cells= 220V/(1.25V/cell) = 176 cells
P=IV, I=P/V= 5500W/220V = 25A (5500W is the power produced)
Capacity, C= 25A x 36.1min x hr/60min x 1/25%depth
C=60.17Amp-Hours

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5.) Weight

Given: Batteries weigh 0.1Lb/Amp-hour/cell. Case weight is 20% of cell weight, and mounting plus instrumentation weight is estimated at 50 Lb for the batteries. From Walter Allen's notes.
Photovoltaic systems generate 4.40W/Kg.
Solar Dynamics generate 17.60W/Kg. PV and SD from NASA TM 88E34

Find: Weight of each component system.

Solution: Battery Weight, BW= (0.1Lb/A-H/Cell)x176 cells x 60.12A-H x (1+20%) + 50 Lb= 1319.7Lb
Photovoltaic weight, PVW= 5000W x 2.205Lb/Kg /(4.40W/Kg)
PVW= 2505.8Lb
Solar Dynamic weight, SDW= 50000W x 2.205Lb/Kg /(17.60W/Kg)
SDW= 6264.2Lb

6.) Cost

Given: 36.1 minute eclipse. 50kWe solar dynamics, 5kWe batteries and photovoltaics.

Find: Cost of each component.

Solution: At $1.2 billion per 75kWe, the 50 kWe SAGE solar dynamics will cost $1.2B 50/75= $0.8 billion. (#'s from Hallinan.)
At $1.1 billion per 75kWe, the 5 kWe SAGE photovoltaics with batteries will cost $73.3million.
Based on a simple weight ratio, for lack of better information, the battery cost was estimated as a component of photovoltaics' cost.
BC= Battery cost   PVC= Photovoltaic array costs

PVC+BC= $73.3E6   BC/PVC= 1319.7/2505.8

Solving both equations simultaneously gives the solutions:
BC=$25.3E6   PVC=$48.0E6

CRYPES
MARZEC
PIGNATARO
SEIBERT
WALKER

Communications

4.1 Summary:

The communications system of the SAGE space station adjunct will draw heavily upon existing technology used throughout the space station complex, the space shuttle systems, and the data handling capabilities of the Tactical Data Relay Satellite System, referred to throughout as TDRSS. Required capabilities include a space to space communication link, a space to ground link, internal audio and video systems, and access to TDRSS. For the purpose of orbit determination and tracking a Global Positioning System Link is planned.

4.2 Space to Ground Link

The principle communications link between space and ground will go through TDRSS, in conformity to the TDRSS Handbook. The design data rates and frequencies are listed in table 4.2.1.

Table 4.2.1

Space to Ground Data Rate and Frequencies

Ku-Band forward link (to SAGE):	12.5 Mbps at 13.775 Ghz
Ku-Band return link (to TDRSS):	300 Mbps at 15.0034 Ghz

The link budgets for the space to ground system are as indicated in tables 4.2.2 and 4.2.3. Information source was the TDRSS User's Guide, Sept. 1984.

Table 4.2.2

Forward Link Budget

1	TDRSS EIRP	46.5 dBW
2	Space Loss	-207.9 dB
3	Antenna Gain	49.4 (design value)
4	Polarization Loss	-.1 dB
5	Receiver Losses	-1.7 dB
	RECEIVED POWER	-113.8 dB
6	System Noise	-200.7 dBW/Hz
7	Rec. Signal-Noise Dens.	86.9 dB/Hz
8	Data Rate	71.0 dB/Hz
9	Rec. Eb/No	15.9 dB
10	Implementation Loss	-2.5 dB
11	Coding and other Gain	21.7 dB
	MARGIN	3.P dB

Table 4.2.3

Return Link Budget

1	Transmit Power	13.0 dBW (20 Watt Xmitter)
2	Transmitter Loss	-2.0 dBW
3	Antenna Gain	50.1 (TRW design criteria)
4	Pointing Loss	-.2 dB
NET EIRP		60.9 dBW
5	Space Loss	-208.6 dB
6	Polarization Loss	-.1 dB
RECEIVED SIGNAL POWER		-147.8 dB
7	Data Rate	84.8 dB/Hz
8	Required Received Power	-153.0
MARGIN		5.2 dB

Space to Ground Antenna

The space to ground antenna will employ existing technology based on TRW Corporation's LANDSAT antenna design. As indicated in tables 4.2.2 and 4.2.3, the nine foot diameter Ku-Band antenna planned will have design receiving and transmitting gains of about 50 dB. Of particular interest is the fact that space to ground communications can also be accomplished employing the S-Band capabilities of this TRW design antennae.

The S-Band capabilities in terms of data rate and user frequencies for space to ground communications are listed in table 4.2.4. This capability will be of particular value during the initial construction phases of the SAGE satellite, during which time only the S-Band system will be operative. Also, this provides a suitable backup transmitter, although not capable of 100% of the design Ku-Band data handling.

Table 4.2 4

S-Band Space to Ground Link Capability	
Forward Link to SAGE	1 kBps at 2025.8-2117.9 Mhz
Return Link to TDRSS	16 kBps at 2200-2300 Mhz

4.3 Space to Space Communications

The Space to Space Communications System planned for the SAGE satellite is designed to be completely compatible with planned user operating frequencies, to include the Space Shuttle, the Space Station, the Orbital Maneuvering Vehicle, and the Manned Maneuvering Unit for EVA. The system is a multiple user system employing two twelve foot diameter dual band (Wide and Narrow Band) antennae such as the multiple access communications system designed for the space station. Multiplexing techniques with the two dual band antennae increases the available transmitted data rate, allowing for a complete video link with extra-vehicular astronauts. Based on the criteria established for a space to space system on board the space station, and predicted use aboard SAGE, the design frequencies and data rates are established in table 4.3.1.

The space to space system will allow a maximum of thirteen simultaneous users, with a typical maximum range of 2000 km.

Table 4.3.1

Space to Space Link	
Narrow Band return link	128 kBps at 13.64-13.70 Ghz
Wide Band return link	25 MBps at 14.00-14.30 Ghz
Forward link	1.2 MBps at 14.50-14 [illegible] Ghz

Space to Space Link Budget Predictions:

The projected margin for the pair of twelve foot diameter Ku-Bard antennae is between 1.9 and 4.0 dB based on the work of R.P. Hockensmith and others of the Goddard Space Flight Center as published in NASA Technical Memorandun 87793 of July 1986. These figures are for a five watt transmitter at 125 kBps. They are conservative estimates based on actual spacecraft results, although no identical system has yet been flown.

4.4 Antenna Pointing Accuracy

Antenna pointing accuracy is of paramount importance due to the possible signal loss for a poorly aimed high gain antenna. The typical accuracies and results for S- and Ku-Band antennae are listed in table 4.4.1

Table 4.4.1

S-Band	+/-.66 deg. for a 1 dB pointing loss
	+/-.47 deg. for a .5 dB pointing loss
Ku-Band	+/-.26 deg. for a 1 dB pointin
	+/-.18 deg. for a .5 dB point

Antenna Pointing Methods

The requirement for extreme accuracy in pointing the SAGE antennae will be met using the previously developed technology of program track comparison. NASA orbital parameter data will provide, for example, a rough pointing vector to lock on to TDRSS. Comparison is then made by comparing phase differences between receiving antennae and moving to minimize the phase difference and hence the error is reduced. Pointing losses of less then 1 dB have been repeatedly achieved by LANDSAT satellites using this technique while locking on to TDRSS. The same method will suit the needs of SAGE well.

4.5 Internal Audio and Video

Internal communications for SAGE will consist of a fiber optical audio/visual system throughout all modules. Each of the four circumferential modules will be equipped with two cameras (one per end) to provide for sounding and security watch, as well as additional camera setups as needed for the purpose of experiment monitoring. The surveillance system will be tied in to a central video control, which will produce the desired view when called upon at the video station also found in each module.

The video station in each module will consist of a television monitor and video access controls. In addition the modules will employ fiber optical voice link, controlled at the video station. The technology to be used is identical to that already planned for the space station. The advantage of the fiber optics system is the lack of radio frequency interference that is normally associated with the conventional wiring systems. Also, the fiber optics system is lighter and less voluminous as well as having a greater data rate and volume capability than previous systems.

Each module will also employ relatively simple computers for the purpose of module housekeeping and data handling from experiments. Due to the extensive data processing capabilities on earth and, by comparison, the space station, the emphasis for SAGE is on data transmission to either the Earth through the TDRSS Link, or to the space station, during real time. Therefore, the data storage requirements aboard SAGE are not great. There will be a total of 6 magnetic disk storage devices aboard each module, for a total of 24, each having a capacity of 3E9 bytes and an input/output rate of 20 MBps. Weight, power and volume for the design data storage are listed in Table 4.5.1.

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Table 4.7.1: Power, Weight, and Volume

ITEM	Size (cu. in.)	Wt. (lbs)	Power (Watts)
1 Control and Monitor Subsystem			
Freq. Standard	2473	10	200
C&M Processors	1382	45	100
Controller	173	2	15
2 Space to Space Subsystem (Ku-Band)			
Transceiver Assy.	400	24	30
Antenna Monitor	400	25	30
Switching	1071	38	50
Pointing Ant.	20	1	0
Antenna Assy.	1600	65	60
Gimbal/Elect.	5182	150	50
EVA Radio Assy.	500	10	48

Table 4.7.1 (Continued)

3 Space to Ground Subsystem			
Ku-Band Transc.	360	20	40
Tracking Rec.	360	25	25
Antenna Assy.	2160	95	40
Gimbal/Elect.	5182	150	50
S-Band TDRSS	473	16	18
S-Band Antenna	343	1.5	0
4 Internal Audio/Video			
Video Recorders	2142	60	110
Cameras	220	10	12
Cam. Control	1000	13	30
Monitors	900	10	30
Sync. and Control	646	20	50
Audio Bus	72	2	8
Handsets	210	3	5
Terminals	84	4	4
Control Panels	8	1	1
5 Signal Processing Subsystem			
	17000	500	1800

TOTALS 25.7 cu.ft., 1301 lbs., 2.8 kW

4.8 TRACKING SUBSYSTEM

The tracking subsystem for SAGE will employ the Global Positioning System to provide position and velocity information with accuracies of up to 10 meters in position and .1 meters/sec. in velocity using the restricted priority P-code, or information one order of magnitude less accurate using the C/A (coarse acquisition) code available to all users.

The tracking subsystem will be dual redundant GPS systems consisting of the GPS L-Band antenna, the receiver/processor unit, and the GPS interface. The receiver/processor unit is capable of position and velocity calculation after GPS signal acquisition without beginning estimates. In addition, the GPS link will provide an accurate, repeatable time signal for the SAGE satellite.

Tracking of nearby orbital objects with GPS systems aboard will be accomplished by comparing GPS position fixes between SAGE an object of tracking interest. The requirement for tracking of non-GPS equipped satellites is not a requirement of the SAGE tracking subsystem, but may be accomodated by various means, to be discussed in the growth options section.

4.9 TRACKING GROWTH OPTIONS

A number of tracking options are available for expansion of the tracking facilities of SAGE, as SAGE missions require more refined systems and funds are available. These options are listed in table 4.9.1

TABLE 4.9.1B:Growth Options

1) X-Band Phased Array Radar: For missions involving non-GPS spacecraft within the 37 km range of the space to space communications system.

2) Video Tracking: Contrast lock video tracking similar to the Navy's TCS contrast lock targeting system on board the Grumman F-14A Tomcat. Useful for EVA and close-in vehicle tracking.

3) Laser Rangefinding: Similar to laser weapon rangefinding equipment (TRAM) used aboard the Navy's Grumman A-6E Intruder.

4) Electro-optical Sensor: Narrow field-of-view tracker for smaller debris and objects.

4.10 ANTENNAE POSITIONS AND TYPES

The three major antennae positions and types are listed in table 4.10.1.

TABLE 4.10.1 : Antennae Position and Type

1) Space to Space : Omni Antenna, (2), Center Module, Low-Medium Gain

2) Space to Ground : 9 meter High Gain Parabolic Antenna, (1), Center Module

3) GPS Link : Standard GPS Antenna,(2), Center Module

The antennae positions are indicated in figure 4-10-2.

Figure 4-10-2

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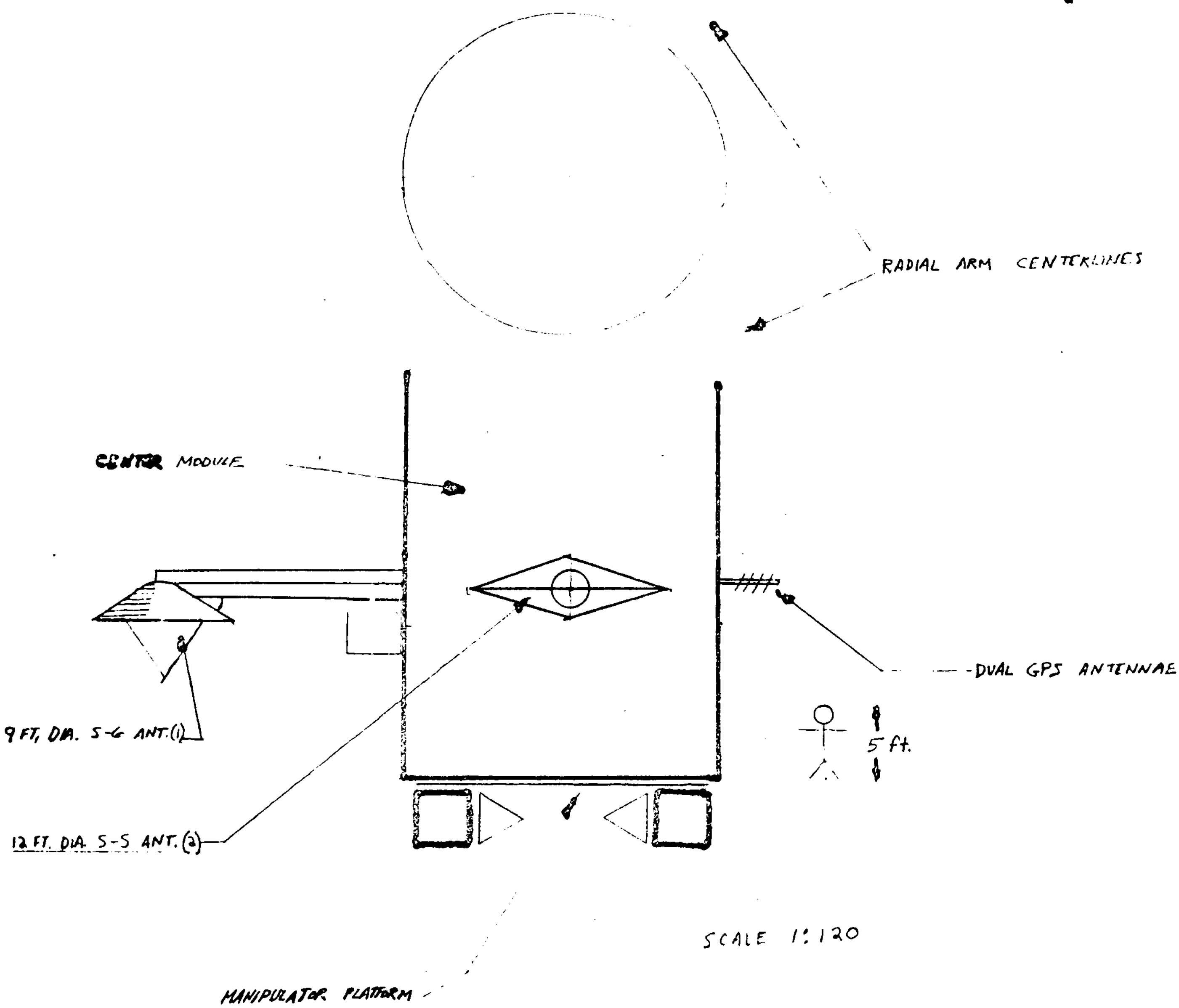

SAGE Antennae Placement

4.11 COST PROJECTIONS

The cost predictions for major components of the SAGE communication and tracking subsystems are listed in table 4.11.1.

TABLE 4.11: Cost Predictions (in thousands of dollars)

1) Space to Space Antennae (2)	40
2) Space to Ground Antenna (1)	20
3) S-S Dual Band Electronics	700
4) S-S Gimbal Controls	350
5) S-G Electronics	500
6) S-G Gimbal Controls	250
7) GPS Link (complete,2)	700
8) External Gimbal Hardware	1500
9) On-Board Data Storage	100
10) Internal Audio/Video	1800
11) Fabrication	3000
TOTAL	9.98 Million

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ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS (ECLSS)

5.0 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS (ECLSS)

The Spinning Artificial Gravity Environment (SAGE) provides for long-term investigations into the effects of a pseudo-gravity environment on man in space. To facilitate this objective the need for a closed loop, regenerative life support system is imperitive to create and maintain a safe and comfortable environment. This system will supply the consumables essential to human existence and will provide a means to extract the by-products. These by-products will either be isolated for disposal or regenerated for subsequent consumption. In addition, the life support system will monitor the environment for conditions non-condicive to the human environment and provide for its correction.

ECLSS onboard SAGE will be designed to operate in the micro-gravity environment produced by spin-up and will also be capable of operation in a zero gravity environment during spin-down and initial set-up. Each module will contain two four-man systems that can operate independently from the systems in other modules or in conjunction with the other modules through distribution systems. The independent operation mode meets the requirement for a safe haven in the event of a catastrophic disaster. The ECLSS in each module will be capable of supporting a crew of eight for 28 days, in addition to food storage. The two four-man concept also provides for redundency and through distribution systems it compensates for high use areas. No ECLSS is provided for the connecting arms since only a minor fraction of crew activity takes place in the arms (mainly a passageway), however fans are provided to smooth any gradients in temperature, humidity, or constituents which might appear in the arms.

To provide compatability with Space Station and since most research into long-term, space-based life support systems is a result of Space Station, the ECLSS onboard SAGE was developed from Space Station concepts. ECLSS functions include atmosphere control and supply, atmosphere revitalization, temperature and humidity control, water recovery and management, waste management, fire detection and suppression, food management, and personal hygiene.

5.1 ATMOSPHERE CONTROL AND SUPPLY (ACS)

The ACS system is responsible for oxygen supply, nitrogen supply, module repressurization, and the monitoring of the partial and total pressures of gases present in the modules and regulation of the atmospheric composition.

The monitoring of the partial pressures of the atmospheric constituents is provided by a mass spectrometer which analyses the atmosphere for oxygen, nitrogen, carbon-dioxide, hydrogen, water vapor, methane, and other gases which represent a hazard to the safe operation

One constituent analyser is placed in each module and each arm and provides a direct readout to the control center.

The total pressure of the atmosphere is monitored directly in addition to the summation of the partial pressures of the constituents. The cabin pressure is maintained at a total pressure of 14.7 psia.

To compensate for losses due to metabolic consumption, leakage, EVA, and airlock losses, the monitors control such functions as oxygen generation, carbon dioxide removal/reduction, nitrogen feed, venting, humidity control, and the caution and warning system.

Oxygen is continuously generated and supplied to the cabin atmosphere via the Atmospheric Revitalization system. Control of this process is maintained by the ACS system to regulate the rate at which oxygen is produced. All oxygen for SAGE use is provided by this system except for emergency repressurization (i.e. no oxygen storage is utilized). All oxygen generation units are centrally connected, and emergency or high use areas are compensated for by use of a distribution system where oxygen can be supplied to one area from a separate system.

Nitrogen for atmospheric makeup is supplied solely from storage. Liquid nitrogen is stored in the central hub where it is boiled off at high pressure and fed into a low pressure gaseous nitrogen storage unit. Upon demand of makeup, gaseous nitrogen is supplied, through the distribution system, to any module or arm. This [illegible]s entirely open loop (i.e. non-regenerative) and requires that liquid nitrogen is initially present, sufficient for the 180 day resupply period. Upon resupply, the liquid nitrogen tanks are topped off.

The ACS system provides for the emergency venting of the entire atmosphere of one module. A module's atmosphere is vented independently of the other modules, and one such system is present for each module. The need for emergency venting may arise from some catastrophic disaster such as shell penetration, fire, or chemical leak. The valves necessary for this subsystem are located in the bulkhead and can be operated either manually or automatically.

As a complimentary system to the emergency venting system, a repressurization system is also provided. This system has the capability to recharge a single module to normal atmospheric pressure within any one resupply period. One system is present for each module and consists of high pressure gaseous nitrogen and oxygen tanks external to the module. The tanks are maintained at approximately 3000 psia and are connected through the oxygen and nitrogen distribution systems. This system will be only manually activated and can repressurize a module within five minutes.

5.2 ATMOSPHERIC REVITALIZATION (AR)

The AR system regenerates the cabin atmosph provide a safe and habitable environment for the crew. AR functions include Oxygen Supply, Carbon dioxide Removal, Carbon dioxide Reduction, and Trace Contaminant Monitoring and Control.

5.2.1 Oxygen Supply

Oxygen is supplied from a static feed water electrolysis process consisting of a series of electrochemical cells connected electrically in series. As electrical power is supplied to the electrodes, water is electrolyzed generating oxygen and hydrogen. The electrolysis creates an electrolyte concentration gradient between the feed water and the electrolyte in the electrochemical cells. Water difusses from the feed system into the cells due to the electrolyte gradient, and water from the feed system is replenished from supply tanks. Incorporated into the electrolysis system is a pressure controller to maintain the pressure differential necessary for the liquid/gas exchange within the cells. Oxygen is supplied to the cabin atmosphere, and hydrogen is fed to the carbon dioxide reduction precess.

5.2.2 Carbon dioxide Removal

Man generates approximately 2.2 lbs. of carbon dioxide per man per day. This amounts to 17.6 lbs. of carbon dioxide per day for an eight-man crew. At about 3% of total atmospheric pressure this carbon dioxide becomes toxic, and active CO2 removal systems are necessary to maintain the partial pressure within tolerable

This is accomplished by the preferential absorbtion of CO_2 by a zeolite or molecular sieve. This material has the affinity to absorb molecules of a given size (i.e. 4 Angstroms). Because the efficiency of these sieves is inversely proportional to the amount of CO_2 already absorbed, two of these sieves are used alternatively, one absorbing CO_2 while the other is desorbing. In addition, two silica gel beds are used to prevent water vapor from entering the molecular sieves since these sieves have a preferential affinity for water over CO_2. (See Figure 5.2.2-1).

Air is chilled to condense water vapor for removal, and then the partially dried air is forced into the system through the first silica gel bed where the remainder of water vapor is removed. From this bed the air goes to the molecular sieve where most of the CO_2 is removed. The CO_2 depleted air is then heated and enters the second silica gel bed where moisture absorbed from a previous cycle is desorbed into the airstream for return to the cabin atmosphere. Both sets of silica gel beds and molecular sieves are operated alternatively first absorbing either water vapor or CO_2 to their capacity and then desorbing to either the exiting air stream (water vapor) or fed to the carbon dioxide reduction system (CO_2).

5.2.3 Carbon dioxide Reduction

Carbon dioxide reduction is accomplished using the Bosch process where one mole of CO_2 combines wi[illegible] [illegible]les

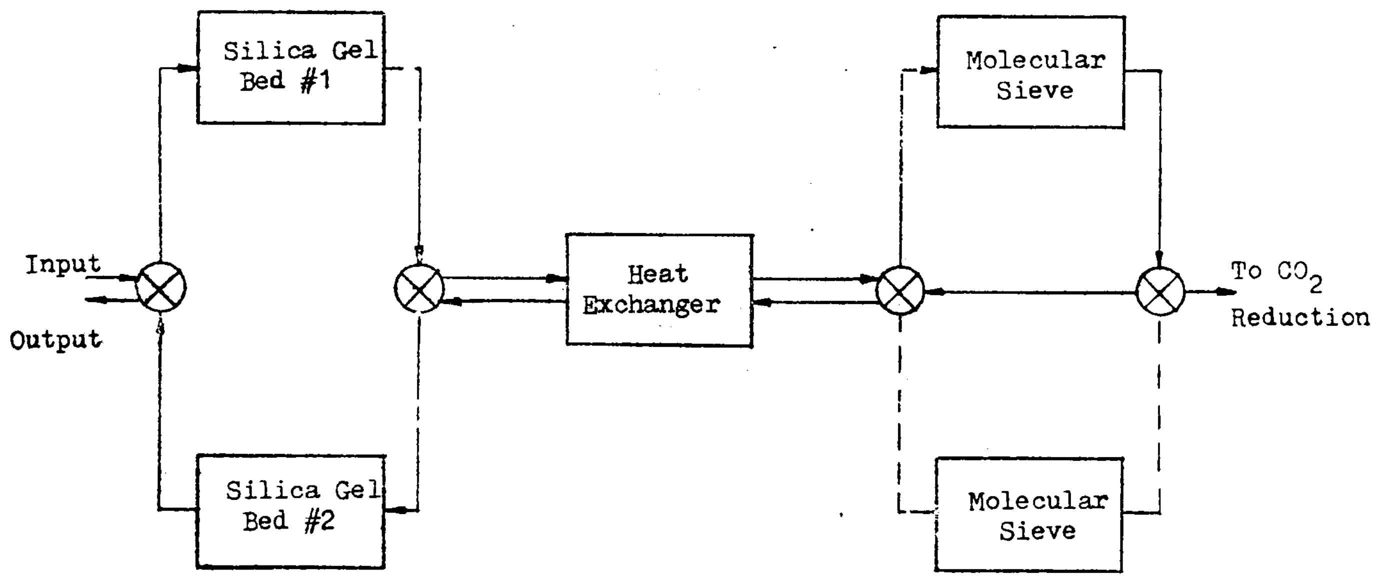
Silica Gel Bed #1
Silica Gel Bed #2
Input
Output
Heat Exchanger
Molecular Sieve
Molecular Sieve
To CO_2 Reduction

Figure 5.2.2-1

of H_2 to form one mole of carbon and two moles of water vapor. This reaction occurs at approximately 980-1340°F and is aided by an iron catalyst, shown below.

$$CO_2 + 2H_2 \longrightarrow C + 2H_2O$$

In practice, this process achieves about 10% efficiency in a single pass. This is compensated for by recycling the process gases and the continuous removal of carbon and water vapor. (See Figure 5.2.3-1).

Gases are continuously recycled through the system by a compressor. After leaving the compressor, the gases are heated prior to entering the reactor. Inside the reactor, CO_2 and H_2 are reacted over an iron catalyst bed to produce carbon and water vapor. The exit gases partially depleted of CO_2 and H_2 leave the reactor at approximately 1200°F, and are passed into a heat exchanger to heat the gases entering the reactor. The mixture is then forced into a condensor where water vapor is separated and collected, and the the mixture is returned to the compressor. Condensed water is fed into the Water Recovery and Management System.

5.2.4 <u>Trace Contaminant Monitoring and Control</u>

Trace contaminant monitoring is achieved with a dual system consisting of gas chromatography and mass spectrometer combination. This system utilizes the advantages of each subsystem to separate and identify expected contaminants. The gas chromatography provides separation of contaminants into specific categories such as alcohols, aldehydes, and ethers. Once separater

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CARBON DIOXIDE REDUCTION

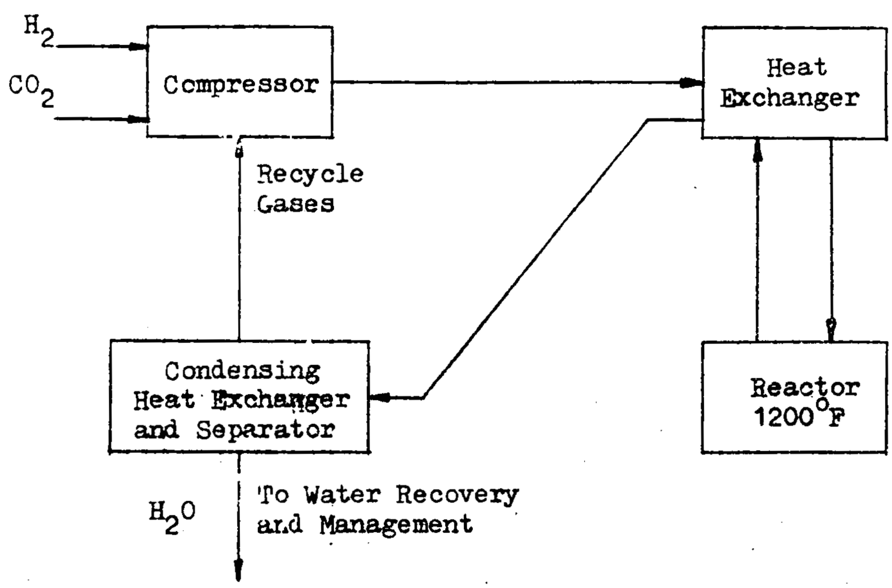

Figure 5.2.3-1

categories, the mass spectrometer determines the specific compound present. The outputs of these sensors are connected to the control center to provide a running average of compounds present in the cabin atmosphere.

Expected sources of contaminants are metabolic processes and off-gases of volatile gasses from plastics and coatings. Contaminants from specific chemicals kept onboard SAGE have individual "color change" sensors to detect chemical spills.

To control contaminants, SAGE utilizes three different subsystems. Specific sorbents are provided to absorb ammonia, carbon monoxide, hydrogen, and acid gases. In addition, a carbon bed is used to absorb contaminants and odor. These subsystems are non-regenerative and must be replaced at each 180-day resupply. Contaminant control also utilizes a high temperature catalytic oxidizer to oxidize contaminants present in the cabin atmosphere for their subsequent removal.

5.3 TEMPERATURE AND HUMIDITY CONTROL (THC)

The THC system provides a means to regulate and maintain the temperature and humidity of the cabin atmosphere. (See Figure 5.3-1)

The system consists of a fan and condensing heat exchanger sub assemblies. Warm, moist air is drawn into the system by the fan, and a portion of the air i

TEMPERATURE/HUMIDITY CONTROL

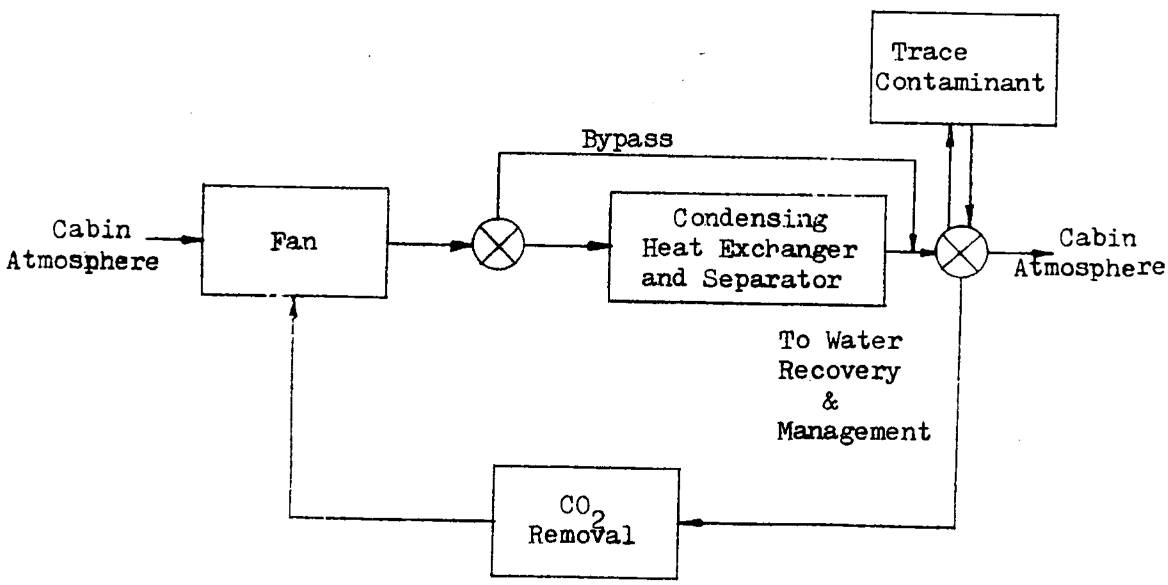

Figure 5.3-1

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and partially dried. Water is separated and collected and fed to the Water Recovery and Management System. The cool, dry air is then mixed with the bypass air for return to the cabin. Temperature is maintained by varying the amount of air entering the heat exchanger and bypassing the heat exchanger.

The THC system is designed to remove a maximum of 6500 Watts of sensible and latent heat from the cabin air, and the temperature is maintained between 65°F and 75°F. The humidity is 25-75%.

A forced convection flow path for operation at zero gravity is used. Warm air is drawn from the ceiling of the module where it is cooled and condensed. Cool, dry air is then directed through ducts where it enters the module at the floor. The THC system employs a particle filter at its intake to remove debris from the air and silencers at the intake and exhaust to reduce noise in the crew compartments.

The THC system is the initial staging point for AR functions, CO2 Removal and Trace Contaminant Control. A portion of the THC output is directed into the CO2 Removal System where it enters the silica gel bed. The output of the CO2 Removal System is at the intake of the THC.

Another portion of the THC output is directed to the Trace Contaminant Control unit. Here the inputed air is filtered to remove any contaminants, and the filtered air is outputed into the output of the THC for retu

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cabin atmosphere.

Each module contains a THC unit, and conditioning of air within the connecting arms is handled with circulation fans. The vast majority of crew activity is expected to take place within the modules, and the greatest loads are encountered there. The circulation fans provide sufficient mass flow for maintaining the atmosphere within the arms and smoothing any gradients in temperature, humidity, or constituents.

5.4 WATER RECOVERY AND MANAGEMENT (WRM)

The WRM system provides the collection, processing, and dispensing of water for all SAGE needs. Pretreatment of waste water to prevent chemical breakdown and microbial growth prior to processing and post-treatment and monitoring systems to ensure water quality prior to use are provided.

The collection of water is divided into two categories, potable water and hygiene water. Potable water is used to supply drinking requirements and the preparation of food. Sources for potable water collection are THC, CO2 Reduction, and resupply. Hygiene water is all water which may come into contact with the crew. It is used in the O2 generation process, urine flushing, shower, hygiene and hand washers, dishwasher, laundry, and any other system requiring purified water. Sources of hygiene wa collection include: hygiene and hand wash waste water, waste potable water, galley waste water, dishwasher water, shower water, laundry water, and processed urine.

After collection, potable water is processed using a four stage multifiltration system. The first stage is a large particle filter to remove any large matter in the water. The second stage is an absorbtion bed which consists of a specifically selected granular activated carbon. The carbon has a pore structure which includes a wide variety of sizes to capture molecules of the lightest charged organic material. The third stage is an ion exchanger consisting of a specifically selected blend of deionizing resins. The fourth stage is a sterilization filter.

Following processing, the water is checked by an on-line water quality monitor and pumped into a fill tank. The water qulaity monitor samples the water, determining pH, conductivity, and total organic carbon. There are four tanks used in each module designated as fill, test, stand-by, and use. Once a tank has been filled, it becomes the test tank and is tested for bacteria content prior to use. After the test has passed the bacteria test it is designated stand-by and is fit for human consumption. Once the use tank is empty, it becomes the next fill tank, and the stand-by becomes the use tank. Should a tank fail either the water quality monitor or bacteria test, the water is returned to a collection tank for repr

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After collection, hygiene water is processed in a separate multifiltration system.

After processing, hygiene water is tested using a separate water quality monitor and bacterial test. Failure to pass these tests causes the water to be returned for reprocessing. Hygiene water is also stored as is potable water consisting of fill, test, stand-by, and use tanks.

The processing of urine requires additional treatment from the rest of the hygiene return water. First, the urine is pretreated to stabilize the urine, preventing enzymic breakdown to ammonia and providing a bar to bacterial growth. This is accomplished with sulfuric acid and oxone. The sulfuric acid reduces the pH and stabilizes ammonia as ammonia sulfate. Oxone inhibits bacterial activity.

Following pretreatment, urine undergoes air evaporation or wick evaporation. A wicking material is saturated with the pretreated urine, and water is evaporated from the wick by forcing heated air past the wick. Solids are trapped in the wick. When solids have been sufficiently deposited on the wick to reduce efficiency, the wick is dried and removed for disposal. Water recovered from this process is fed into the hygiene water collection tank for further processing.

5.5 WASTE MANAGEMENT

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5.5.1 Feces and Vomitus Collection and Processing

Feces and vomitus are collected in an as Earth-like manner as possible. Waste products are collected in the commode aided by air transport for zero gravity use. The wastes are removed in the fan separator, and subsequently air dried. The wastes are collected in one use containers that provide microbial protection to the crew and facilitate crew servicing. The entire container is then placed into a trash compactor, and a replacement is installed into the commode.

Dual odor/bacteria filters are provided at the exhaust of the fan separators to prevent noxious odors and protect the cabin atmosphere.

5.5.2 Trash Collection and Processing

Solids for disposal as trash are collected in a bag system. Continuous air flow over the trash is provided for drying and to keep the trash in the container when it is opened in the zero gravity situation. When the bag becomes full it is placed into the trash compactor which has a compaction ratio of approximately 20:1. There is a trash compactor in each module.

Following compaction, the trash is stored in designated storage bays for removal upon resupply.

5.6 FIRE DETECTION AND SUPPRESSION (FDS)

The FDS system provides the sensors and su

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to extinguish any fire on SAGE. Each module and arm has its own subsystem which detects the presence and specific location of a fire. In addition to sensors and suppressants, the FDS system includes the distribution system and emergency breathing packs.

Fire detection sensors are provided that are capable of detecting a fire at any stage of development. These include ionization, thermal and infared sensors. Once a fire has been detected and located the sensors output to the caution and warning system to sound an alarm. Output is also connected to the control center to provide a visual alarm for the location.

Fire suppression sub system consists of portable CO2 extinguishers for small, local fires and CO2 ports for suppression of larger fires. The suppression sub system also has the capability to dump CO2 into a module to completely extinguish a large scale fire. The atmosphere in this module becomes unusable for human existance, and an alarm will sound prior to this event to allow for evacuation. The suppression ports are connected through a distribution system that can be activated automatically or manually. The distribution system is connected throughout each module and connecting arm.

Emergency breathing packs are provided to the crew for evacuation purposes or for fighting the fires.

5.7 FOOD MANAGEMENT

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The Food Management system consists of the hardware necessary to store, prepare, dispense, serve and consume the food and to clean up after preparation. The system will satisfy the need to accomidate one to eight meals per serving.

Storage space will be provided for a 180-day supply of ambient, refrigerated, and frozen food for an eight-man crew. The galley area provides storage for only 14 days of food, and the remainder is contained in a logistics module. The logistics module has the capacity for 62 cubic feet of refrigerated food and 126 cubic feet of frozen food. The galley has the capacity to hold 15 cubic feet of refrigerated and 30 cubic feet of frozen food. The refrigeration/freezer sub system is achieved using a vapor compression process with freon as the working substance. A double isolation feature is incorporated in the freon loop to prevent contamination of the cabin atmosphere.

The galley also provides for the preparation of food including defrosting, heating precooked food, and baking uncooked food. This is accomplished with an oven which is capable of operating as a microwave, forced air convection, or conduction oven. Utensils and other small appliances are also supplied as part of the galley equipment.

To aid in the clean up of dishes a spray type washer is included in the galley. The dishtub is designed to spin inside the dishwasher to provide an even cleani   and

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an air/water separater is provided for zero gravity operation.

5.8 PERSONAL HYGIENE

Personal Hygiene sub systems will consist of hand washers, showers, and laundry facilities. These sub systems use water from the hygiene water system including oral hygiene, and local heating is supplied. A shower is available in two of the modules, and a hand washer is available in each module and supplied in conjunction with the commode assembly. Only one washer/dryer sub system is provided to SAGE. In all cases the Personal Hygiene system uses an air assist for operation in zero gravity. This requires an air/water separater common to each sub system.

The showers are a full body aparatus with no sharp corners preventing inaccessable areas for water clean up. All water used for showering is contained in the enclosure, and a portable vacuum is provided for clean up in zero gravity.

The washer/dryer sub system operates in the same manner as conventional washer/dryer combinations. The washer uses water and soap to cleanse clothing. After the wash cycle, clothes are rinsed, and a majority of the rinse water is collected in the spin cycle. This is returned to the WRM system.

The dryer is a hot air, tumble process whe r is passed through the dryer while the clothes are tumbled to aid in drying. A filter is placed at the exhaust of the hot air to trap any lent removed in the drying process.

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6 PROPULSION AND ATTITUDE CONTROL SYSTEM

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6.0 Propulsion System Drivers

SAGE demands on a propulsion system include long component lifetimes, ease of maintenance and replacement, reliability, redundancy, commonality with other systems, low enviromental contamination, cost efficient consumable storage and resupply, satisfactory automation, low cost, and safety. This system will be used for altitude control, spin dynamics, attitude control, collision avoidance, and rendezvous maneuvers with the NASA space station(SS). Linked to the chosen orbit for SAGE, are several other unique considerations. For drag adjustment, continuous low-thrust makeup will impose longer duty cycles for the thrusters, but will allow stationkeeping and the benefit of using continuously produced waste gases. A 180 day resupply period will require sufficient storage without being too voluminous. A sun pointing spin vector will need to be precessed one degree every day. The large moment of inertia about the spin axis(5.7x10^7 slug-ft^2)will require large torques to precess, spin up, and despin. Finally, SAGE is designed for a 30 year lifetime.

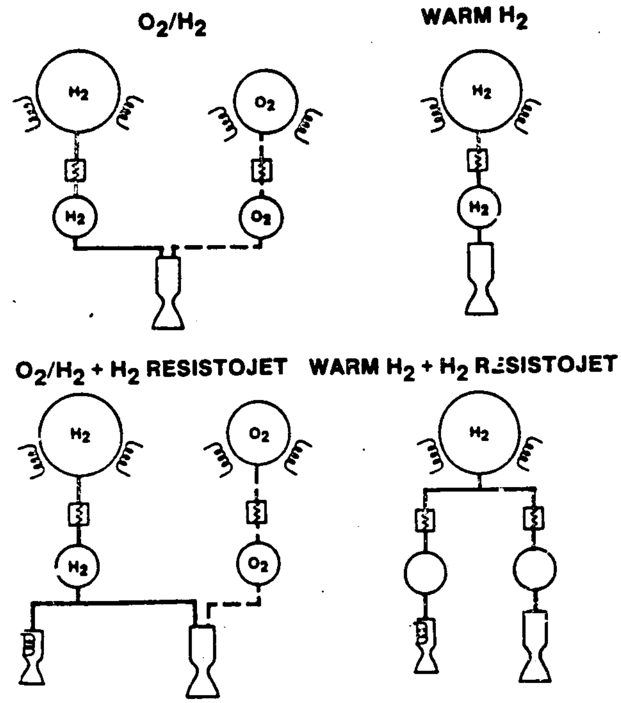
6.1 Orbit Data

The orbit of SAGE was chosen to optimize several factors, but mainly to serve as support to the NASA SS. By serving as ˙ -unications link, recreation and recuperation facility, and sa for the NASA station--the two would be synergistic. From estimates, the SS altitude will vary from 200 nm at resupply to 250 nm right after boost. SAGE will maintain an altitude around h=223 nm depending upon SS separation. The eccentricity will be zero and the inclination will be 28.5 degrees(consistent with the SS). This establishes a period of 92.7 min, with 15.53 orbits per mean solar day, and a shadow time of 36 min. SAGE forward velocity is 7.6641 km/sec. For this orbit, the neutral atmospheric density is 7.718x10^-12 kg/m^3, and the atomic oxygen present is 100 atoms/cm^3.

6.2 Thruster Background

As mentioned, the large mass and moments of inertia of SAGE dictate thruster control. No provision is made for any other attitude control system except for magnetic coils. Various thrusters (monomethylhydrazine, bipropellant nitrogen tetraoxide)were examined but gaseous warm or cold O2/H2 thrusters complemented by multipurpose resistojet thrusters were chosen(see figure 6.2-1). Typically, the GO2/GH2 system has much higher thrust(on the order of 10)than the resistojets.

Prototype GO2/GH2 thrusters have a 25 lbf thrust level, mixture ratios of O2:H2 varying from 3-8:1, specific thrusts of 360-405 sec, total impulses of 2 million lbf-sec, maximum steady-state thrust chamber temperatures of 850 F(indicative of long life), long duration firings of 1868 sec, over 10,000 pulses during operation, combustion chamber pressures of 100 psia, and total [illegible]hts of 8.25 lbm per thruster. O2 is injected into an annular [illegible] chamber where it mixes with H2 and is ignited by a spark e[illegible] H2 is



SAGE Propulsion System

Figure 6.2-1

Life (Hrs)	10,000 (minimum)
Full Thermal Cycles	10,000
Total Impulse (lb-sec)	2×10^6 (minimum)
Structural Ruggedness	Compatible with Space Shuttle Launch
Propellants	CO_2 CH_4, CO_2/CH_4, N_2, Steam, N_2H_4 decomposition products
Specific Impulse (sec)	
CO_2	130
CO_2/CH_4	160
H_2	500
Steam	200
N_2H_4 gas products	250
Thrust (lbf)	0.030 - 0.100
Thrust Chamber Pressure (psia)	15–45
Maximum Specific Power per Thruster (watts/millipound of thrust)	
CO_2	5.5
CO_2/CH_4	5.5
H_2	15.6
Steam	6
N_2H_4 gas products	10
Maximum Current Per Thruster (amps)	50
Maximum Mass of Thruster (kg)	2

Table 1. Potential Waste Fluids and Sources

Fluid	Source
CO_2, CH_4, CO_2/CH_4, H_2O	Environmental Control and Life Support System
O_2, H_2	O_2/H_2 Propulsion System Option Water Electrolysis System Lab Modules OTV Tanks in Growth System
N_2H_4 Decomposition Products	N_2H_4 Propulsion System Option
N_2, He, Ar	Lab Modules Platforms

Multipurpose Resistojet Characteris'

Table 6.2-1

ourtesy of Rockwell International

used to cool the thruster, and this serves to condition the H_2 for ignition. When electrolysis of H_2O provides the gases, a mixture ratio of 8:1 is used if total fuel consumption is required. This lowers the specific thrust to 360 sec.

Prototype resistojet thrusters(see figure 6.2-1, table 6.2-1) can operate on H_2O, CO_2, CH_4, H_2, N_2, and inert gases. The specific thrusts vary appreciably with each gas and the augmentation heater power. In resistojets, a gas is heated to enhance its specific thrust, before exiting from the nozzle. These thrusters are capable of large flow and electrical power throttling. By adjusting electrical power to the heater element, maximum efficiency is achieved when gas pressure is less than optimal. Thermal efficiencies are typically around 92%, and are designed around total reusability over a 15 year lifetime rather than max performance. Operating lifetimes of 10,000 hours have been achieved with platinum-sheathed heaters coaxially centered within the insulator. Maximum power usage per thruster runs at 1 kw, and corresponds to a maximum temperature of 2500 F.

In other aspects, this combination of systems provides many advantages. Through system monitoring and fault detection, the operating conditions can be varied accordingly to provide maximum thrust or prolonged lifetime. Mixture ratios, fuel and coolant flows, and temperature can be adjusted. Thruster redundancy will provide alternate units, and replacement at the lowest level, the orbital replacement unit(ORU), simple valve design ' quick disconnects will minimize if not eliminate EVA. sters have survived 50,000 full thermal cycles and over .ours of operation. The fuel is safe to humans, and can be integrated with the Enviromental Control and Life Support Systems(ECLSS), and power systems. Waste and other gases can be furnished to or supplied from the ECLSS. These waste gases will provide drag makeup continuously, and are a free source of propellants, save storage needs, and reduce the SAGE down transport requirements. Fuel can also be electrolyzed from waste or STS scavenged H20 or from fuel cell overcharge. Transfer and resupply are also simplified because no toxic liquids and complicated valves or compressors are involved.

6.2.1 SAGE Reaction Control System(RCS)

For the impulse requirements calculated, each Reaction Control Module(RCM)will contain 6 100 lbf, 6 25 lbf GO2/GH2 thrusters, and 8 .25 lbf multipurpose resistojet thrusters(see figure 6.2.1-2). The GO2/GH2 thrusters will be configured for cold and warm gas modes, with the thermal conditioning available from the solar dynamics. These thrusters will have an assumed specific thrust of 550 lbf-sec/lbm. The resistojets are designed for all types of gases, but GH2 will be supplied for all thrust needs, and the resulting specific thrust will be 800 lbf-sec/lbm. Each complimentary thruster will fire to avoid stresses on the structure and the thrust level will be monitored and fuel flow or power level will be adjusted accordingly. The RCM will be self-contained, and each thruster will be easily replaced. Upon on-orbit assembly, the RCM will be attached to the crosspieces in order to provide attitude control. The fittings on the crosspieces and modul ting area will be identical with respect to fuel line interc hich will be quick disconnect types. Each RCM will con , in^3 of

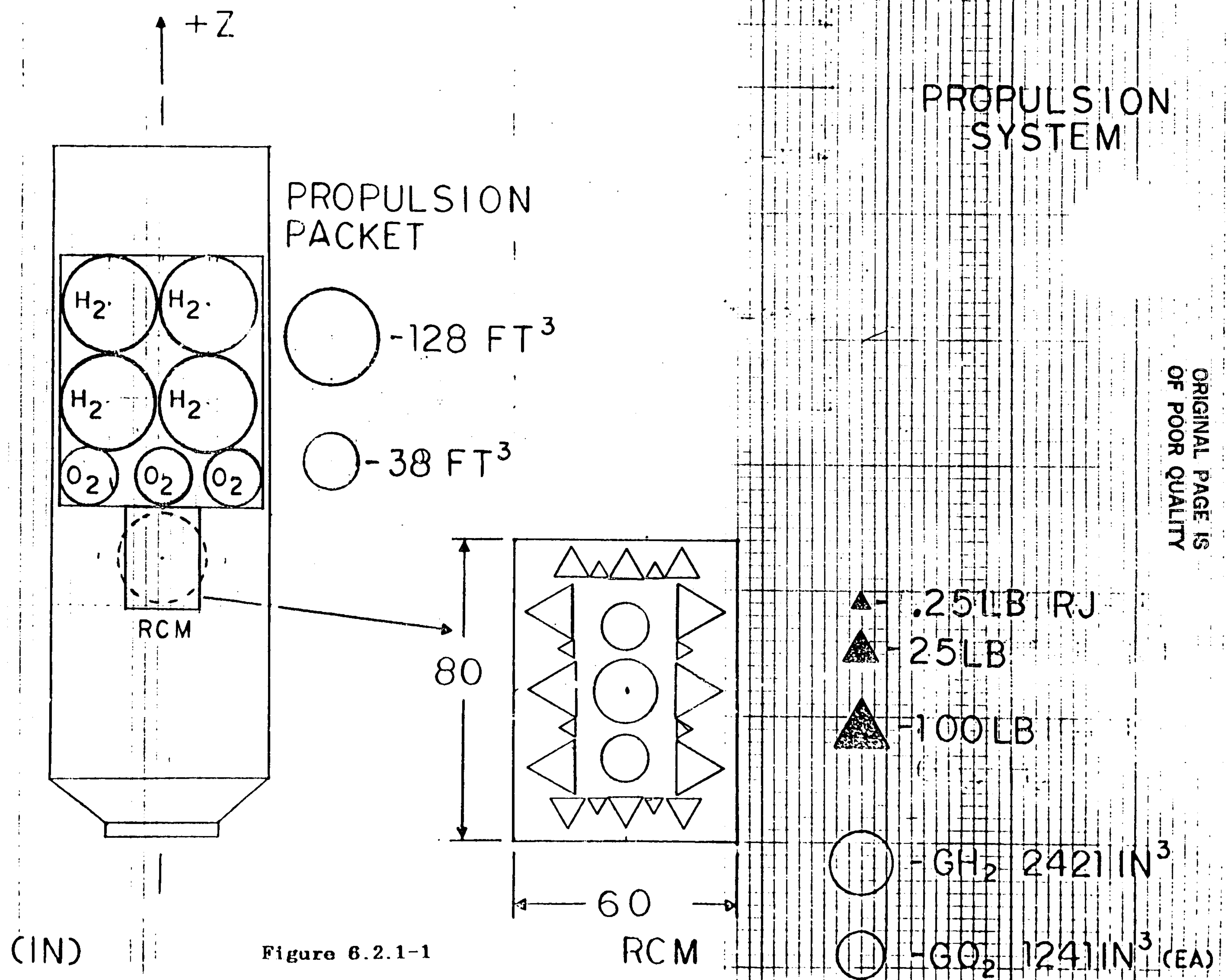


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Figure 6.2.1-1

spherical volume to accommodate waste gas production storage and initial fuel loadout during SAGE assembly. Next to the RCM, connections will exist for propulsion packet attachment. The propulsion packet for each RCM will provide 512.2 ft^3 of H_2 and 76.5 ft^3 of O_2. The temperature will be maintained at 240 K and the pressure at 2500 psia, and each will be monitored by gauges. Since the RCM will be at the maximum distance from the core module(CM), on the outside of each HAB/LAB module, a robot arm will be required to place the fuel carrier. Connections will interface with the fuel electrolysis unit, fuel cells, ECLSS equipment, O_2 storage in the CM, and each other RCM. Pressure vessels will be designed to leak before rupturing and release of any other gases will be done non-propulsively.

For accurate thruster firings, attitude determination will be made by coarse and fine sun and earth horizon sensors, and GPS receivers in each of the modules.

6.3 Altitude Maintenance

Atmospheric drag plays a critical in LEO altitude maintenance. Factors in the drag force include atmospheric density, orbit velocity, surface area, and a drag coefficient. The neutral value for density was used to present a worse than average case, and the normal and planar areas were averaged out over an orbit. The resulting drag force of .0417 lbf meant the orbit would decay at an uncompensated rate of -15.7 nm per 180 day period. [illegible]te gases will maintain this orbit, and it can be allowed to dec[illegible]wer altitude for STS resupply or to rendezvous with th[illegible]ore being reboosted. The impulse required to compensate for this drag is 6.8×10^5 lbf-sec. When making any attitude adjustments, thrust will be directed toward increasing orbit energy and altitude

In years with high solar activity, a 223 nm orbit would consume too much fuel to maintain altitude. It is feasible to increase the orbit to 275 nm, decrease fuel requirements, and absorb the loss in STS lift capacity. SAGE will be assembled in year 2007 when solar activity is a minimum, at an altitude of 200 nm, and will be boosted and maintained at 223 nm until drag proves unacceptably high or the SS average altitude is revised.

6.4 Spin Dynamics

For normal spin/despin 8 of the 12(appropriately pointed)100 lbf thrusters will be used, and all 12 will be used for emergencies. The .25 lbf resistojets per RCM will maintain the spin rate at an accuracy of +/-.01 rpm, and will be used to start the initial spin in order to keep stresses on the structure to a minimum. For normal spin/despin the angular acceleration is .00135 rad/sec^2, and .00203 rad/sec^2 for emergencies. At the maximum rotation rate of 4.7 rpm, the normal thrust rate would stop the station in 6.06 min, while the emergency rate would do this in 4.04 min. Spin up to the minimum rate of 2 rpm would take 2.56 min at the normal thrust rate. Provision in the fuel storage is made for 3 spin/despin cycles at the normal rate, to the maximum of 4.7 rpm, and 1 despin from 4.7 rpm at the emergency rate. This sums to a total imp[illegible] of 2.04×10^6 lbf-sec over a 180 day period.

Initially, SAGE will be despun for berthing, but the Logistics module(LOG) alone can be despun while berthing with the Orbiter Spin and despin is costly in fuel requirements, and after the berthing procedure with SAGE has been validated, the Orbiter will berth while SAGE is spinning. The savings in fuel will be used fo. more frequent rendezvous with the SS for crew transfer. While despun, SAGE also loses the Sun-pointing accuracy required for the solar dynamics. STS visits last 5.6 days on the average, and this would be an additional drain on fuel in order maintain attitude.

6.5 Attitude Control

SAGE is a sun-pointing station, that has close tolerances due to the solar dynamics used to generate power. Only thrusters and magnetics will be used for attitude control since momentum wheels of an adequate size would be too constraining. Tne function of the attitude system is to keep the angular momentum vector aligned with the spin vector, while the spin vector is aligned towards the Sun. With this system, accuracies of +/- .01 degrees pitch and +/- .1 degrees yaw are predicted.

6.5.1 Gravity Gradient Torque

A large structure in LEO, with widely separated masses will have a significant gravity gradient torque(GGT). This precession of the spin axis will be muted by the large moment of inertia about the z axis, and ultimately, will equal zero over an entire [illegible]--but this GGT will be used to help precess the spin axis the [illegible] degree per day. The magnitude of the average GGT over a q[illegible]bit is

32.6 ft-lbf. At the slowest rotation of 2 rpm, this will precess the spin axis by .2826 degrees per quarter. However, only .06439 degrees is required per orbit, so this additional .2182 degrees must be canceled by thruster firing. By strategically thrusting in quadrants 2 and 3, the desired rotation will be achieved when the eccentric anomaly is 0 degrees--at which time another cycle starts. By using the .25 lbf thrusters, during quadrants 2 and 3, maximum sun-pointing accuracy is achieved on the sunlit side, and fluctuations in the shadow zone are unimportant. The total impulse required for this over 180 days is 1.32x10^6 lbf-sec.

6.5.2 Magnetic Torque

To maintain the correct attitude with respect to pitch in the Sun-earth plane, magnetic coils can be used instead of thrusters. These coils can also dampen any wobble created by GGT or mass unbalances. By aligning 2 magnetic moment vectors towards the sun(on opposite sides of SAGE), and 2 away from the sun, pitch in both directions can be controlled. These coils will be located in the truss structure connecting the HAB/LAB modules, and will not interfere with the modules, and will not be used during communications. Assuming an inclination or zero, the earths B vector is .258 gauss perpendicular to the Sun-earth plane, a 85 degree angle exists between M and B, with 1 kw per coil(4.81 A current), an area of 70 ft^2, and 1.75x10^5 turns--an 9.62 ft-lbf torque can be exerted on SAGE. This would provide fine pointing in one axis, and wobble damping. Actually, a 28.5 de[illegible] inclination would provide control over the yaw axis, but at a [illegible]educed amount. This is an open option meant to conserve

6.5.3 Mass Imbalance

Ideally, SAGE is perfectly balanced with respect to the z axis, no products of inertia exist. Once a wobble begins, it will dissipate since spin is around the maximum moment of inertia, but this will cause unacceptable pointing, crew comfort, and stresses on the structure. For instance, the movement of the Mobile Service Center(MSC) carrying a loaded node weighing 3628 kg(8,000 lb), from its CM position to a HAB/LAB module will cause a coning half-angle of .601 degrees(the MSC on the other crosspiece moves also so only the node weight is included). For a movement of 8 180 lb(653 kg total)crewmembers from the CM to a HAB/LAB module, a half-angle of .1016 degrees results. The magnetic coils will help to diminish this wobble, but more importantly, mass management must be carefully controlled. In this respect, the MSC's on each crosspiece can be moved to balance out a mass shift. They can also be moved in and out to decrease wobble once it has started, and would save additional fuel or power.

6.5.4 Summary

These systems have been designed to maintain attitude control to strict accuracies, with minimum expenditure of fuel. The scenarios presented are the worst case possibilities, and the fuel requirements have been scaled accordingly. To help in fuel management, the moment of inertia about the x axis i[illegible] x10^7 slug-ft^2, and all thrusting intended to precess th[illegible]tor will take advantage of this.

6.6 NASA Space Station Rendezvous

Although SS support is a SAGE mission, precise station-keeping on SS is not practical because SS periodic reboost does not mesh with SAGE continuous drag makeup, different ballistic coefficients would cause the stations to drift apart anyway, the station-keeping would not be fuel efficient, and the orbits of the two stations would intersect periodically anyway. Defining formation flying as having direct line of sight communications with the SS provides more latititude in orbit maneuvers and becomes more fuel efficient. Even so, the drag differential(SS has a greater surface area)means the altitude decay rates will cause relative nodal regression and phase differences between SAGE and SS(see figure 6.6-1). For rendezvous, corrections must be made in relative altitude, relative true anomaly(orbital phase difference), and relative longitude of the ascending node. If the relative longitude of the ascending nodes for two orbits is nonzero, the orbits are not coplanar, and the angle between the orbits is the wedge angle. The data in these figures places the SS at 370 km(200 nm)with a 28.5 degree inclination.

The total fuel cost to rendezvous(see figure 6.6-3) is a sum of the three independant maneuvers(altitude, orbit plane change, and phase). For SAGE, wedge angle corrections are impossible due to thruster location and spin dynamics. A combination of phase and altitude change can be used to allow the different nodal regression rates to null the wedge angle. Phase corrections o[illegible] [illegible]crease up to 180 degrees, and the maximum difference in rela[illegible] [illegible]udes between SAGE and SS would be 23 nm. When SAGE fli[illegible] SS, the

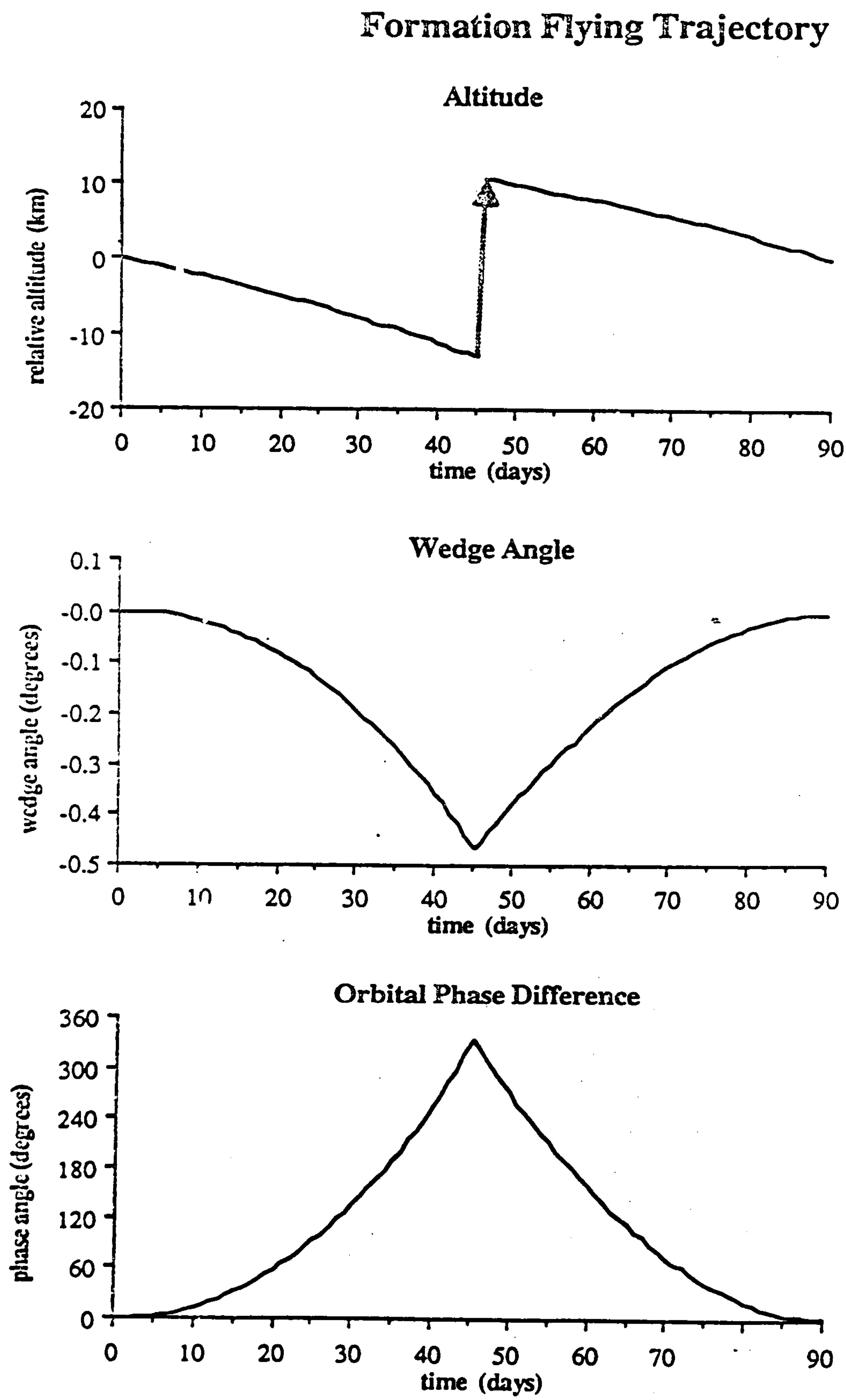

Figure 6.6-1

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Propulsive Boomerang Trajectory

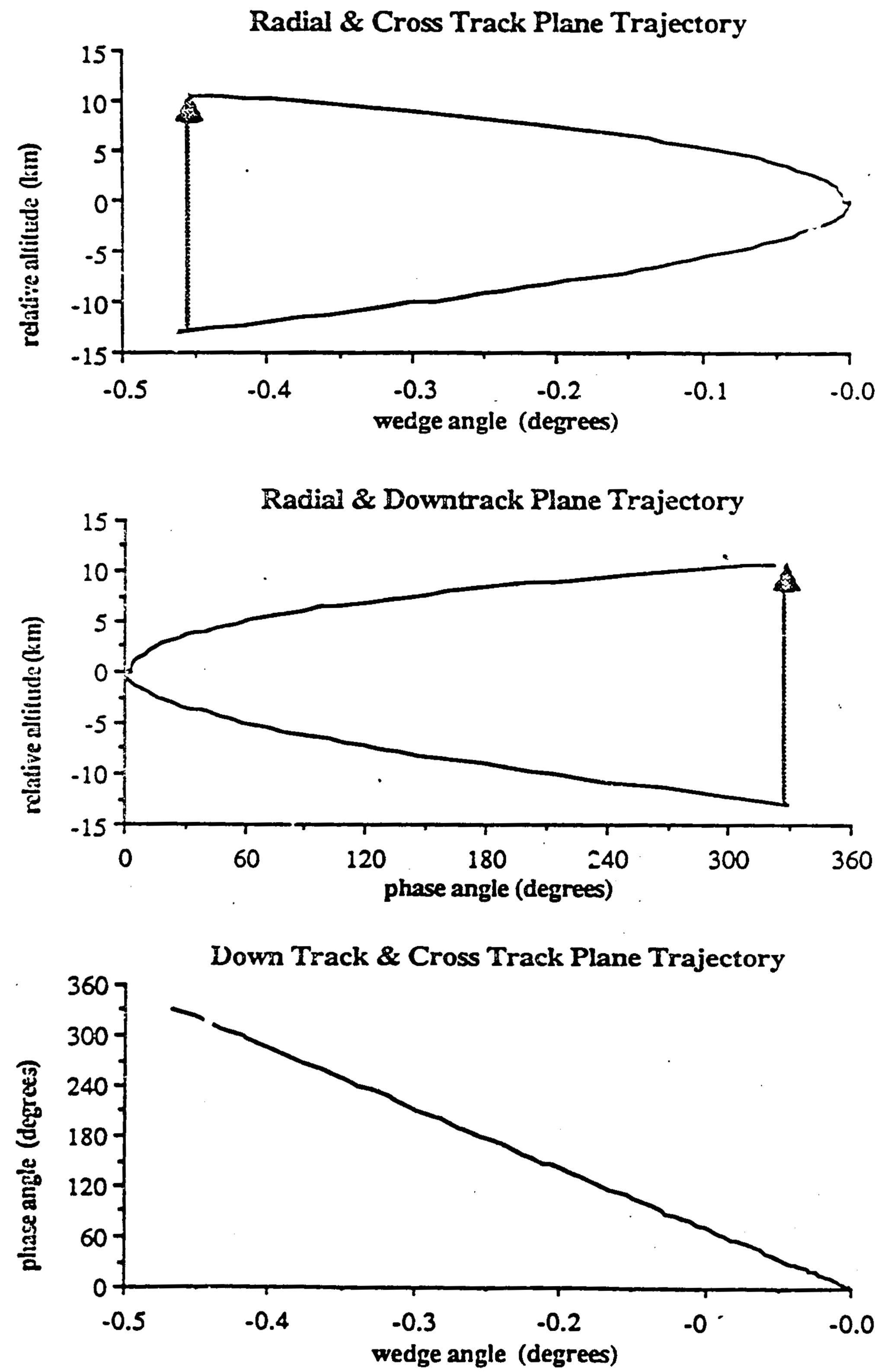

Figure 6.6-2

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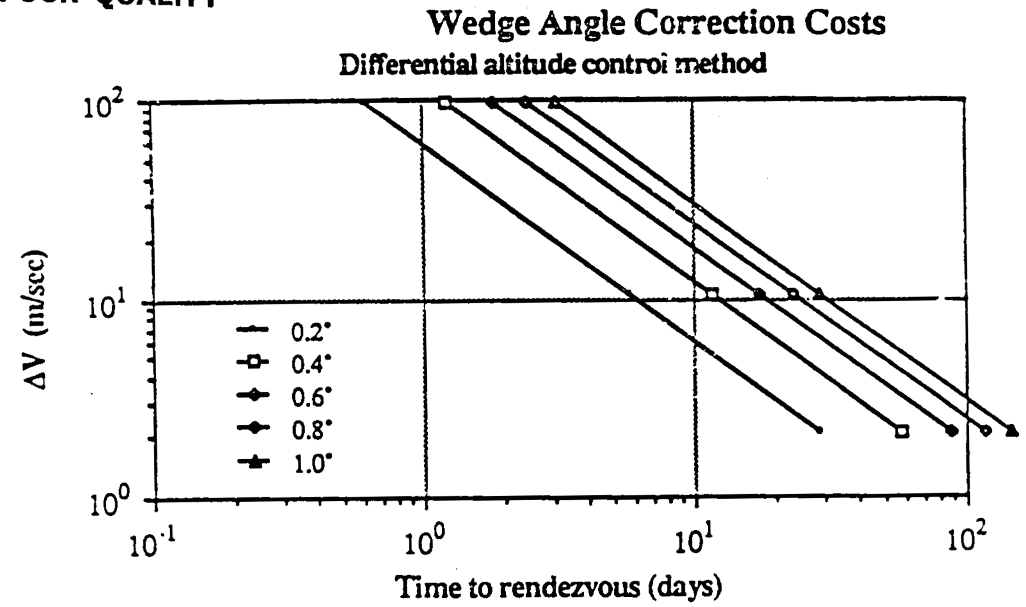

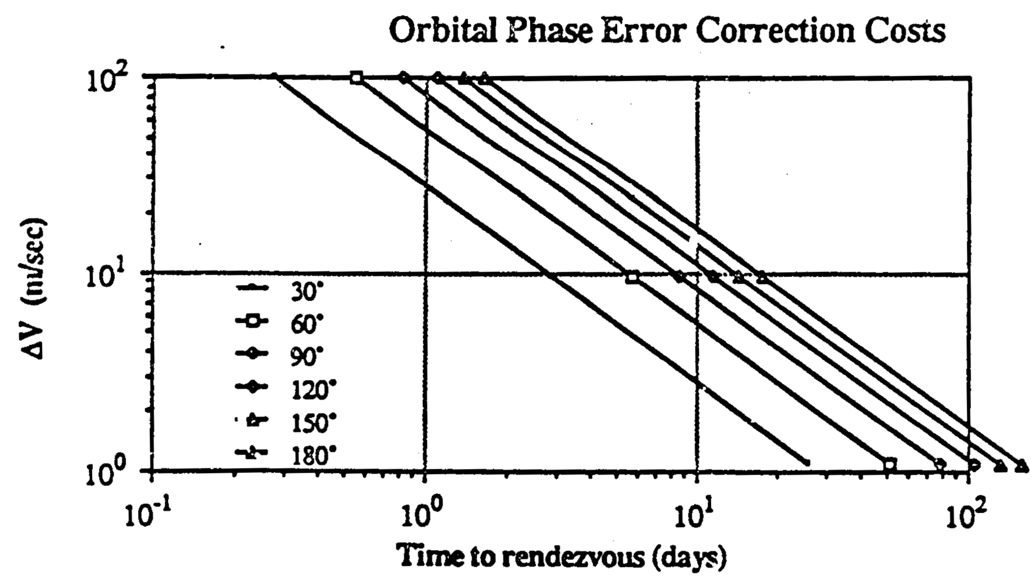

Figure 6.6-3

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relative longitude of the ascending node of SAGE increases, and conversely when SAGE is below SS(see figure 6.6-2). An inexpensive altitude maneuver can put SAGE at the correct altitude above or below the SS in order to correct differences in the longitude of the ascending node. This time of execution, and magnitude of the burn can be determined so the wedge angle between the orbit planes is zero, at a point in the future. As the SS cycles up and down, the accumulated differences will nearly cancel;however, nodal regression rates are not linear with altitude.

Precise formation flying strategies can not be defined, but a general goal is a separation distance of less than 2000 km in order to maintain LOS communications. Since 2000 lbm of fuel(28% of the total mass)would only produce a delta V of 28.6 m/s, the phase angle difference must be kept below 30 degrees in order to rendezvous within one day(see figure 6.6-3). In a real emergency, the remaining fuel on board SAGE can be burned for a rendezvous, and fuel can be produced from hydrolysis until the orbiter arrives to evacuate the SS, while replenishing SAGE.

6.6.1 Collision Avoidance

In case of possible collision from debris, or trackable meteoroids, SAGE will execute collision avoidance maneuvers. If warned sufficiently in advance, this can be a low thrust, prolonged burn. Otherwise, rendezvous or despin fuel would be allotted. As always, the maneuver will serve to raise the altitude of SAGE. A 20 nm orbit change requires a delta V of 200 m/s.

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6.7 Propellant Su›ply

All the estimates for 180 day impulses assumed the worst. No additional contingencies were included. No provision was made for using waste gas or electrolysis--these are variable supplies. ECL^S resupply is minimized when enough H2O is supplied so that O2 needed for metabolism and cabin leakage is generated by CO2 and H2O reduction. Through this process, some CO2 and CH4 will be available for waste gas. An eight man crew will produce an estimated 8.2 lbm of CO2 and 4.1 lbm of CH4 per day. For H2O electrolysis, 2.227 kw-hrs/lbm of power are required(see figure 6.7-1). Typically, the orbiter can dump 1323 lbm of excess H2O before de-orbiting. Through electrolysis, this would provide a major portion of the required resupply.

6.7.1 Propellant Storage

The total impulse required for 180 days in orbit is 6.8x10^5 lbf-sec for the 800 sec Isp resistojets, and 3.35x10^6 lbf-sec for the 550 sec Isp GO2/GH2 thrusters. The GO2/GH2 thrusters used 6091 lbm of a 4:1 ratio of O2:H2. The resistojets required 850 lbm of H2. Using a gas temperature of 240 K, and a pressure of 2500 psia, the total volume of fuel required was 2355 ft^3. This volume of fuel will be supplied by four Propulsion Packets(PP) which the orbiter can easily carry. The fuel lines for the H2 will be outside the SAGE pressure shell, while the O2 system will be integrated with the ECLSS for an emergency storage. The O2 tanks would be manufactur[illegible]m an Inconel liner with a graphite/epoxy overwrap, whil[illegible] anks would be 6061-T6 aluminum with the graphite epoxy o

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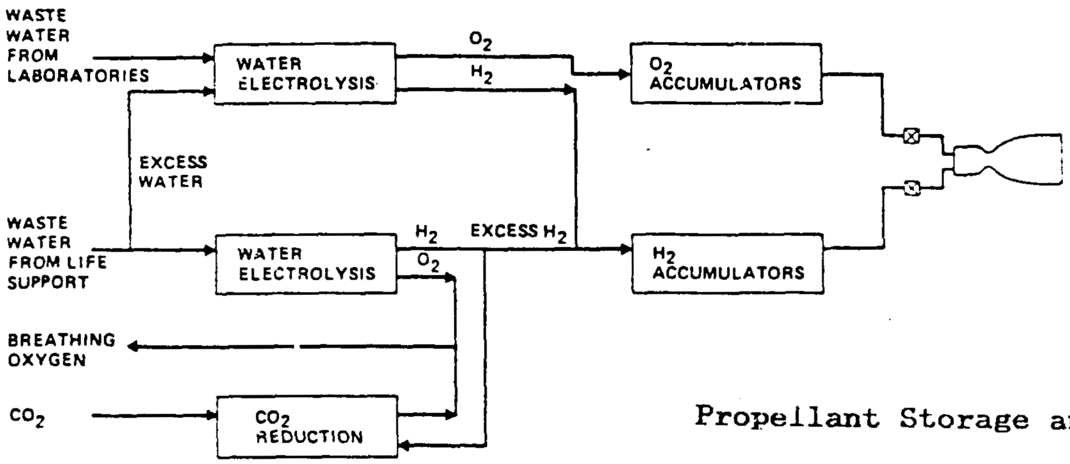

Propellant Storage and Production

Figure 6.7-1

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6.7.2 Propellant Resupply

Propellant Pallets(PP) can adequately carry the maximum amount of resupply propellant in STS. Each carrier would weigh 2500 lbm and would be placed above the RCM by the MSC, requiring no EVA. Also, a port on the LOG module would allow O2 transfer to the internal ECLSS storage in the CM. If one propellant carrier was not completely empty, its contents would be pumped to another one so only empty PP were returned on the STS. Pressure and temperature gauges in each tank would monitor usage. Again, the hoses will be quick disconnects, and the pressure vessels will leak before bursting. Each propellant carrier will have a meteoroid shield, and will be individual to SAGE--but reusable. The high temperature containers will be inspected when brought to earth and returned if found to be safe.

6.8 Final Summary

The SAGE propulsion system meets the drivers for propulsion component requirements, and the demands of the attitude control. The estimated time of orbit integration is 2007 since this will be a period of low solar activity, and the NASA Space Station will be past the certification stage, and nearing the growth stages. Thruster technology will have advanced where these higher assumed specific thrusts and component lifetimes will be common. Since fuel resupply accounts for an estimated 43% of the SS o· ·onal cost, SAGE will be a much more efficient station. Alth a first step, advanced propulsion systems will eventually .ng

permament colonies to Mars.

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CRYMES
MARZEC
PIGNATARO
SEIBERT
WALKER

SAGE

THERMAL CONTROL

7.0 THERMAL CONTROL

The objective of the thermal control design is to maintain the the temperature of the SAGE structure and its internal components within their operating limits. To accomplish this, it is necessary to collect, transport, and reject waste heat. Passive techniques are used wherever possible; however, an active thermal control system is necessary to accomidate waste heat from onboard systems and environmental sources. Sources of heat to be removed include direct solar energy, Earth reflected solar energy, Earth thermal energy, and internal thermal loads.

7.1 PASSIVE THERMAL CONTROL

Passive techniques for thermal control are white/black painting scheme and thermal insulators. The solar pointing side of SAGE is painted with a white paint with an absorptivity of 0.04 to 0.05, and part of the dark side is painted black with an emissivity of 0.90 or higher. In addition, the outer portion of the modules and arms are covered with a multilayer insulation consisting of approximately 20 layers of organically coated aluminized film with dacron mesh separators. The separators allow for venting and pressure changes due to launch.

7.2 ACTIVE THERMAL CONTROL (ATC)

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To provide a high capacity heat rejection capability, SAGE employs an active thermal control system. The active system for thermal control consists of a two-phase ammonia loop to carry waste heat to the dark side for rejection. The ATC system is centralized in the central hub, and four thermal control loops radiate down each arm and through each module. These loops consist of two low temperature and two moderate temperature systems to accomidate high and moderate temperature heat sources. By providing two each of the low and moderate loops, SAGE achieves redundancy for each module/arm section. In addition, the moderate temperature loops have the capability to be manually converted to low temperature loops to accomidate the safe-haven requirement.

The ATC system has the capability to dissipate 100 kW of thermal energy. This allows for the energy balance shown in section 7.3 and any loads generated by experimentation on SAGE.

The central hub contains the inner workings of the ATC system. These include the accumulator, Non-Condensible Gas (NCG) Trap, pump, regenerator, and control bus. Ammonia near its saturation temperature leaves the central hub and travels down the sun pointing side of the arms collecting heat from the arms and solar panels. It then enters the modules and collects heat from the onboard systems. Superheated ammonia is returned on tl ide of SAGE where heat is rejected through condensing heat exchangers.

In the accumulator ammonia is collected and maintained at its temperature setpoint. This is accomplished using an electromechanical motor. Ammonia in the accumulator is placed under pressure by the motor which maintains the temperature within 5° of the setpoint.

The NCG trap is responsible for removing any gas bubbles in the subcooled liquid prior to entering the pump. This will prevent any cavitation in the pump or possibly vapor lock.

The pump provides the positive pressure differential to move the working substance through the loop. In addition the pump will supply the proper pressure for the operation of the thermal cycle.

The regenerator reheats the subcooled liquid from the pump to a temperature near the saturation temperature. This is accomplished by a heat exchange with vapor flowing to the condensing heat exchanger. A temperature monitor is provided to prevent the liquid from being heated too much. In this event flashing becomes a problem.

In the control bus, the working substance is designated and supplied to each loop. The control bus controls the flow rate into each module/arm section allowing for high load areas.

7.3 EXPECTED LOADS ON THERMAL CONTROL SYSTEM

While in orbit SAGE will encounter heat inputs from the following sources, direct solar radiation, Earth reflected solar radiation, Earth thermal radiation, and internal thermal sources. Since SAGE is solar pointing, only the module ends and the length of the arms will be subject to solar radiation, however, a larger area must be taken into account for the Earth thermal and reflected radiation. Considering the area relationships and the properties of the outer coatings, SAGE will encounter the following thermal loads:

PARAMETER	THERMAL LOAD (kW)
DIRECT SOLAR RADIATION	15.2
EARTH REFLECTED SOLAR RADIATION	6.1
EARTH THERMAL RADIATION	3.5
INTERNAL THERMAL LOAD	55.0
TOTAL	79.8

References:

Rockwell International. Space Station Work Package 2--Definition and Preliminary Design Phase. Vol. 7, Book 1-3, Space Station Systems Division, 1986.

8 LAUNCH AND CONSTRUCTION

8.1 OVERVIEW

8.1 OVERVIEW

As previously mentioned, SAGE is composed of modules designed to fit into the Space Shuttle cargo bay. However it is not intended that each module be completely finished when it is launched into orbit. Due to the fragile and mobile nature of some of the equipment included on the SAGE station, it will be launched last in a seperate launch launch designed to make accomodations for for the unique and special features of certain pieces of equipment that could not be protected from the launch environment properly if launched within a module. The crosspieces of the station will be made in two sections with a diameter of seventy two inches and a length of 44 feet with connectors. It will probably be possible to get three of these sections into the Shuttle cargo bay at one time, making it possible to launch only three times in order to get all of the crosspiece sections into orbit. It is planned that the module launches be seperated by launches of crosspieces in order to develop a habitable configuration as soon as possible. The solar cell arrays and the reflector sections of the solar dynamic arrays are to be constructed in a prefabricated, compactable form so that they may be stowed and secured inside the upgoing modules for launch. The construction to take place over nine launches as described table below.

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LAUNCH #	SECTION(S) LAUNCHED	CAPABILITY
1	Central hub- Solar panels	None
2	2 Crosspiece sections/ Solar dynamic boilers	Limited power
3	3 Crosspiece sections	
4	Crew work module	
5	Medical module	Habitable/power
6	3 Crosspiece sections	
7	Habitation module A	Limited 3 axis stabilization
8	Habitation module C	All modules man rated
9	Detail package	COMPLETION

The launching schedule will be adjusted as construction progresses to allow astronauts assembling the station the right amount of time to complete work on one section before another launch goes up. The entire construction time is expected to take approximately as little as eighteen months because of the requirement that the parts of the station be built in a manner that will allow ease of construction.

CRYMES
MARZEC
PIGNATARO
SEIBERT
WALKER

SAGE

9 MODULE PLANNING

9.1 PRELIMINARY DISCUSSION

9.2 BASIC MODULE DESIGN

9.3 MODULE LAYOUT

9.1 PRELIMINARY DISCUSSION

The preliminary module layout to be described in this section is not meant to be a series of working drawings, the space allocation charts and spatial diagrams contained herein are meant only to illustrate the feasibility of the SAGE concept and to provide the reader of this technical report with the basic knowledge of the internal arrangement of SAGE. It may appear, at first glance, that there is a large amount of unaccounted for space in the station. This appearance is due to the fact that only items of major importance and necessary equipment are assigned to both the chart and the diagrams. The remaining space not used as free space will certainly be filled with piping, wiring, venting, and access openings. All figures contained in the charts and diagrams are estimates which, although rough, give assurance that there exists enough room on board SAGE to accomodate all equipment and facilities necessary to meet the mission criteria as well as to provide the desired comforts with a substantial degree of backup and safety features.

9.2 BASIC MODULE DESIGN

Figure 9.1-1 is a design for the basic interior structure common to all modules of SAGE. The crawl space is designed to allow machinery access underneath the module floor and along the length of the module. The overhead space will have different uses in different modules as will b bed later. A six foot diameter circle is sketched in on all module floor plans (Figures 9.1-1 to 9.1-4) and may actually be painted in red on the module floor after construction. This is due to the danger involved in radial transit and will serve to remind crew members not to place any objects under the ladders extending from the crosspieces into the modules because of the potential harm that could come to anyone descending into the module. Below is a chart describing the elements which are to be included in all modules as well as the basic volume divisions of the space in each module and the volume requirements of some miscalleaneous items which are to be included on board SAGE.

Items included in all modules

Item	Volume (cubic feet)
Commode	28.40
Water recovery and management system	109.13
Fire detection and suppression system	2.75
Atmospheric control and supply	155.71
Temperature and humidity control	101.79
Atmospheric revitalization	254.02
TOTAL	680.20

Items specific to certain modules

Laundry (washer and dryer)	70.00
Shower	74.00
Handwasher(zero g capable)	8.30
GALLEY ITEMS:	
Oven	4.70
Inventory unit	4.70
Refrigerator	35.40
Freezer	35.40
Water dispenser	4.70
Hand washer	8.30
Dishwasher	4.70
GALLEY TOTAL	97.90
Medical	undetermined

Volumes contained in modules (in cubic feet)

FOR THE BASIC MODULE:	
Overhead	1263.70
Between decks (overhead to deck)	4047.98
Crawlspace	273.44
Below deck	990.26
TOTAL VOLUME	6575.38

It appears from the tables above that there is a lot of extra space on board SAGE. This is not the case. Not included in the above charts are the requirements for piping, venting, wiring, and storage space. What is indicated by the charts above is that enough space is available on board SAGE to accomodate all necessary equipment.

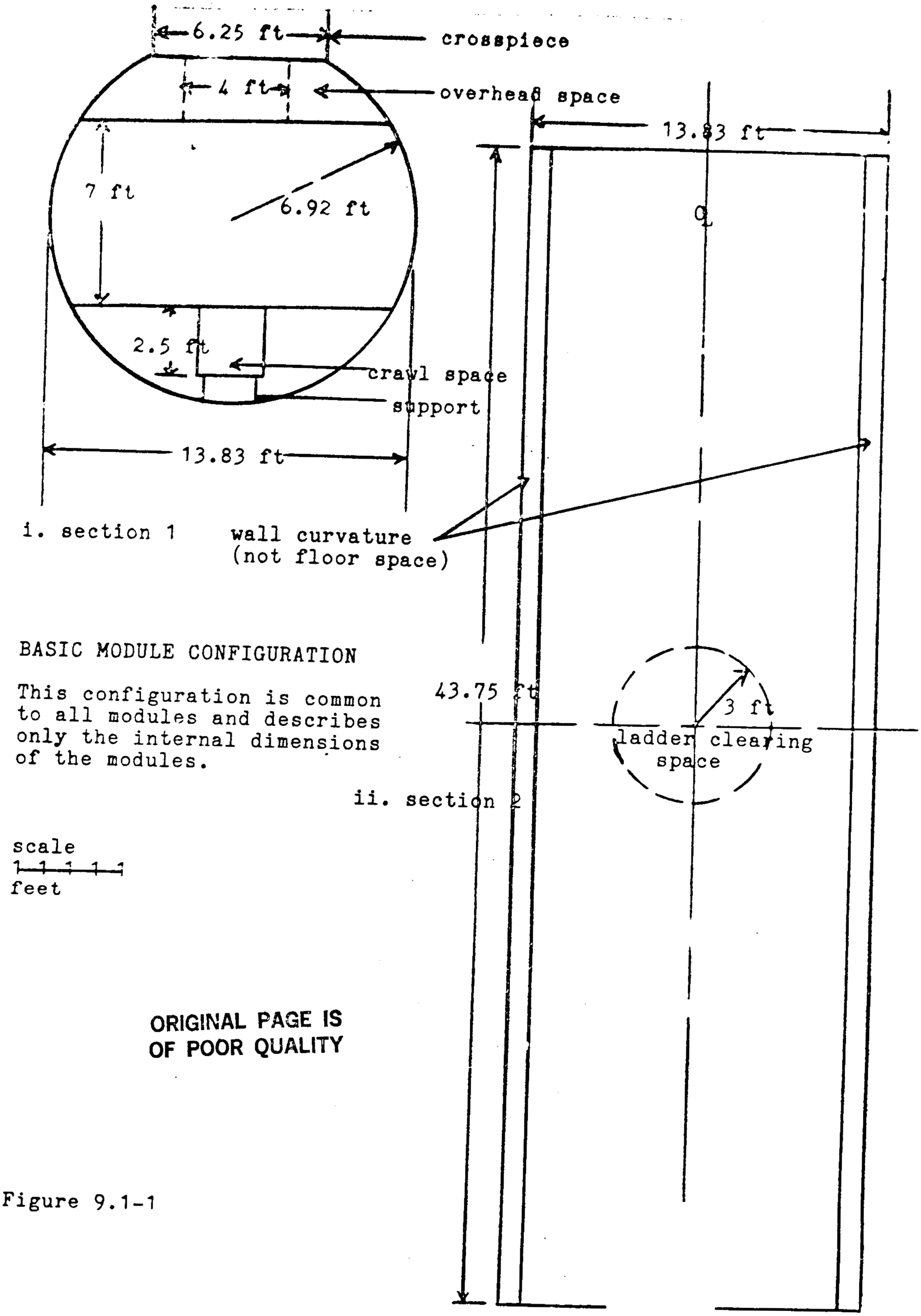
9.3 MODULE LAYOUT

Modules A and C (Figure 9.1-2) are the crew habitation modules. Each of these modules contains personal quarters for four crew memoers with 54 square feet of floor space in each individual's quarters. There are two showers and toilets in each of these modules, with one of the toilets in each module designed to operate in zero g in case of planned or accidental de-spin. There is a large open area in the center of the module to serve as a crew lounge area. There will be computer terminals in each crew member's quarters to allow for work in quarters. System monitoring consoles will be mounted in the overhead to allow easy observation of the SAGE systems status. Alarms will alert the occupants of the habitation modules should an emergency occur or should a system need immediate attention.

Module B (Figure 9.1-3) is the crew work module and galley. The galley is designed after the planned galley on Space Station and contains all of the equipment listed in the tables above. There is a large open area for t to dine in which may alternately be used as a work or recreation space when it's primary purpose is not being fulfilled. The on board computer system is contained in this module along with control consoles for other systems. The consoles contain controls for the systems listed on the diagram. Because the solar dynamic arrays are located on the sun pointing ends of both modules B and D, the system controls are located directly adjacent to the arrays on the inside of these modules.

Module D (Figure 9.1-4) is the medical and primary control module. The medical portion of the module contains equipment which is described later in section 10. This module houses the main ECLSS system controls for SAGE along with the primary spin and de-spin control system. Emergency systems controls and secondary docking system controls are also located here. The primary docking controls are located in the central hub module. The arrangement of controls for the solar dynamic array is the same as in module B.

Simply because a system's controls are located in a particular module does not mean that the entire system is contained in that module. SAGE is designed to prevent single point failures which could lead to catastrophic loss of the station and insrease the chances of crew survival should a failure occur.



BASIC MODULE CONFIGURATION

This configuration is common to all modules and describes only the internal dimensions of the modules.

scale
feet

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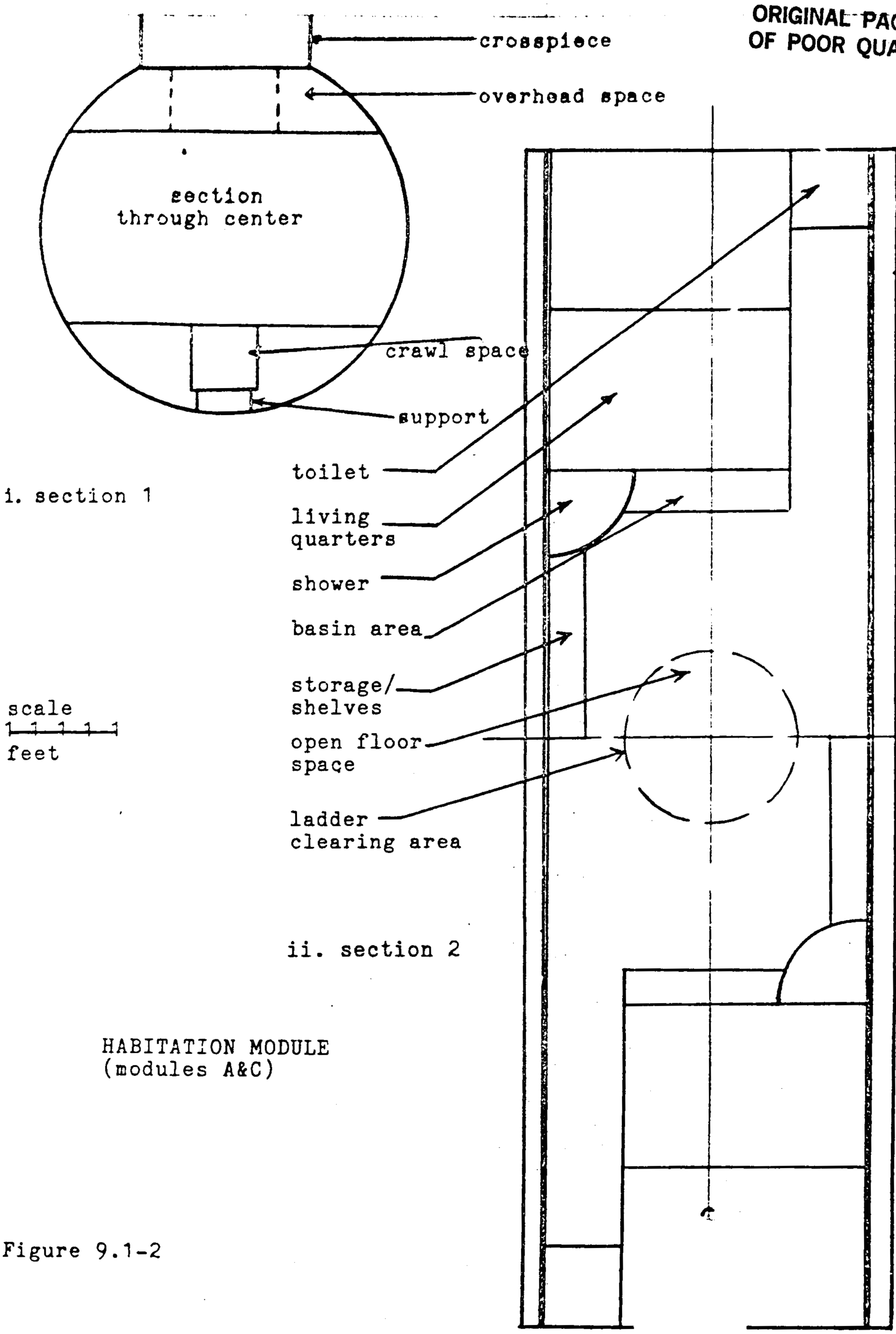
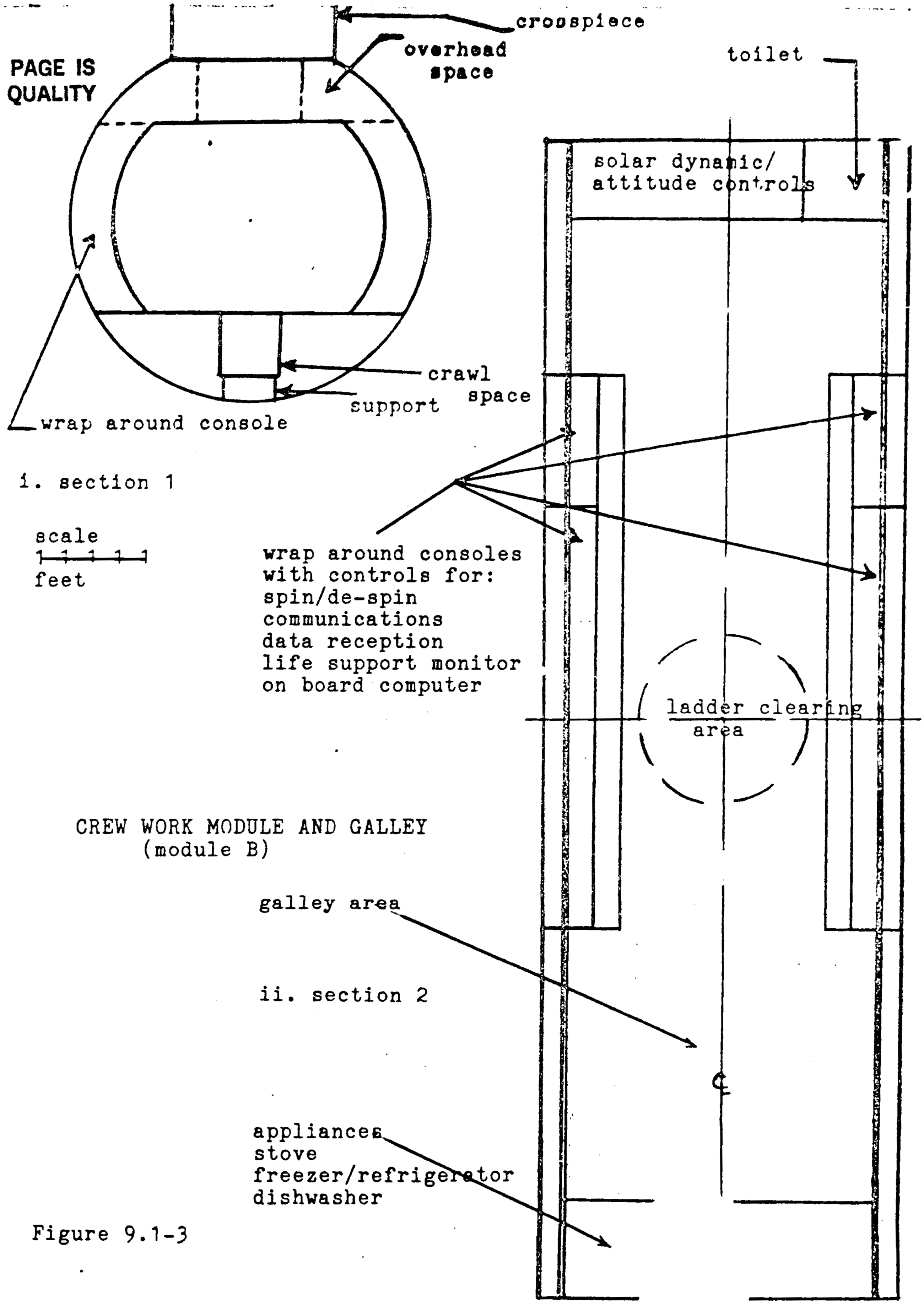
Figure 9.1-1



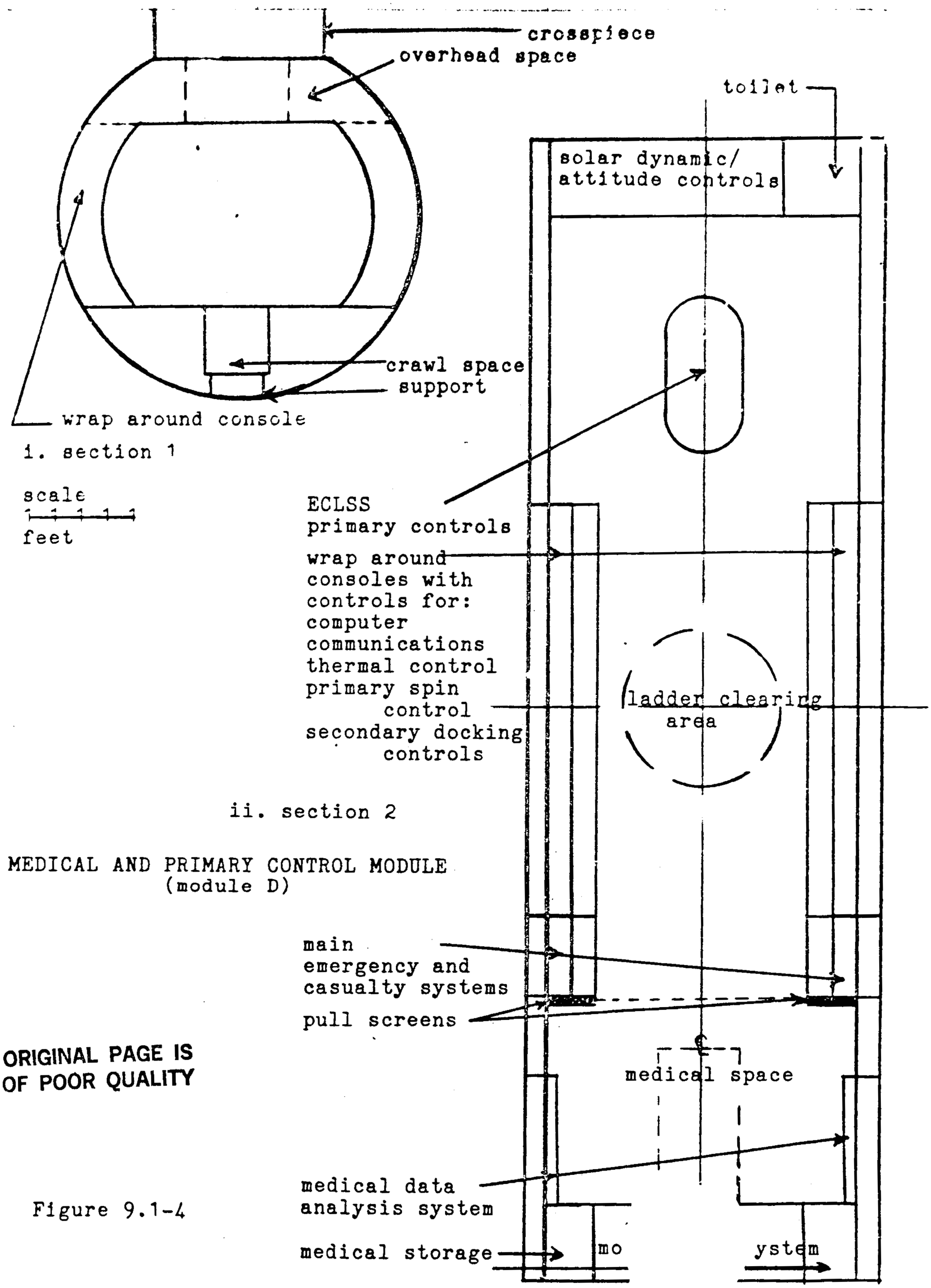
HABITATION MODULE
(modules A&C)

Figure 9.1-2



CREW WORK MODULE AND GALLEY
(module B)

Figure 9.1-3



MEDICAL AND PRIMARY CONTROL MODULE
(module D)

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Figure 9.1-4

10 EXPERIMENTAL OPPORTUNITIES

10.1 OVERVIEW

10.1 OVERVIEW

The entire purpose of the SAGE station is to serve as an experimentation ground for future space missions to establish long term inhabitation of space. The capability of the SAGE station is in itself an experiment. Probably the first experimental data collected on board SAGE will be a graduated increase in gravity level over a long period of time. Measurements will be made to determine the medical effects of these very low levels of gravity on the crew of the station. For the purpose of having a data base to compare against, the initial SAGE crew will probably be composed of astronauts who have been living in weightlessness for a length of time. As the level of gravity is increased it will probably be of scientific benefit to keep a few members of the original crew on board as a control group while new crew members, from both Earth and a weightless environment, are exchanged with the experimental group already on board. In this way it will be possible to construct a set of curves describing the gravity necessary to prevent the deleterious effects of weightlessness as a function of time to be spent in space. As SAGE continues in it's mission it is likely that the data profiles will be extended to include other variables such as age, present health, level of physical fitness, and sex.

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Studies will also be conducted on SAGE to determine the extent of disorientation caused by higher RPM levels and the actual information will be able to be collected as opposed to using studies conducted in centrifuges on Earth. This data will also be characterized by a number of parameters and will be very valuable if future space colonies are to be built with artificial gravity.

Aside from the medical data which can be aquired on SAGE, information pertinent to other areas will also be uncovered. One area of particular interest for those interested in future space efforts will be in variable g manufacturing. Already planned for space station are a number of experiments centering around manufacturing in space. While this data is collected at Space Station, data will be conducted on board SAGE to help develop new manufacturing technologies for use at different gravity levels. Because gravity has an effect on many manufacturing processes, including density variations and the way that different products of reactions form, it will be important to discover exactly what the benefits and problems of manufacturing at different gravity levels are. This information will certainly be useful if we ever decide to set up manufacturing stations on the surface of the Moon or Mars in the course of exploring the solar system. New manufacturing technologies may develop which will allow prod[illegible] to be made in space with more desirable qualities f

Earth.

In addition to the above specifically mentioned types of experiments there will be plenty of opportunity for the crew members of SAGE to monitor other experiments yet to be thought of as a part of their daily duties. As scientists themselves, the astronauts on board SAGE may have the opportunity to observe their own experiments and develop new ideas that may help uncover better or safer ways of exploring space. The opportunity to conduct experiments in so many areas under conditions never before variable will surely prove to be one of the greatest opportunities for discovery yet and will no doubt drive scientists and engineers to use the opportunity of SAGE to it's full advantage.

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SAGE

Launches, Cost, and Feasibility

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11.0 Overview

The SAGE mission of providing an artificial gravity environment to be operated as an adjunct to Space Station is a necessary component of any long term commitment to the maintenance of a manned Space Station by the United States. The adverse physiological effects of prolonged astronaut subjection to zero gravity are well documented and quite debilitating, especially upon return to Earth. The benefits of SAGE include increased crew productivity, increased comfort, decreased physiological side-effects, decreased crew replacement frequency, the ability to vary the gravity level from 0 to 0.6g, and the capacity to gather medical data on the physiological effects of varying gravity levels. The importance of these factors cannot be overstated as the rotation of eight-man crews between Space Station and SAGE will provide vastly increased maximum safe flight times for astronauts. This longevity would provide continuity and would thoroughly demonstrate and fulfill our commitment to a permanent manned U.S. presence in space.

11.1 Launches

The SAGE system was limited in several ways when its design was first conceptualized. One of the limits was the desired maximum number of STS launches to lift the entire system into orbit. This maximum was set at 30% of the number of launches required to lift Space Station. Figure 10.1-1 shows the breakdown of the launches, resulting in a total of nine launches to establish the IOC. Space Station has been fluctuating so much in its size, cost, and capability that a precise comparison of launch percentages is quite impossible. However, considering the possible Space Station design, which includes five modules, four solar dynamics arrays, a hangar, very large keel, thermal radiators, and robotic arms, it is highly likely that Space Station will require at least 20 launches for its IOC. This places SAGE at less than 45% of the number of launches required by Space Station. This is obviously over 30%, but lifecycle launches will be reduced so significantly by decreased resupply and crew replacement missions that we feel the launch number overrun will be made up over the lifetime of SAGE. It must also be recognized that SAGE will help reduce Space Station's expected lifecycle crew replacement launches by providing the crew with the benefits of rotation to SAGE, while permitting them to continue performing worthwhile tasks.

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Figure 11.1-1 SAGE Launch Budget

Launch #1	Hub
Launch #2	Crosspieces(2)
Launch #3	Crosspieces(2)
Launch #4	Module
Launch #5	Module
Launch #6	Module
Launch #7	Module
Launch #8	Power Systems
Launch #9	Crew, Supplies, Misc.

11.2 Cost

Another limitation placed upon SAGE during its conceptual design was the desired maximum cost, which was set at 20% of Space Station cost. Again, the fluctuations in the cost, size, and capability of Space Station greatly impair any precise effort to compare the cost percentage. Figure 10.2-1 shows the projected cost of SAGE in decidedly approximate estimates based on the varying degrees of precision with which we could specify the systems and find cost estimates for them. Space Station has fluctuated from $14 billion to $18 billion, and back down to $12 billion. These fluctuations have all taken place during the design of this project and it is difficult to say which to use. However, the primary cost adjustment period occurred at the beginning of the phase of design when we were designing the major systems and finalizing the structural design. This time frame was also the period in which Space Station cost was projected at $18 billion. This makes the SAGE IOC cost limit $3.6 billion. SAGE is not an inexpensive design. Components like the $570 million power system make meeting the 20% goal for IOC cost difficult.

Once again, however, we feel that the lifecycle benefits of decreased resupply and crew replacement frequency will introduce savings of such proportions as to make up any IOC cost overruns. In addition, advanced technologies will make great savings likely. The power system is a strong example of such savings. The life-cycle costs for the power system, for a 30 year lifetime, are projected at $1.14 billion which is a 57% savings over the $2.64 billion that would be required for an all photovoltaic system. Space Shuttle launches presently cost about $80 million; so one can see that one resupply launch every 180 days will result in a cost of only $160 million per year for launches, whereas any shorter resupply time or any less physiological maintenance effort would result in an increased number of launches, and an increased number of astronauts to be paid, trained, and conditioned to life in space. Furthermore, the closed loop life-support systems not only decrease costs through decreasing resupply launches: they also reduce the required quantities per man per day of fresh supplies to be brought in those resupply launches.

Figure 11.2-1 SAGE Cost Budget

System	Cost in $ Millions
Structure	1600.0
Power Systems	873.3
Communications	9.0
Life Support	?
Propulsion	120.0
Thermal Control	?
Launches (9)	720.0
Experiments	?
Supplies	?
Sub-Total Estimated Cost	3322.3
Total Estimated Cost	4600.0

(Based on size comparison with Space Station, accounting for the fact that R&D will be done by Space Station.)

11.3 Feasibility

The necessity of having any space station is fiercely argued in political circles. That same arguing has resulted in much of the fluctuation in the Space Station design. The primary reason for this is that, as the economy of the United States continues to suffer from fierce competition from imports, the increasingly unfavorable balance of trade, the declining strength of the dollar and a sickly stock market, the people of the United States and their elected representatives in government are reluctant to appropriate funds for programs which do not promise short-term, tangible benefits to the constituency. Short-sightedness has nearly always been the one facet of Congress that has troubled the space program, making the funding of any ambitious NASA program almost as difficult an accomplishment as the program itself.

Their are three major justifications for any space program of reasonable proportions. Firstly, there is an extremely high rate of technology return to society as evidenced by space program spin-offs like car vacuums, space blankets, tinted windows and thousands of other products. It is certainly arguable that the profits and paid wages of the companies which produce such items exceed the investments made in NASA, which made possible the existence of such companies. Secondly, there is a great amount of scientific data which can be collected from space which cannot be be collected on Earth. This scientific data makes possible weather prediction, navigation, and thousands of industrial applications like oil surveying and fish finding. Thirdly, and very importantly for the justification of SAGE is the strategic advantage of both being in space and maintaining a technological advantage over potential adversaries. The final analysis of the cost of SAGE and any important space program is that money appropriated for space is not money spent, but money <u>invested</u> in the economic and strategic future of this country. SAGE is a timely investment in very real terms: it is not merely an academic exercise; but a realistic proposal to secure the United States' manned place in low earth orbit and to do so with capabilities and longevity which assure the permanence of man's move to space.