ENVIRONMENTAL DESIGN GUIDELINES FOR A SECOND GENERATION, LEO, PERMANENTLY MANNED SPACE STATION

by

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To Dr. Dahesh

the dream and the memory burns in my heart...

To be able to rise from the earth;
to be able, from a station in outer space,
to see the relationship of the planet earth to other planets;
to be able to contemplate the billions of factors
in precise and beautiful combination that make human existence possible;
to be able to dwell on an encounter of the human brain and spirit
with the universe -
all this enlarges the human horizon. . .

NORMAN COUSINS, 1973

1.0 ACKNOWLEDGEMENTS

Ranko Bon and Dennis Frenchman openly undertook the challenge of being my advisors in this endeavor. I am grateful to them for their discussions with me on topics that were both inside and outside the realm of this thesis. They successfully nurtured many ideas with their respective areas of expertise that ultimately became the framework of this thesis. I have benefitted from their input and their friendship.

2.0 PREFACE

The history of human journey into the sky and the space beyond is as brief and recent as it is bright with spectacle. People surely have dreamed and aspired to rise from land with the freedom of a soaring bird for as long as they have inhabited the planet. Yet, less than two-hundred years have passed since the day in December of 1783 when two Frenchmen rose from a field outside of Paris in a linen and paper balloon; and less than twenty years have passed since December 1968 when three Americans first orbited the moon.

Fewer than eighty years spanned the time from the first controlled wing aircraft at Kitty Hawk, North Carolina in 1903 and the first landing of a winged spacecraft in the Mojave Desert in 1981. Just fifty years separate the backyard rockets of Robert Goddard in 1926 and the behemoth Saturn V launches of the 1970's.

Two centuries hold the recorded history of our adventures into the sky and two decades hold the recorded history of our adventures into space.

We now stand at the threshold of the next chapter of man's adventure beyond the realm of his planet: The Space Station.

3.0 TABLE OF CONTENTS Page

4.0 ABSTRACT

This thesis is a continuation of the thoughts and efforts of the author's participation and co-organization of the Space Station Design Workshop (SSDW). The SSDW was a student run event whose inception surfaced in the Spring of 1986, materialized over the summer of that year, and subsequently "launched" itself in the Fall term.

The emphasis of the SSDW was on the development and design of a deployable truss system which would be transported in, and deployed from, the cargo bay of the space shuttle. The design emphasis on deployability over an erectable system was based upon the former's lower construction overhead, the creation of "instant real estate", and the inherent lower Extravehicular Activity (EVA) time resulting in a higher margin of crew safety. (See Appendix A and Appendix B for summary and drawings)

This thesis is a continuation of the groundwork laid by the SSDW into the design criteria and implementation strategy for the living habitat of a six man Space Station. The scope of the thesis can be summarized in its six sections:

1. A study of appropriate space station analogs with a presentation of conclusions and recommendations based upon the findings
2. A study of the anthropometrics of the human body in a zero-gravity environment with a presentation of conclusions and recommendations based upon the findings
3. A study of the physiological effects of zero-gravity on the human body with a presentation of conclusions and recommendations based upon the findings
4. A study of three strategies of interior module design with a presentation of conclusions and recommendations based upon the findings
5. A presentation of the the current NASA Space Station art as a basis of comparative study to this thesis' proposed design
6. A presentation of a complete space station design proposal and implementation strategy based upon recommendations of the preceeding studies

Concepts Developed

The focus of the final design is on a Digitally Enhanced Psychoacoustic Environment (DEPE) system coupled with a 360° projection communication/entertainment assembly, a Personal Autonomous Domain (PAD) system with a rotating gravity inducing sleep/exercise platform[1], a perimeter rail utility supply system with a movable beam assembly, a concept for containment /evacuation procedures, and a central galley/communal space with built-in logistics support.

5.0 BACKGROUND PHILOSOPHY

The design of a permanently habitable environment in space calls upon the orchestrated interdisciplinary involvement of the likes unprecedented in the fields of research and development. The surrounding site conditions of the space environment are far more remote and extreme than any analogous earth-based condition. Access to and from the "site" are expensive; both from the standpoint of overhead economics, and, as was seen from the Challenger disaster in January of 1986, potentially from the standpoint of human life.

It is one endeavor which could potentially be a peaceful call to service on an international scale of cooperation and involvement. The technologies and devlopments of a program on such a scale would trickle down and subsequently impact and hopefully enhance all levels and aspects of the human condition here on earth. It is a seed of adventure whose possiblities are only limited by the people and societies behind them working towards their fruition.

The interior of the Space Station is the aspect of the project in which the majority of human productivity and innovation will occur. It is a unique volume with foreign conditions to our present physiological being, perspective and awareness. Several concepts are explored in this thesis in an effort to illuminate potentials for the design of a human environment within this larger environment. There is much research and analysis yet to be done in the design of habitable environments in space. The concepts and recommendations here are only the beginning of the process leading to a fully manned Space Station.

6.0 INTRODUCTION

6.1 Physical Design Constraints

One of the main constraints and design considerations in space station design is the fact that all components must be delivered to orbit by the space shuttle, from which they may be either assembled or deployed. Specific considerations of the shuttle are those of payload mass (29,484 kg, maximum) and payload size (18m long by 4.5m in diameter, maximum). Economic considerations are understood and accepted in the systems analysis as they relate to the cost of assembly time on orbit and the replacement cost to orbit. Modularity is noted as an advantage in packaging, transportation, organization and expansion potential.

6.2 Purpose of the Space Station

A primary purpose of the proposed space station is that of developing metalurgical, chemical and pharmaceutical manufacturing processes and products in a low gravity environment. The station is also to be used for stellar observation and research, and as a transportation node for future missions. Facilities must also be available to provide servicing and maintenance operations for satellites.

6.3 Programmatic Considerations

As for programmatic requirements, living spaces for sleeping, eating, food storage and preparation, hygiene and exercise, recreation, work and medical support must be provided. Logistics equipment must be available for waste removal; thermal, humidity and carbon dioxide control; energy production and storage; and data and communications systems. Satellite hangars and orbital maneuvering vehicles are necessary, and systems for refeuling and storage must also be integrated in the overall design.

7.0 STUDY OF ANALOGOUS CONDITIONS

There are many strategies in the endeavor to generate a successful and fully operational space station design. In as much as there are knowns we can predict and design for, there are equally as many, if not more, unknowns that we must creatively anticipate and incorporate into our holistic design strategy.

Foremost in this area is the study of human adaptation to isolation and confinement that would be encountered aboard the space station. One way to begin to understand what some of the resulting problems may be, is to look at analogous conditions of groups living and working in confined and isolated settings here on earth. By no means will this give us the complete picture of the implications of living in environments outside our terrestrial realm, but rather it may serve to give us a general basis of strategy that will approximate what may be encountered under such conditions.

7.1 Antarctic Reasearch Stations

During the 1960's and early 70's, a comprehensive study concerning the behavior and selection of Antarctic personel was conducted by E.K. Eric Gunderson of the Naval Health Research Center. His objectives were to study the nature and degree of stress experienced in the Antarctic environment, construct improved selection methods, and to develop effective performance measures. The study groups were comprised of groups ranging from 8 to 36 men of which 60% were Naval personnel and 40% were civlian scientists and technicians. The data was collected through clinical examinations, military records, questionaires, station leader's logs and diaries, debriefing interviews, and site visits. Gunderson found that although cases of psychosis or severe neurosis have been extremely rare at A4ntarctic stations, minor emotional disturbances were very common[2].

Figure 1 depicts a small South Pole Station typical in Antarctica. Of the several nations maintaining year round habitation on such stations, the United States is unique in its organization and heterogeneity of personnel. The facilities are provided by the U.S. Navy and staffed by the National Science Foundation. Typically, a group of 20 Navy and scientific personnel spend year-long sojourns at the base. Of the 12 month stay, 8 months is spent in total isolation and confinement at the base and its immediate surroundings.

Human performance very often deteriorates during these extended tours of isolation, and the individual under study is usually the last to realize the degraded condition[3]. Solutions which helped to alleviate these problems were keeping oneself occupied with an activity, creating a comfortable personal and private space, and special attention to specific human productivity variables within both the work and non-work environments. Of particular note, is that the adverse effects of isolation seemed more pronounced on the self motivated college educated staff, than on the union labor force with experience in other remote camps[4].

The total perception of a remote or hostile environment isn't just limited to the abstract of human emotions. The technical aspects of life sustaining equipment and related implements quickly become important and are perceived quite differently than tools used in day-to-day operations. For example, in one camp everyone had to sleep with their parkas on, survival bag and boots within arm's reach, no artificial lighting on and a large bulldozer running all night in a nearby shed with the explicit purpose of cutting the camp in half in case of fire. Conversely, in another camp that was adequately equiped with a sprinkler system, normal activities such as sleeping were nowhere as near as life threatening.

General rules of thumb quickly develop in these remote bases to predict and circumvent potential catastrophes. What may seem a minor annoyance or inconvenience in a less severe environment could have fatal implications in a remote environment. These "rules" include warmed utilities, water lines that can't leak towards electrical lines, and no connection whatsoever between fresh and grey water systems.

Overly cautious procedures can also have very noticable and negative repercussions.

Such is the case of bentonite being used in a drinking water sytem at one base. The result was a very distictive, unpleasant taste which cut drinking water consumption to almost zero[5].

7.2 Nuclear Submarines

The advent of nuclear-powered submarines stimulated interest in the behavioral/psychological feasibilty of long-duration submerged patrols. The earliest such study was in 1953. Known as Operation Hideout, its primary concern was the effects of a hyperbaric environment on human performance. The two month study consisted of 23 crew members sealed aboard a submarine that was tied to a dock. The crew's psychomotor performance and alertness were measured and showed no significant decline in function[6].

In another study conducted in 1957, symptoms of stress resulting from submerged isolation and confinement aboard the U.S.S. Nautilus were recorded. The studies showed signs of fatigue, dizziness, headaches, muscular tension, and amotivation[7].

In 1960 the crew of the Triton was monitored during its historic 84-day submerged circumnavigation of the globe that traced Magellan's course. It was this experience that prompted the setting of the optimal patrol length at 60-70 days.

In a later study aboard a Polaris-class submarine, some of the primary causes of stress were identified during the 60-day submerged patrol. These included the inability to communicate with persons in the outside world, lack of sufficient personal territory, monotony, and the concern for the conduct and welfare of family members ashore. It was found that a state of depression was the common mode of adjustment to the confined and isolated conditions aboard the submarine[8].

An ongoing Naval research program on behavior has incorporated several design features and organizational/motivational techniques in its submarines. These include:

a) "Gold" and "Blue" crews rotated on 90 day tours.
b) Extensive self-paced educational opportunities such as films, arts and crafts.
d) Superior food, open mess hall, ice cream locker, soft drinks and snacks available at all times.
e) Psychologically benevolent interior design.
f) "Periscope Liberty".

Most of the study in "submarine psychology", however, has focused on the issues that will help lead to the selection of the most appropriate persons for extended tour duty, rather than on the habitabilty of the premises. It is interesting to note, however, that at any given moment, there are approximately 10,000 U.S. military personnel living and working in these confined and isolated conditions beneath the waves. FIgure 2 shows the layout of a fleet ballistic missile submarine.

7.3 Undersea Habitats

The expansive depths of the ocean have often been compared to the vastness of the depths of outer space. In many aspects, the life sustaining preparations that are necessary for each of the environments parallel each other.

The first serious underwater habitat experiment was conducted in 1962 by the French adventurer and entrepreneur, Jacques Cousteau. Named the Conshelf Program, the design was to test the feasibility of extended duration commercial diving at extreme depths. Six "oceanauts" spent over three weeks living in the self-contained spherical module. Work was conducted outside the habitat, located 328 feet down in the Mediterranean Sea, to demonstrate the range of human capability in seabed industrial operations. All performance was closely monitored by topside personnel. The only reported difficulties were technical ones dealing with pressure and humidity[9].

Between July 1964 and October 1965 the U.S. Navy launched the Sealab I program. The 9 x 40 foot Sealab laboratory was located at a depth of 192 feet in the waters off Bermuda. Four navy divers lived in and conducted marine observations in the vicinity of the habitat for a period of eleven days.

Sealab II, (Figure 3) slightly larger than Sealab I, was located at a depth of 205 feet on the continental shelf off La Jolla, California. Three ten-man teams, consisting of Navy divers and civilian scientists, each spent 15 days in the habitat. In addition to extensive psychological tests and monitoring, the behavior of the men was systematically observed and recorded. This data included eating and sleeping habits, activity levels, variation of mood, morale, motivation and cooperation. Following the submersion period, each participant completed questionnaires, was interviewed and subjected to a medical examination[10].

Sealab III was a 10 x 10 domed cylinder with an open bottom located at a depth of 50 feet off Anacapa Island, California. Two four-man teams each made dives of 12 hours. The project was upset by an accidental death of one of the divers while testing a new piece of diving equipment.

Conclusions drawn form the Sealab program were:

a) All future ventures of a similar nature would require improved coordination of medical and engineering phases with a great deal of control vested in the medical compliment of the team
b) A degradation of human performance was evident which increased with the complexity of the task (a portion of this performance decrement was associated with personality variables)
c) Persons who were of a more social nature tended to acccomplish more in their diving operations

d) Social interaction was strongly related to successful adaptation to the undersea environment

Project Tektite (1969-70), was a multi-agency experiment conducted by the U.S. Navy, NASA, the Department of the Interior, and the General Electric Company. The habitat consisted of two domed cylinders 12.5 x 18 feet high, connected by a tunnel. (See Figure 4) The habitat was mounted on a support structure at a depth of 49 feet in Great Lanreshur Bay, St. John, Virgin Islands. The crew of Tektite I consisted of four male scientists from the Department of the Interior. They performed domestic chores, habitat maintenance and repair, marine science research, and biomedical and behavioral science programs. The duration of the duty was 60 days.

Tektite II involved crews of four scientists and one engineer each. There were four missions of 14 days duration and six missions lasting 20 days each. One mission was performed by a crew of five women.

One of the primary goals of Project Tektite was to evaluate the behavioral dynamics of small groups over long-duration mission operations. This was accomplished by administering a variety of testing instruments, collecting personal interviews, and continuously monitoring operations via closed circuit video and audio channels[11]. Decompression time from the Tektite station was 19 hours. Some of the relevant conclusions derived from this project are:

a) Individual gregariousness was positively correlated with operational performance.
b) Privacy was very important, especially to individuals who did not relate well to the group.
c) "Aquanauts" tended to sleep longer during the mission than pre- and post- mission periods.
d) Conversing was the most frequent leisure activity.
e) One of the most popular places in the habitat was the bridge (control room) where contact with topside personnel was possible.

It was also recommended that future habitat or space vehicle design provide variability (particularly visual), good quality food with dietary variety, adequate work aids, individual privacy, and to the extent possible, the design should avoid multiple-use spaces.

7.4 Skylab

The most closely related analogue to aid in adaptation criteria evluation is Skylab. It was the first experiment in actual space station building and was constructed primarily of surplus hardware from the Apollo program. It was launched on May 14, 1973. In addition to the unmanned launch, there were three manned missions of 28, 59 and 84 days duration conducted between May 1973 and February 1974. Figure 5 is a diagram of the Skylab station docked with the Apollo Command Module.

As part of the research program aboard Skylab, evaluations were conducted concerning the crew quarters and overall station habitability. Habitability was viewed in this evaluation as being comprised of nine elements:

a) Environment
b) Architecture
c) Mobility and Restraint
d) Food and Drink
e) Garments
f) Personal Hygiene
g) Housekeeping
h) Interior Communications
i) Off Duty Activity

It was concluded that while habitability is often considered only in terms of comfort and convenience, the Skylab experience indicated that effective habitability features could be measured in hours available to productive tasks[12].

Many of the shortcomings in Skylab's design were a result of the workstations not being fully responsive to the zero-gravity body position, (discussed elsewhere in this thesis in greater depth). This caused undue fatigue to the crew; the result being inefficient expenditures of time and energy.

Aside from these anthropometric shortcomings, another, probably more pertitant issue became prevalent. In any remote environment, suitable evacuation procedures and means of egress must be available and operational in the advent of a major emergency. The availability and accesibility of such means is even more critical in an orbiting station. Skylab was equiped for evacuation through the docking port at one of its ends. At the opposite end was the sleeping compartment. In studying surveys taken of the Skylab crews, several comments surfaced indicating the uneasiness felt each night because of this; if there was an emergency during the "night", the crew would have to make it across the entire length of the station to reach a safe haven - while in an alarmed, still freshly awakened state.

7.5 Conclusions relevant to Space Station Design based upon a study of analogous conditions:

a) In long duration tours, the individuals seem to require personal time as a period of mental rejuvination.
b) The quality of the volume in which this personal time takes place is critical.
c) The personal aspect or the individual's view of the volume and hardware involved is significant.
d) Crew safety is not only perceived through hardware anthropometrics, but also hardware accessibilty, proximity and orientation.
e) Pleasing food of sufficient variety adds the potentiality of a more pleasurable tour duty.

f) A multitude or cycling/variety of activities for both on-duty and off-duty time helps to alleviate monotony.
g) A defined area for communal gathering aids in maintaining a relaxed social context.
h) Communication with outside world, particularly with family members, is of high importance.
i) Minimization of multiuse spaces is preferred, but adaptibility of spaces is highly desirable.

7.6 Recommendations relevant to space station design based upon a study of analogous conditions:

a) Personal spaces should be integrated into the overall planning strategy of the Station.
b) Egress routes and evacuation/containment strategies should be addressed based upon proximities to sleeping areas and other long period usage zones.
c) The technical aspects of equipment and interior design elements should emloy evaluation criteria that is weighted toward life sustaining equipment.
d) Tactile perception in "work" areas should be of a variety different than the tactile perception of "non-work" areas.
e) Develop a communication/entertainment system that can be used in private quarters and/or in communal situations.
f) Designate by function/activity or location a communal territory.
g) Respond to the anthropometric design implications of the neutral body position when making all interior architecture decisions.

8.0 HUMAN FACTORS OF ZERO-G AND ACCELERATION

The initial execution of the first U.S. space station design will be of an orbiting craft circling the earth every ninety minutes, at an altitude of 250 miles above the surface with fully autonomus life support systems. Crew rotations via the space shuttle will occur every 90 days, including transfer of equipment and changeout of logistics systems. At a distance of 200 miles, this "work site" is a shorter commute than most of its terrestrial antilogs.

However, a major factor influencing the habitability of this extra-terrestrial work place, is that these initial designs will be environments of zero-g (zero gravity). Until recent times, man has seldom experienced accelerations upon his physical being other than that of one-g (one-gravity, that of earth). This force of nature has had instrumental effects upon the shaping of our physical beings and upon how we build to house our societies.

Manned space flight, as we now know it, is an experience of a variety of gravitational environments. From lift-off, to orbit and re-entry, the astronaut is subjected to accelerations that his physical and mental being must adjust to.

8.1 Definition of Terms

For the sake of consistency and clarity, a brief explanation of the termonology used in reference to the different gravities is in order. First, since gravity is a form of acceleration, these two terms may be used interchangeably, where acceleration refers to the accelerational force due to gravity. Likewise, zero-g and weightlessness can be used in place of one another. The single letter "G" refers to a unit of acceleration where one-g equals the gravity on earth. Zero-g, on the other hand, is a unit of measure describing the condition where a body is in a constant state of free fall. The physical musculature of a man in a normal relaxed state in a zero-g environment, is referred to as the neutral body position.

8.2 Neutral Body Position

The study and understanding of the design implications of this neutral body position is critical in the understanding of anthropometric design criteria for a zero-g environment. In as much as the conceptual representations of Leonardo de Vinci's Vitruvian Man, Le Corbusier's La Modular, and Henry Dreyfuss' Measured Man trace a lineage of aids in man-machine design, they no longer administer to a design world outside of the one-g realm.

The newly introduced design variables of this environment not only affect posture, but also have a dynamic affect upon man's anatomical, physiological and kinesiological make-up. Figure 6 illustrates the basic changes in anthropometrics resulting in the neutral body position of a male in a zero-g environment. Figure 7 illustrates the same male in a one-g environment.

8.3 Neutral Body Position: Dimensional Changes

The greatest dimensional change occurs along the spinal and lumbar region of the back. The spinal musculature, no longer having to rigidly tension itself to maintain balnce and upright posture, relaxes, thereby elongating the back structure and resulting in a loss of the thoracolombar curve. At the same time overall height of a subject in this environment is decreased due to the legs approaching a quadruped position and the head tilting down and forward. The arms also naturally assume this affinity towards a quadruped position. Figure 8 illustrates this in the profile and ventril orientations with reference to the one-g posture.

8.4 Neutral Body Position: Angular Relationships

Figures 9, 10 and 11 show the angular relationships that are the resultants of the neutral body position. Notice that from a horizontal reference line, the line of sight has dropped from a normally 10° angle of declination in a one-g environment to a 25° angle of declination in a zero-g environment. This becomes one of the key criteria in the determination of the heights and inclinations of various controls, monitors and related apparatus at workstations.

Figure 12 illustrates the forward and aft positions of a foot restrained body with respect to the neutral body position. Figure 13 illustrates the nominal limits of movement in the neutral body position and the 90° dynamic envelope of movement between the forward and and aft positions. Figure 14 shows an extrapolation of the range of movement in Figure 13 into the projection of a workstation around the dynamic zero-g envelope. Figure 15 depicts schematically a possible workstation designed around the neutral body position dynamic envelope.

8.5 Orientation Analyzers

Figure 16 illustrates the four main analyzers germain to space flight that man has as his tools for percieving orientation in his environment. Figure 17 shows these same analyzers within the zero-g environment. These are to be used as a simplified base for understanding isolated components of orientation.

A comparative study between the one and zero-g environment shows a major difference in two receptor areas. The most paramount of these being the loss of the gravireceptor. This loss in the zero-g environment invariably will need to be compensated for by the other "active" receptors if some degree of orientation stabilization is to be maintained. The second difference, which was illuminated previously in the discussion of angles of reference with respect to neutral body position, is that of a lowered vision horizon angle.

8.6 Conclusions based upon the study of the anthropometrics of the human body in a zero-g environment:

a) The human body tends to seek a neutral body position when relaxed in zero-g.
b) The zero-g neutral position is definable and quantifiable within a predictably repeatable envelope.
c) Workstations that ignore these postural implications may present interfaces that are "workable" but the crewman's efficiency and stay time at that station may be adversely affected.

8.7 Recommendations based upon the study of the anthropometrics of the human body in a zero-g environment:

a) The neutral body position should be taken into account in the design of workstations and other manned interfaces.
b) The overall design configuration of the interior architecture should have orientaional clues to compensate for the loss of the gravireceptor in the zero-g environment.

9.0 HUMAN FACTORS/HUMAN PRODUCTIVITY VARIABLES

9.1 Framework of Analysis

In order to evaluate and make appropriate design decisions, a framework of reference must be established as a background. The evaluational system must explain the use, function and interaction of the components and volumes of the space station. It is in a sense, the application of the classical tools of architecture within the context of leading edge technology. These human factors of the total volume may in some cases be more important to the productivity and well being of the crew than the engineering design of the individual components[13].

9.2 Methodology

The methodology for identifying, selecting and implementing the design criteria is a combination of the general areas of evaluation:

TECHNICAL
EFFICIENCY
HUMAN ACCEPTANCE
MAINTENANCE

The above criteria with user defined weighted factors provides at best a loose standard in the design analysis of the various components and volumes of the space station. The weighting factor of each element above varies depending upon the type of situation to be evaluated. For example, the personal crew quarters system, (PAD) would be weighted heavily on human acceptance, whereas the evaluation of commercial hardware would be weighted more heavily on technical and efficiency aspects.

9.3 Criteria Definitions

The technical criteria deals primarily with the weight, volume and technical operation of the component under study. The efficiency criteria deals with volumetric analysis of packing density, utility volume and life cycle considerations. The human acceptance criteria includes ergonomics, safety, crew efficiency, on orbit training time, personalization/human feel, and crew traffic. The maintenance criteria includes logistics and equipment changeout, repair sequencing, maintenance required and component commonality.

The exact weighting and breakdown of these general catagories is indeed a matter of opinion. The attempt is to at least develop a similar strategy of criteria across the multitude of disciplines involved in the design and implementation of the space station.

10.0 PHYSIOLOGICAL CONSIDERATIONS IN ZERO-G ENVIRONMENTS

10.1 Calcium Loss

Biologists studying the human body in zero gravity conditions have identified several problem areas with respect to changes in physiology. One of the most detrimental physiological changes is the loss of calcium in the skeletal bones. It was found that this calcium depletion begins in as little as 10 days into the zero gravity mission, and continues uniformly to an estimated degration of a 25% loss of the total body pool at the end of a one year mission[14].

Earth analogs of bed-ridden adults have also demonstrated calcium loss, but findings from actual comparative space results are more severe.

These studies show a 0.5%/month calcium loss from total body weight and a 5%/month calcium loss from the weight bearing bones among Gemini, Apollo and Skylab astronauts. A five-week recovery period is generally necessary upon returning to earth in order to restore these calcium deficiencies. However, it was found that two of the Skylab astronauts remained significantly deficient in bone mineral 5 - 7 years after their last space flight[15].

An exercise regime (stationary cycling) that conditioned and stressed the larger skeletal and muscular groups seemed to circumvent some of this calcium loss. This also seemed to shorten the subsequent recovery period upon returning to earth.

10.2 Sunlight

Sunlight has played a significant role in the evolution of human physiology. Visual sensitivity peaks near the solar spectrum maximum; solar ultraviolet radiation (UV), is required to produce Vitamin D for bone growth and maintenance; and periodic bright sunlight exposure helps to establish human circadian rythms[16]. During extended space travel, astronauts have generally been deprived of natural solar illumination, and it is likely that various deficiencies of artificial lighting may cause unnecessary physiological and psychological stresses.

10.3 Conclusions based upon the study of physiological conditions in a zero-gravity environment:

a) Calcium depletion begins in as little as 10 days into a zero-gravity mission.
b) Extended space flight in a zero gravity environment could potentially lead to a permanent disfigurement of the skeletal structure.
c) Visual and tactile access to direct sunlight is a vital part of a complete physiological and pschological maintenance program.

10.4 Recommendations based upon the study of the physiological considerations in a zero-gravity environment:

a) An onboard regime should be implemented that addresses and surcumvents the adverse affects of calcium losses in a zero-gravity environment.
b) Windows or observation bubbles should be implemented wherever possible/feasible in order estblish visual and tactile contact with solar illumination a views.
c) Artificial lighting should match sunlight.

11.0 CURRENT SPACE STATION ART

Figures 23 and 24 show orthagonal views of the current NASA Space Station art. It is a dual keel concept measuring approximately 175m long x 110m high. Power is supplied to the station via two photovoltaic arrays located towards the ends of the 175m transverse arm. Habitation and laboratory modules are located at the center of the station on the transverse arm along the station's center of gravity. TDRS systems are located at the top of the dual keel to track and monitor deep space, while earth tracking antennas are located at the bottom of the dual keel to monitor terrestrial activity.

The main truss system is composed of 101 erectable 5m x 5m x 5m cubic modules with diagonal braces along each face. Each of these disassembled modules is brought to orbit via the space shuttle, and assembled by the astronauts 250 miles above the earth. Figure 25 shows a diagram of the assembly sequence operation of NASA's baseline configuration.

The Space Station will be placed in an orbit with an inclination of 28.5°. Placement at this inclination is derived from two factors:

a) The majority of U.S. missions considered can be accomodated at 28.5°
b) This is the inclination to which maximum payload can be delivered by the shuttle

11.1 Goals

NASA's baseline goals are to develop a full time operational orbiting facilty to meet the needs of a research laboratory, an observatory, a service center, a communications and data processing node, a transportation node, a storage facility and a construction/assembly base. In Earth Sciences and Applications, five missions have been defined. A lidar facility is envisioned as a research facility for development of lidar technology and techniques, as well as scientific studies of the tropical atmosphere. Once the development is complete, lidar instruments would be placed on an Earth Sciences Research Platform located in a polar, or near polar orbit. The Earth Sciences Platform is an interdisciplinary facility for the study of the Earth, the oceans, the atmosphere, and biochemical cycles[17].

Life Sciences missions have two concentrations - studies of long duration weightlessness effects on humans, animals and plants in an on-board lab facility and the development of a fully closed life support system. Initially, activities would be devoted to research on plants, humans and small animals. Later on, an Animal and Plant Vivarium would be added.

Various commercial production facilities are under study with an emphasis on pharmaceudical development and Electroepitaxial Crystal Growth (ECG). Additional research with a high potential for implementation are:

a) Isoelectric Focusing (IEF) - Biological Products
b) Directional Solidification Crystal Growth (DSCG) - Gallium Arsenide, Hg, Cd, Te and other crystals
c) Vapor Crystal Growth (VCG) - Hg, Cd, Te and other crystals
d) Optical Fiber - High quality optical fibers
e) Solution Crystal Growth - Crystals with fast switching electronic characteristics
f) Iridium Crucible - High purity iridium crucibles
g) Biological Processes - Proprietary processes for the production of biological materials

The Technology Development Missions are those for the development of space construction technology. This research will enable the erection of large antennas for both commercial communications missions and for future science missions.

The initial power requirement estimate of the Space Station is 55kW. The primary factor in this estimate is the commercial materials processing area. Crew Intravehicular Activity (IVA) associated with materials processing is also a major factor[18].

11.2 International Involvement

Parallel studies of space utilization have been undertaken by the international community. The initial studies of The European Space Agency (ESA), Japanese and Canadian involvement are similar in kind to the aforementioned research identified above. Both ESA and the Japanese will have their own research facilities as a connected, integral part of the overall space station, referred to as the ESA Module and the Japanese Experiments Module (JEM) respectively.

11.3 System requirements

The system requirements for the Space Station as defined by the Space Station Task Force, in the Space Station Program Description Document, Final Edition[19], are as follows:

a) Safety - The Space Station system shall provide for a "safe-haven" and or escape capability. In addition, the Space Station shall be designed in the following order of precedence to: 1) Eliminate hazards by removal of hazard sources and operations; 2) reduce hazards by selection of least hazardous design or operations; 3) Minimize hazards by safety factors, containment provisions, isolation techniques, purge provisions, redundancy, backup systems, workarounds, EVA, safety devices, caution and warning devices and procedures; and 4) minimize hazards through a maintainability program and adherence to an adequate maintenance and repair schedule.

b) Maintainability - Subsystems shall be designed to permit repair and/or replacement at the orbital replacement unit (ORU) level. To effect the desired maintenance, the Space Station shall include facilities and equipment for on-orbit monitoring, checkout, storage, replacement, repair, and test of subsystem hardware. Critical systems shall be capable of undergoing maintenance without the interruption of critical services and shall be "fail safe" while being maintained.

c) Reliability - Space Station Critical Components, subsystems, and/or systems shall be designed to be fail-operational/fail-safe/restorable as a minimum. Mission critical components, subsystems, systems and/or critical ground support hardware shall be designed fail-safe; other hardware shall be designed as restorable. Redundant funtional paths of subsystems and systems shall be designed to permit verification of their operational status in flight without removal of ORU's. Subsystem design shall provide redundancy management and redundancy status to the crew.

d) Operating Life - The Space Station shall have the ability to remain operational indefinitely through periodic maintenance and replacement of components. To this end, all subsystems shall be designed for modular growth, on-orbit assembly, disassembly, and replacement with on-orbit repair and maintenance. All subsystems shall have a specified ten year design life minimum requirement using maintenance as necessary.

e) Growth Buildup - The Space Station shall permit progressive buildup to higher orders of capability. Where technology changes are anticipated to provide economical growth in capability, the initial hardware and software shall be capable of being replaced or integrated with the higher technology systems as they become available.

f) Autonomy - Autonomy shall be incorporated in system and subsystem design to minimize crew and /or ground involvement in system operation.

g) Environments - The Space Station shall be designed to meet all performance requirements in natural and induced environments in which it must operate.

h) Systems Verification - Verification of the Space Station system will be accomplished by a combination of analyses and ground flight tests.

i) Logistics - An integrated logistics requirements plan shall be defined and implemented to assure effective economical logistics support of the development, verification, activation, and operational phases of the Space Station Program.

j) Quality Assurance - An effective program for quality assurance shall be implemented that validates the acceptability and performance characteristics of conforming articles and materials to assure detection and correction of all departures from the design and performance specifications. These quality assurance provisions apply to all ground development and verification testing as well as all on orbit maintenance activity.

k) Commonality - Hardware, software, and technology commonality shall be applied to elements, modules, submodules, and subsystems within the Space Station to enhance standardization for direct interchangeability and to assure compatibility and minimize program development costs. Commonality goals should be applied to structural, electrical, and fluid subsystems for all Space Station system elements.

l) EVA Provisions - The Space Station design shall include provisions for performing extravehicular activity,

m) Cabin Atmosphere - The Space Station crew environments shall be a shirt-sleeve, two gas atmosphere (nitrogen-oxygen). The cabin pressure shall be selected to facilitate productive EVA with no pre-breathing or other operational constraints.

n) Crew Accomodations - Accomodations shall be provided for the Space Station crew which carefully consider both habitability and health maintenance as well as other factors which will maintain the crew at peak effectiveness.

o) Orbit Management - Space Station design shall include provisions for maintenance of desired orbit characteristics with unique propulsive capablity.

p) Resupply Interval - The Space Station shall be able to operate with a full crew complement without resupply for a nominal period of three months. Contingency servicing or resupply shall also be provided as required. All resupply systems shall be designed so that they can be delivered and retrieved by the Space Shuttle Orbiter. Space Station waste products shall also be returned to Earth by the Orbiter.

q) System Disposal - The Space Station should have provisions for non-hazardous disposal of its modules, equipment, elements, etc., and/or the total station at the end of its useful life.

r) Communications - The Space Station communications system shall be capable of command and two-way voice, telemetry, and colr video communications within the Space Station, with the ground, and other interfacing elements of the Space Station as required. The Space Station shall be capable of communication by relay through the TDRSS communication satellite system. Provisions shall be made for secure communications to be provided by the user requiring such security.

s) Information System - The design of the Space Station information system shall be compatible with the overall program integrated data network with which it shall interface in providing efficient data and information handling, processing, and transmittal to the user communities, as appropriate. The information system shall be "user transparent" (i.e., users should not be forced to deal with the complexity of the embedded system).

11.4 Subsystem Requirements

The Space Station requires the functions of the following subsystems:

a) Stuctures

b) Mechanisms
c) Electrical Power
d) Thermal Control
e) Environmental control and life support
f) Information and data management
g) Communications and Tracking
h) Guidance, navigation and control
i) Propulsion
j) Crew systems and crew support
k) EVA
l) IVA
m) Health maintenance
n) Fluid management

11.5 Ground Operations

The Space Station will be controlled from the ground by the Space Station control center during any unmanned periods. During manned operations, the ground will act in a monitoring mode but will be responsible for developing long-range mission timelines for the Space Station crew[20].

11.6 Cost-Effectiveness Considerations

The Space Station system will be designed with the intent to minimize operations-driven costs and to maximize effectiveness for the users. Systems will be designed to include an appropriate degree of autonomy and automation to be easily monitored and maintained on orbit without interruption of critical services[21].

12.0 SUMMARY OF THE INVENTION

12.1 Description

The proposed module configuration is connected to the underside of a 25m x 35m deployable truss as defined in Appendix A's "Summary of the Invention". The drawings in Appendix B illustrate the module assemblies in relationship to the overall Space Station configuration.

A top view, front view and side view of the proposed Space Station module arrangement is shown in Figures 26,27 and 28, respectively. The arrangement consists of a central "corridor" (14) comprised of intermediary modules(2) and shafts(3) that receive laboratory modules(1)(5)(4) laterally; logistic(9), galley(7) and hygiene(8) modules dorsally; and 6 PAD Systems(16)(17) modules ventrally. The laboratory modules (shaded) are designated as U.S. NASA program modules(1), JEM module(5) and ESA module(4). Expansion potential(6) is accomodated next to the JEM module(5).

12.2 Docking Ports

Dual docking ports(15) are incorporated so as to allow redundancy in the system. These docking ports(15) are comprised of intermediary modules(2) that are connected to the main module configuration(Figure 26, top view)(Figure 27, front view) and (Figure 28, side view) via flexible assemblies(12) that dampen vibrational transmissions of Shuttle docking maneuvers. Observation bubbles(10) are located ventrally and dorsally on the docking assemblies(15) in order to establish visual contact with the Shuttle during docking operations.

12.3 Space Station Orientation

The Space Station orbits the Earth at an inclination of 28.5° as defined in "Current Space Station Art" article 11.0. The Station has an Earth orbit time of 90 minutes, thereby affording the six-man crew 16 sunrises and 16 sunsets in each 24 hour period. The Space Station is in a gravity-gradient stabilized orbit which aligns the upper and lower booms of the overall configuration (as defined in Appendix A) to the gravitational forces of the Earth with respect to its center. This defines an "up-down" orientation with respect to the Space Station; where "up" is in the direction away from the center of the Earth, and "down" is in the direction towards the center of the Earth. Where this is applicable on the Figures, an Earth arrow indicator is utilized.

12.4 Shuttle Transport

One laboratory module(1) and an intermediary module(2)(Figure 29)(Figure 30) or six PAD Systems(16) and an intermediary module(2)(Figure 31)(Figure 32) can be packed and transported in one Space Shuttle trip. Each of these payloads is to be within the specific Shuttle load considerations of 29,484 kg and 18m long by 4.5m diameter maximums.

12.5 Emergency Containment Strategy

An Emergency Containment Strategy (ECS)(Figure 33) top view and (Figure 34) side view, is designed so as to be able to isolate a specific module from the rest of the Station in the advent of an emergency. Such emergencies would include a gas leak, loss of module pressure or other such cases where isolation from the rest of the Space Station is necessary. In addition to this ECS, two means of egress are supported in the configuration.

In the event of an ECS in the ESA module(4), evacuation can be facilitated through either the anterior or central corridor hatch(19). ECS procedures can then be performed by closing the hatches(19), thereby isolating the ESA module(4). In the case of an anterior hatch(19) evacuation, a flexible assembly(11) connecting anterior intermediary modules(2) with the central corridor(14) can be utilized. This flexible assembly(11), (which is compressed in the transport configuration), is implemented so as to allow the second means of egress from the ESA module(4). Anterior connection to the JEM module(5) is not possible due to its exterior assembly platform.

Similar ECS's could be implemented in each of the NASA laboratory modules(1), if necessary. The JEM module(5) also has an ECS, but with only one means of egress to the rest of the Space Station module interior.

12.6 Emergency Evacuation Strategy

An Emergency Evacuation Strategy(EES)(Figure 35) side view and (Figure 36) front view, is designed so as to provide Space Station evacuation procedures in the advent of an emergency. Such emergencies would include major rupture/failure of complete module(s)/utility systems that require detachable "life boats" or safe havens separate from the immediate module assemblies.

In the event of such emergencies, the intermediary modules(2) at the extreme ends of the Space Station, and/or the PAD Systems(16) along the central corridor, could be isolated at their respective hatches(19), and detached (dotted lines) from the main body of the Space Station. Each of these safe havens would have a Life Support System(LSS) to sustain human life for a specified period of time until rescue/retrieval operations could be implemented.

12.7 Utility Sizing and Distribution

Figure 37 lists the size, number and kind of utilities that are to be distributed throughout the Space Station(Figure 38) top view and (Figure 39) side view. The logistics module(9) supplies the Space Station with its primary replenishable utilities; an oxygen/nitrogen gas mix and crew water.

The utilities in Figure 37 are distributed through the modules in two independent, parallel systems(20)(21). This parallel arrangement affords a redundancy in the utility supply/return system. Branching off of the main power supply systems(24) are circumferential raceways(22) placed in structural ribs(32) at 3m spacings. These raceways supply the power requirement for equipment in a perimeter arrangement scheme.

A section through a typical laboratory module(1) shows the location of the primary utility supply/return systems; Environmental Control and Life Support Systems (ECLSS)(23), power(24), thermal(25), housekeeping data(26), payloads data(27), and crew water(28).

The main power supply sytem(24) also branches off to supply a central beam assembly(29). This central beam(29) has various plug-in locations along plates(30) that can accomodate a variety of equipment needs. TV and audio feeds(77) are also located in the central beam(29).

12.8 Interior Module Arrangement

The central beam(29) is structurally supported on retractable members(34) that are housed in the utility support frame(35) when in the low central beam position. Removable grates(33) serve as dividers between work and circulation areas(39) and main storage areas(37)(Figure 44). With a preimeter location of equipment, (Figure 44) (Figure47) equipment racks(36) follow the lines of the pressure vessel geometry(31) and are fed power via the aforementioned reaceways(22).

In a central beam location of equipment, console racks(40) are plugged into the central beam's(29) face plates(30). Power is supplied via the beam's(29) raceways(24). Smaller consoles(38) can also be utilized in a similar fashion.

12.9 The PAD System

Connecting to the underside of the the central corridor(14) are the Personal Autonomous Domain(PAD)(16)(Figures 51 -58) Systems. This cluster(17) consists of six individual livng/sleeping quarters which are connected in pairs to intermediary modules(2) which are then connected to the central corridor(14) via circulation shafts(3).

The main components of the PAD System are; a rotating, gravity inducing sleep platform(44), a counter rotating assembly(48), an observation/projection bubble(10), and storage(52). The sleep platform(44) rotates at approximately 23rpms thereby inducing a one-g force towards the legs and feet of the occupant. This stimulus will help to offset some of the detrimental physiological effects (such as calcium loss) inherent in a zero-g environment. The platform would be in operation during the 7 to 9 hours the crew member is sleeping. The platform is so designed ,that when it is in the stationary position(Figure 52), the crew members' feet are in an earth facing position. This is so that upon waking, a consistent earth-based orientation is always immediately established.

The sleep platform(44) and its two arms(48)(Figure 54)(Figure 55) are "connected" via channels(47) to a perimeter rail(46)(Figure 57, detail). At this "connection" are electromagnetic bushings(65) which govern the rotation of the platform(44) and serve to minimize the transfer of vibrations to the rest of the Space Station. Along the arms(48) are a computer controlled, counter weights sytem(54) that offsets shifts in body mass while the platform(44) is in motion thereby assuring smooth operation. To prevent evaporative cooling while in motion, a two piece cover(51) is implemented which is housed in a pocket assembly(63) when not in use. To keep the user's head in the proper orientation with respect to the axis of rotation, a form of head restraint is utilized(62). To accomodate different crew member's heights, an adjustable foot restraint(66)(67) is utilized.

The interior space of this sleeping environment can be thermally regulated(58)(59) as desired. This space is also equipped with a complete audio/visual system comprised of a pull-down video monitor(50) and a Digitally Enhance Psychoacoustic Environment(55)(56)(58) System. The video monitor can be used to watch movies/broadcasts, communicate with the earth or the other crew aboard the Station, and monitor various functions of the Space Station's operations.

12.10 The DEPE System

The DEPE system is an application and variation upon the technology developed for advanced audio recording and sound reinforcement systems. Its basic components are a sound source, (white noise background ambience, digital audio, communications), a digital effects processor to synthesis a predetermined scale of acoustic environment, a psychoacoustic enhancement system which can be adjusted to enhance audio presence and clarity in the 1 kHz to 5 kHz range, a user programmable control center interface, a power amplification system and finally, a sound reinforcement component. All of which when used in conjunction with one another can create spacial acoustic environments of many scales from the very subtle, of say, a seemingly broader acoustic imaging of background ambience noise, to audio experiences of expansive depth when listened to alone or in conjunction with video.

Rotating counter to the sleep platform(44) is an assembly(48) to offset the moment created by the platform's(44) rotation. The assembly(48) operates on an electromagnetic coupling(46)(47)(65) in a similar fashion as described above.

Figure 58 depicts the DEPE System in conjuncion with a projection unit in one of the PAD's observation bubbles(10). The bubble(100) is comprised of two layers (68)(69) with a conductive medium(70) sandwhiched between. When a current is sent through this medium(70) the color and opaqueness of the bubble(10) can be regulated. This is utilized to control the amount of sunlight that enters the PAD(16) unit and to afford using the bubble(10) as a 360° projection screen(72). This form of system is introduced as an attempt to heighten the level of sensory involvement in entertainment/communication. This system also has the DEPE technology mentioned above integrated into its operation. The area of the PAD(16) System (Figure58) is enclosed in a soft womb-like material(49) with entrance at (73).

12.11 The Galley

Utilizing a similar shell as in the PAD(16) System is the communal space/galley (7) of the Space Station(Figure 59)(Figure 30). It is located dorsally along the central corridor(14). It is comprised of an observation bubble(10), food storage(75), logistics support(76) and a table assembly(74). Entrance into the galley is through hatch(41). Foot-restraints(77) are utilized to stabilize the user's position.

13.0 BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a site plan of a typical Antarctica base camp.

Figure 2 is cutaway view of a fleet ballistic missile submarine.

Figure 3 is a plan view of the Sealab II habitat.

Figure 4 is a plan and section view of the Project Tektite habitat.

Figure 5 is a drawing showing Skylab docked to the Command module.

Figure 6 shows the relaxed position of the human body in a zero-g environment.

Figure 7 shows the relaxed standing position of the human body in a one-g environment.

Figure 8 compares the human anatomical changes in a zero-g environment.

Figure 9 shows a profile view of the angular relationships of the human body in a zero-g environment.

Figure 10 shows a ventral view of the angular relationships of the human body in a zero-g environment.

Figure 11 shows an anterior view of the angular relationships of the human body in a zero-g environment.

Figure 12 defines the dynamic zero-g increments with feet restrained.

Figure 13 shows the dynamic zero-g envelope.

Figure 14 shows a workstation diagram based upon the dynamic zero-g envelope.

Figure 15 shows a schematic perspective of a workstation derived from the dynamic zero-g envelope.

Figure 16 shows the major orientation analyzers in a one-g environment.

Figure 17 shows the major orientation analyzers in a zero-g environment.

Figure 18 schematically represents three internal arrangement strategies.

Figure 19 schematically represents four center beam arrangement options.

Figure 20 schematically represents four interstitial arrangement options.

Figure 21 schematically represents four perimeter arrangement options.

Figure 22 is an evaluation of twelve internal arrangement options.

Figure 23 shows frontal, top and side views of the current NASA baseline Space Station configuration.

Figure 24 is an isometric view of the current NASA baseline Space Station configuration.

Figure 25 shows the assembly sequence of the current NASA baseline Space Station configuration.

Figure 26 shows the top view of the proposed module arrangement.

Figure 27 shows the front view of the the proposed module arrangement.

Figure 28 shows the side view of the proposed module arrangement.

Figure 29 is a longitudinal section through the space shuttle showing the packing configuration of one laboratory module and one intermediary module.

Figure 30 is a cross section through the space shuttle showing the packing configuration of one laboratory module and one intermediary module.

Figure 31 is a longitudinal section through the space shuttle showing the packing configuration of six PAD systems and one intermediary module.

Figure 32 is a cross section through the space shuttle showing the packing configuration of six PAD systems and one intermediary module.

Figure 33 shows a top view of the emergency containment strategy.

Figure 34 shows a side view of the emergency containment strategy.

Figure 35 shows a side view of the emergency evacuation strategy.

Figure 36 shows a front view of the emergency evacuation strategy.

Figure 37 shows a schematic of the module utility sizing estimate.

Figure 38 shows a top view of the module utility distribution.

Figure 39 shows a side view of the module utility distribution.

Figure 40 shows a top view of the proposed module arrangement with section cuts references.

Figure 41 shows a frontal view of the proposed module arrangement with section cuts references.

Figure 42 shows a side view of the proposed module arrangement with section cuts references.

Figure 43 is a section through a typical laboratory module showing utility distribution in the low beam configuration.

Figure 44 is a section through a typical laboratory module showing the perimeter location of equipment with the central beam in the low position.

Figure 45 is a section through a typical laboratory module showing the center beam location of equipment with the central beam in the low position.

Figure 46 is a section through a typical laboratory module showing utility distribution in the high beam configuration.

Figure 47 is a section through a typical laboratory module showing the perimeter location of equipment with the central beam in the high position.

Figure 48 is a section through a typical laboratory module showing the center beam location of equipment with the central beam in the high position.

Figure 49 is a plan view of a typical laboratory module with the central beam in the low position.

Figure 50 is an interior elevation of a typical laboratory module with the central beam in the low position.

Figure 51 is a side view of the exterior of a PAD module.

Figure 52 is an interior elevation of a PAD module.

Figure 53 is a frontal view of the exterior of a PAD module.

Figure 54 is an interior elevation of a PAD module showing the rotating sleep/exercise platform.

Figure 55 is an interior elevation of a PAD module showing the rotating sleep/exercise platform.

Figure 56 is a cross section through the sleep/exercise platform.

Figure 57 is a detail of the connection of the sleep/exercise platform to the electromagnetic coupling/rail assembly.

Figure 58 shows a detail of the DEPE System and projection unit at an observation bubble.

Figure 59 shows an interior elevation of the galley/conference room.

Figure 60 is a plan view of the galley/conference room shown in Figure 59.

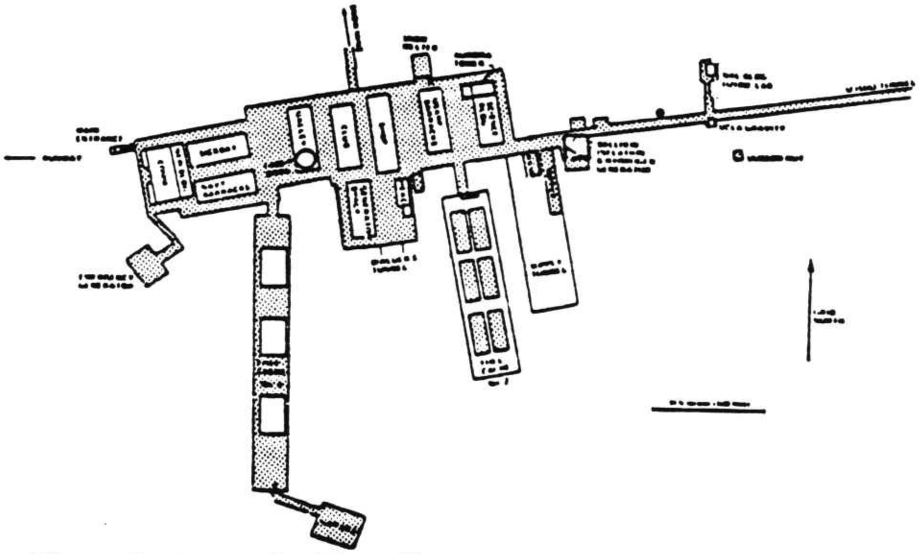


Figure 1: Antarctica Base Camp

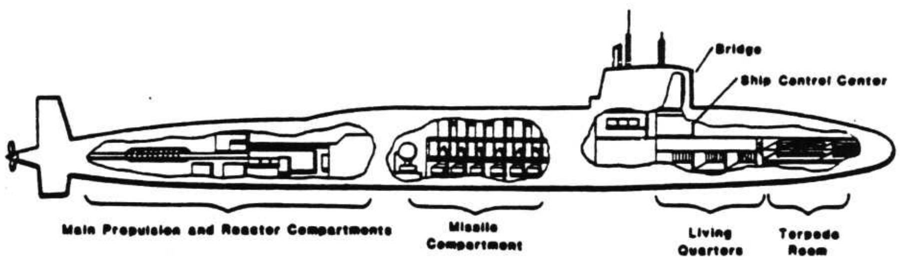


Figure 2: Fleet Submarine Cutaway

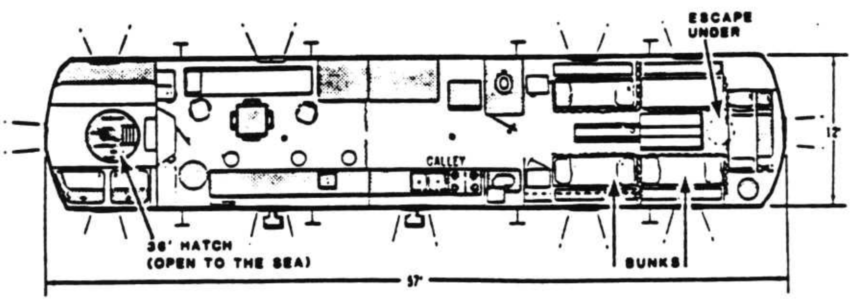


Figure 3: Sealab II

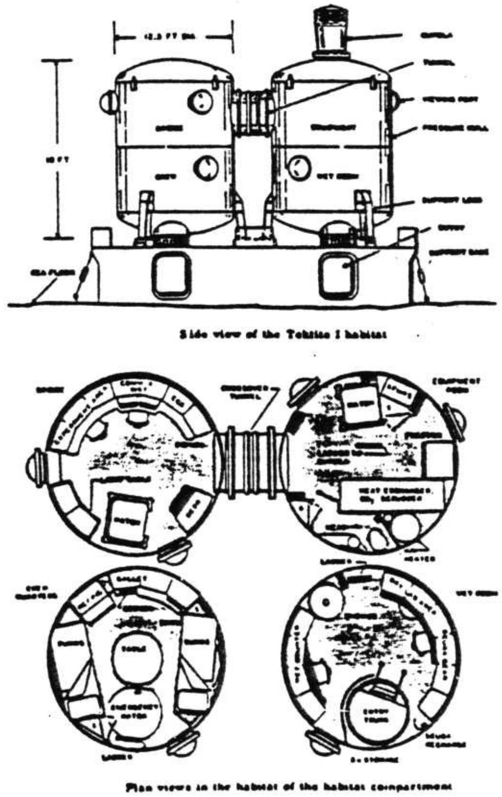


Figure 4:Tektite

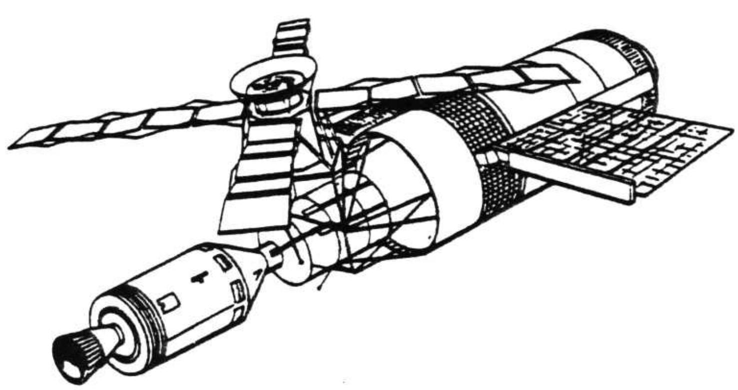


Figure 5: Skylab

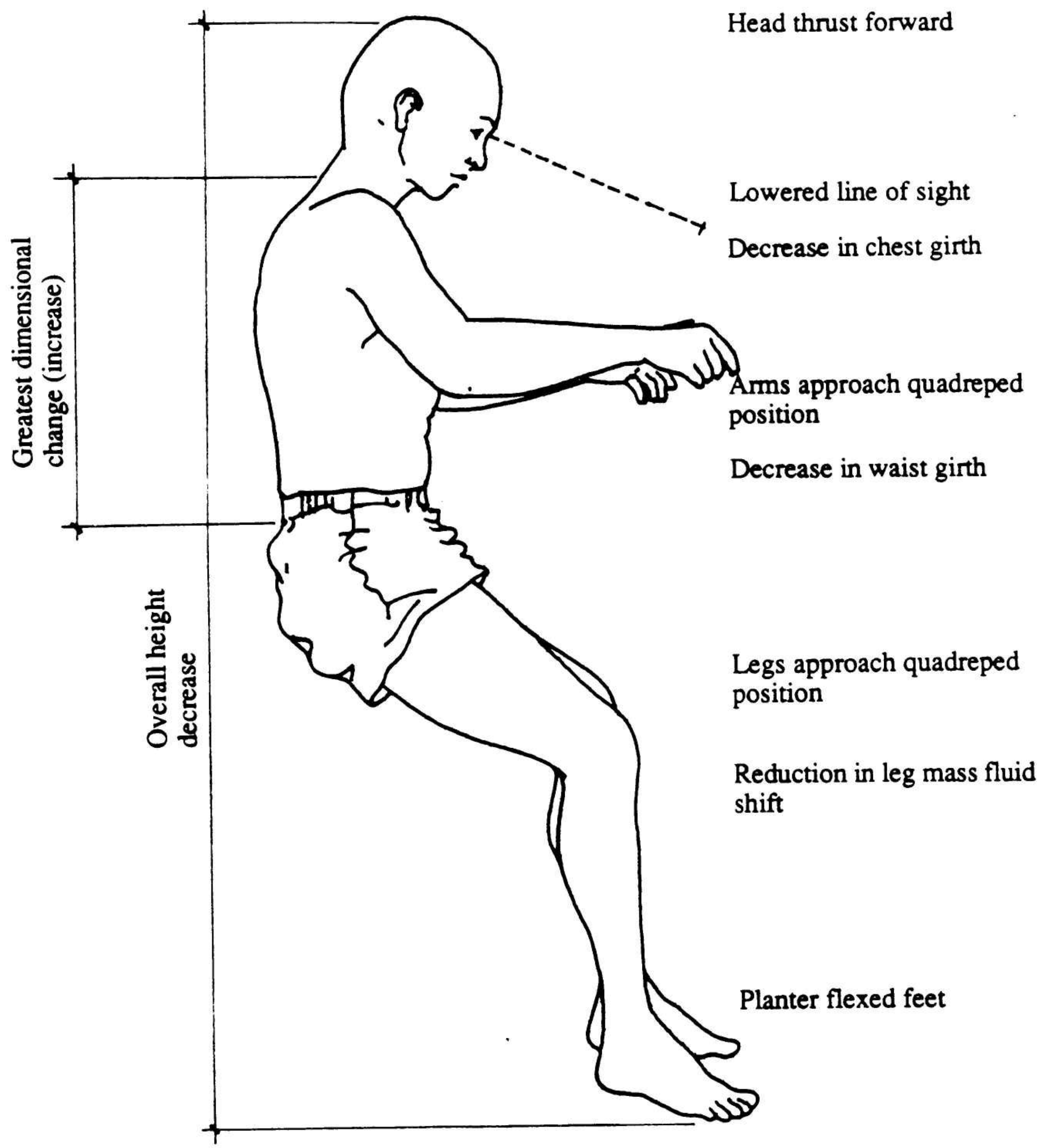


Figure 6: Zero-G Posture

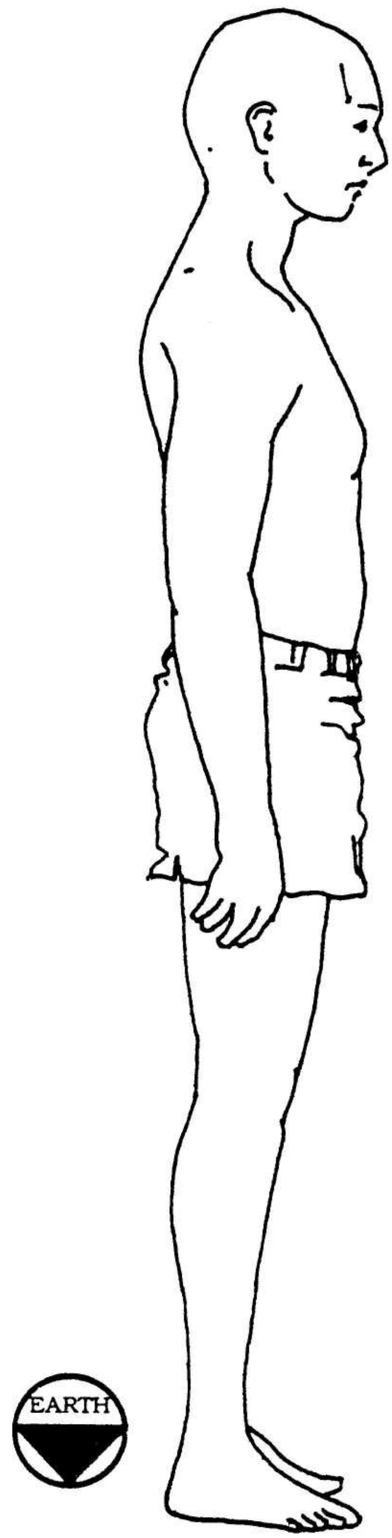


Figure 7: One-G Posture

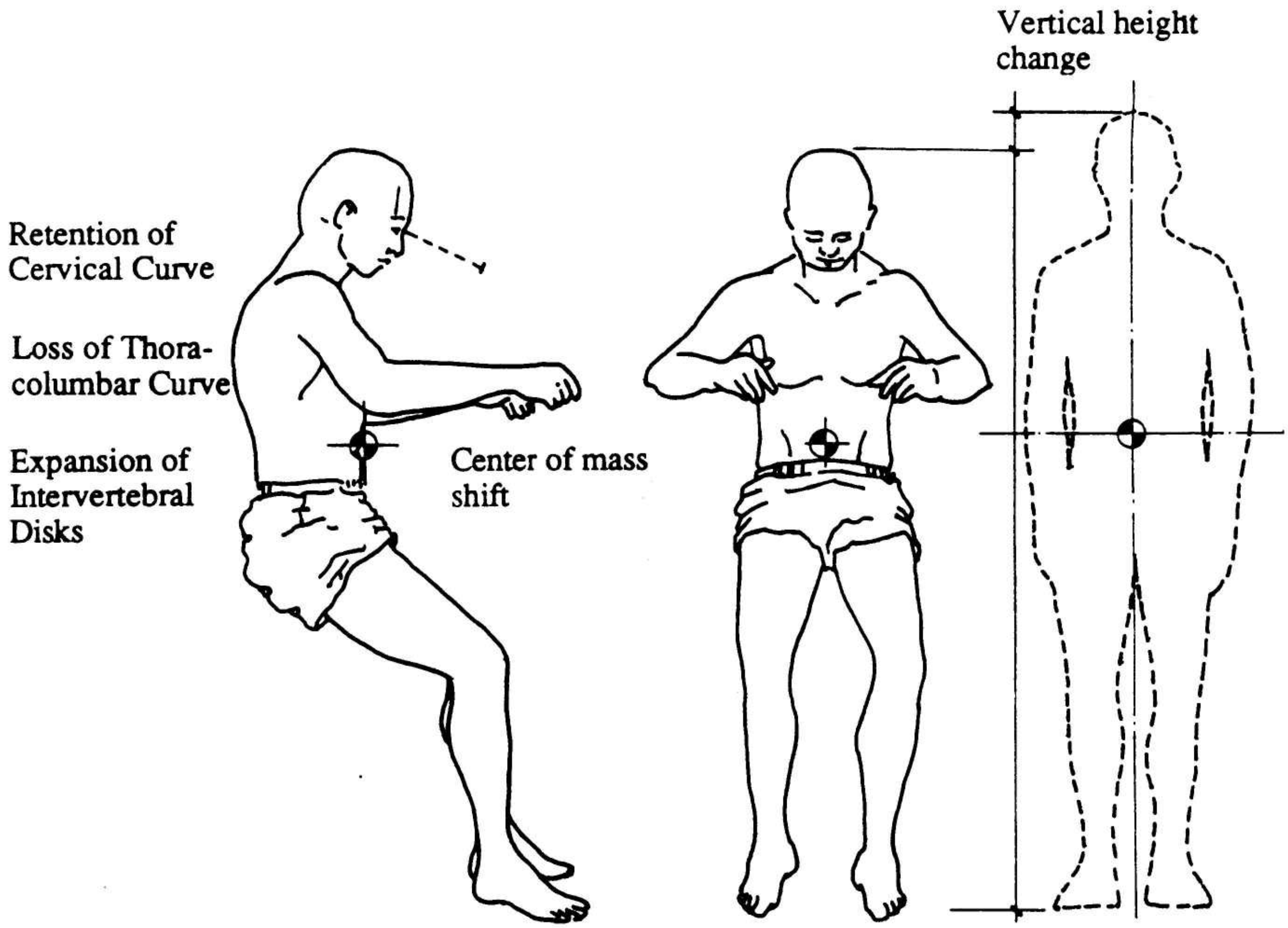


Figure 8: Anatomical Change in Zero-G

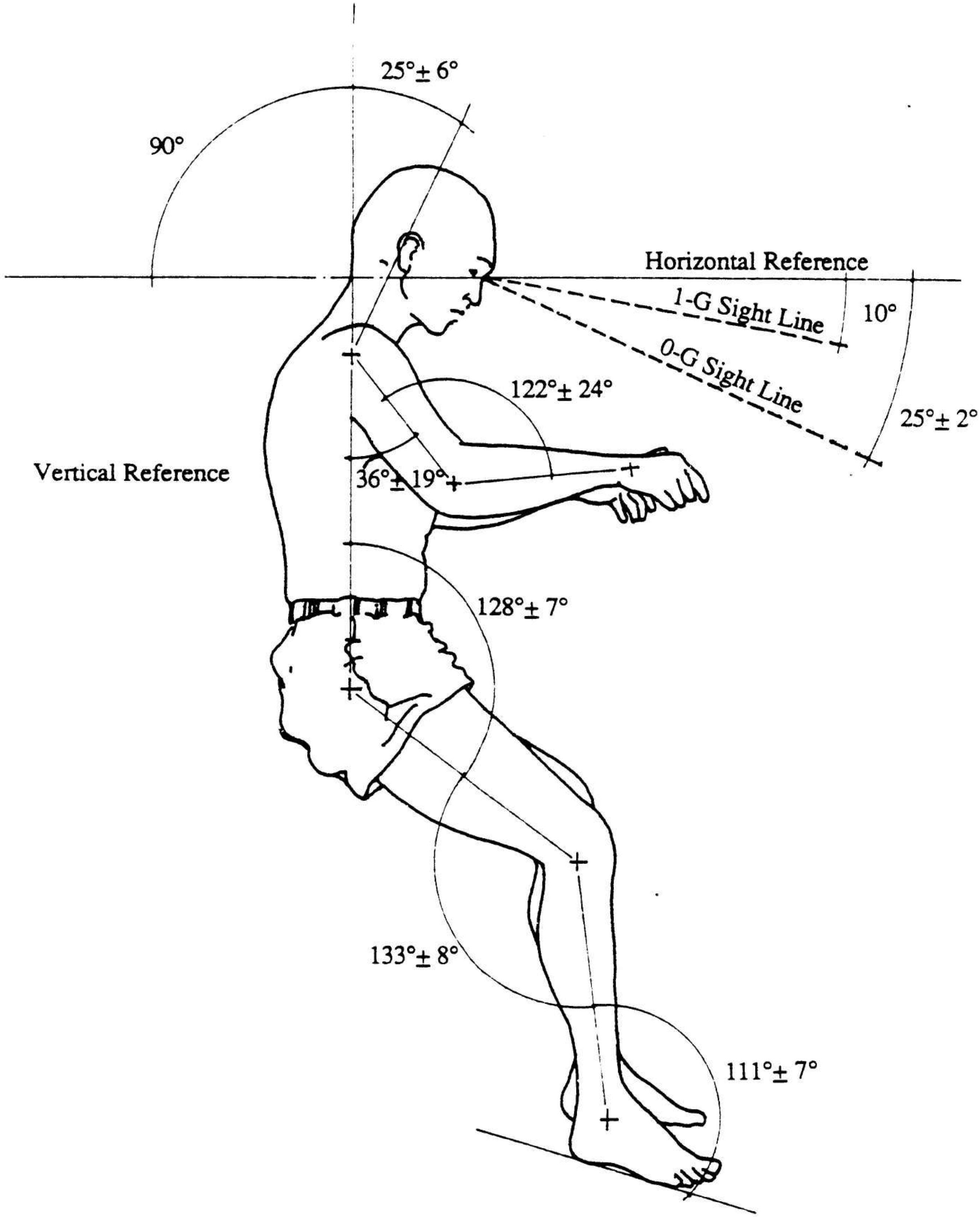


Figure 9: Angular Relationships Profile View

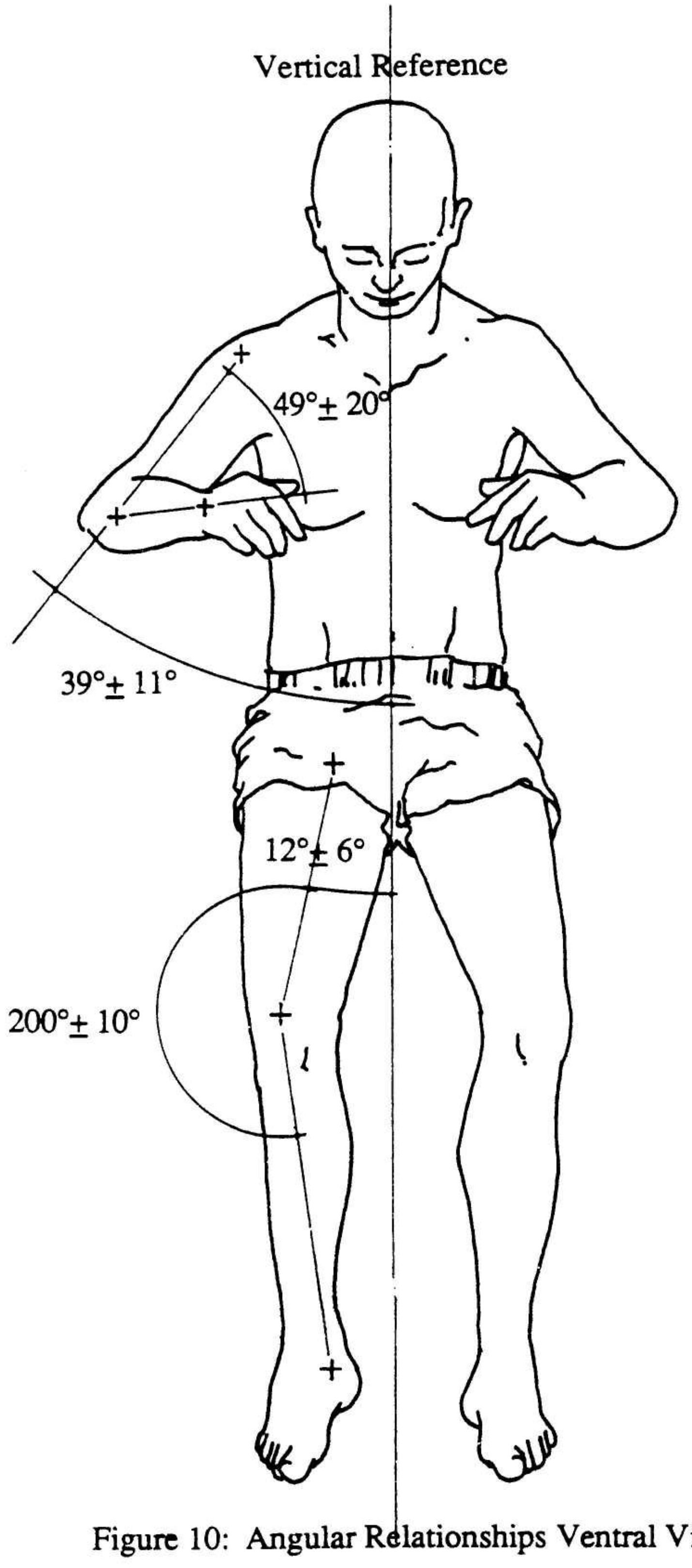


Figure 10: Angular Relationships Ventral View

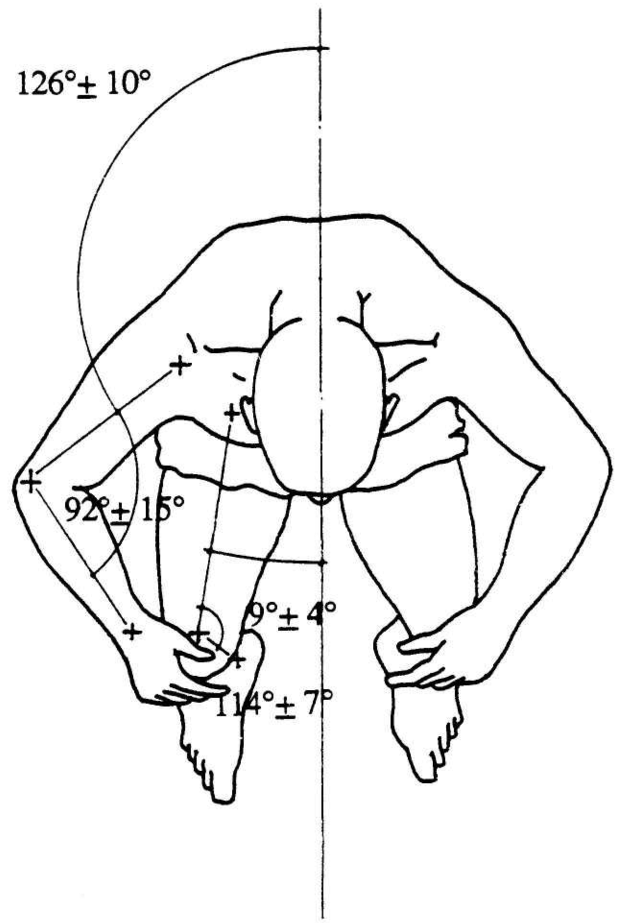
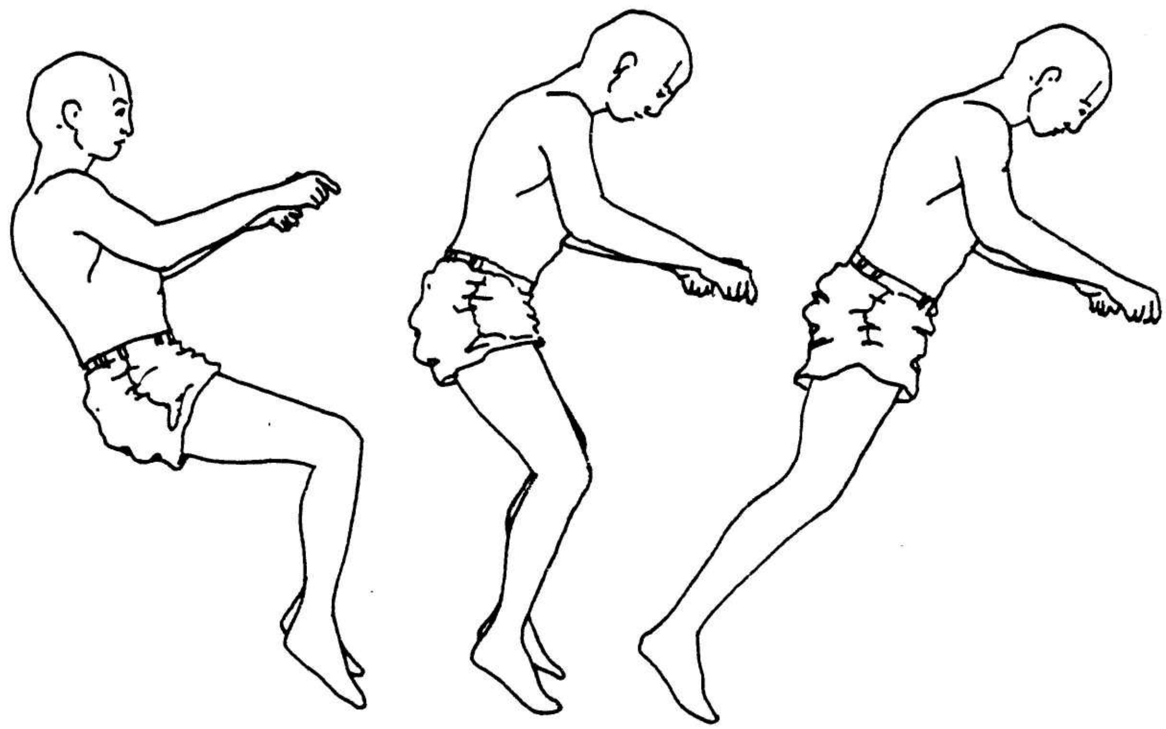


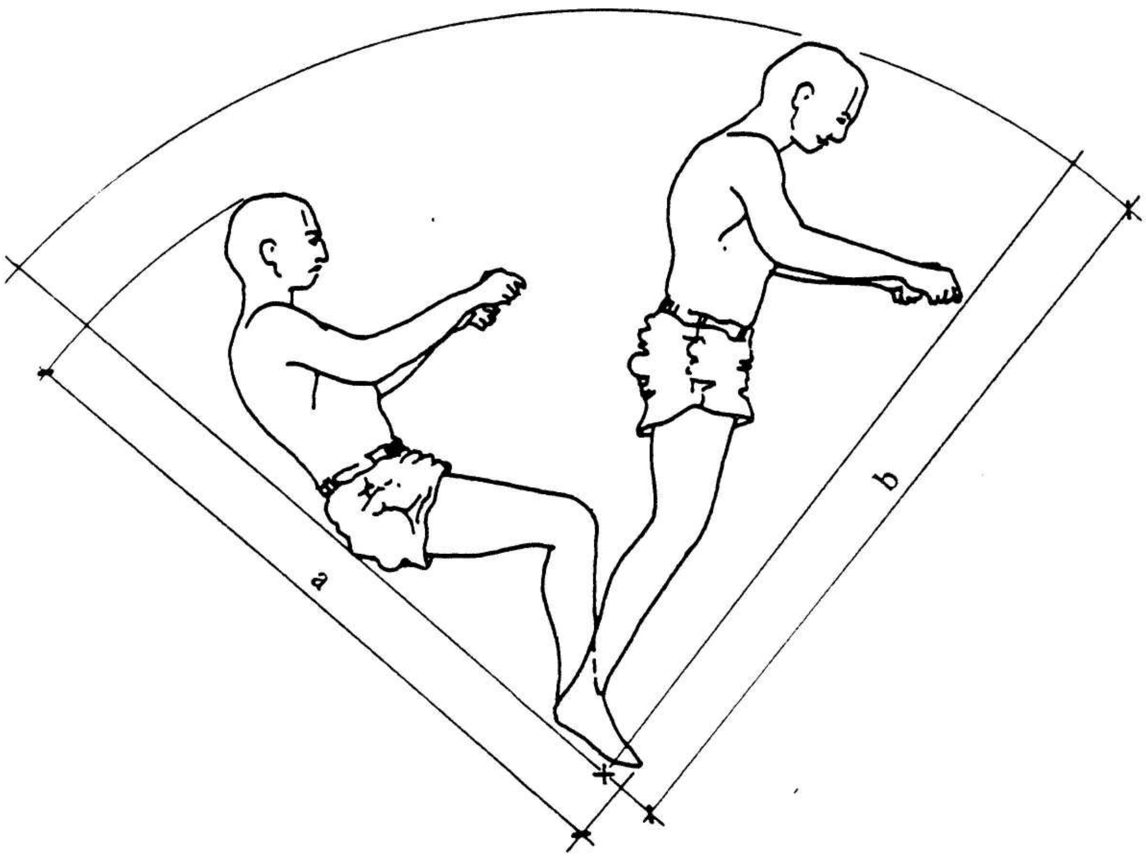
Figure 11: Angular Relationships Anterior View



Aft Position N.B.P. Forward Position

Note: Owing to the the location of the body's center of gravity and freedom about the knee joint, the aft position is easily assumed. The forward position requires a slight effort to achieve and maintain. These positions represent a nominal range and are not the extremes.

Figure 12: Dynamic Zero-G Increments (Feet Restrained)



Nominal Limits of Movement from Restrained Foot Position

	5%	10%	25%	50%	75%	90%	95%
a"	58	59	60	62	75	64	65
b"	65	66	67	69	70	71	72

Figure 13: Dynamic Zero-G Envelope

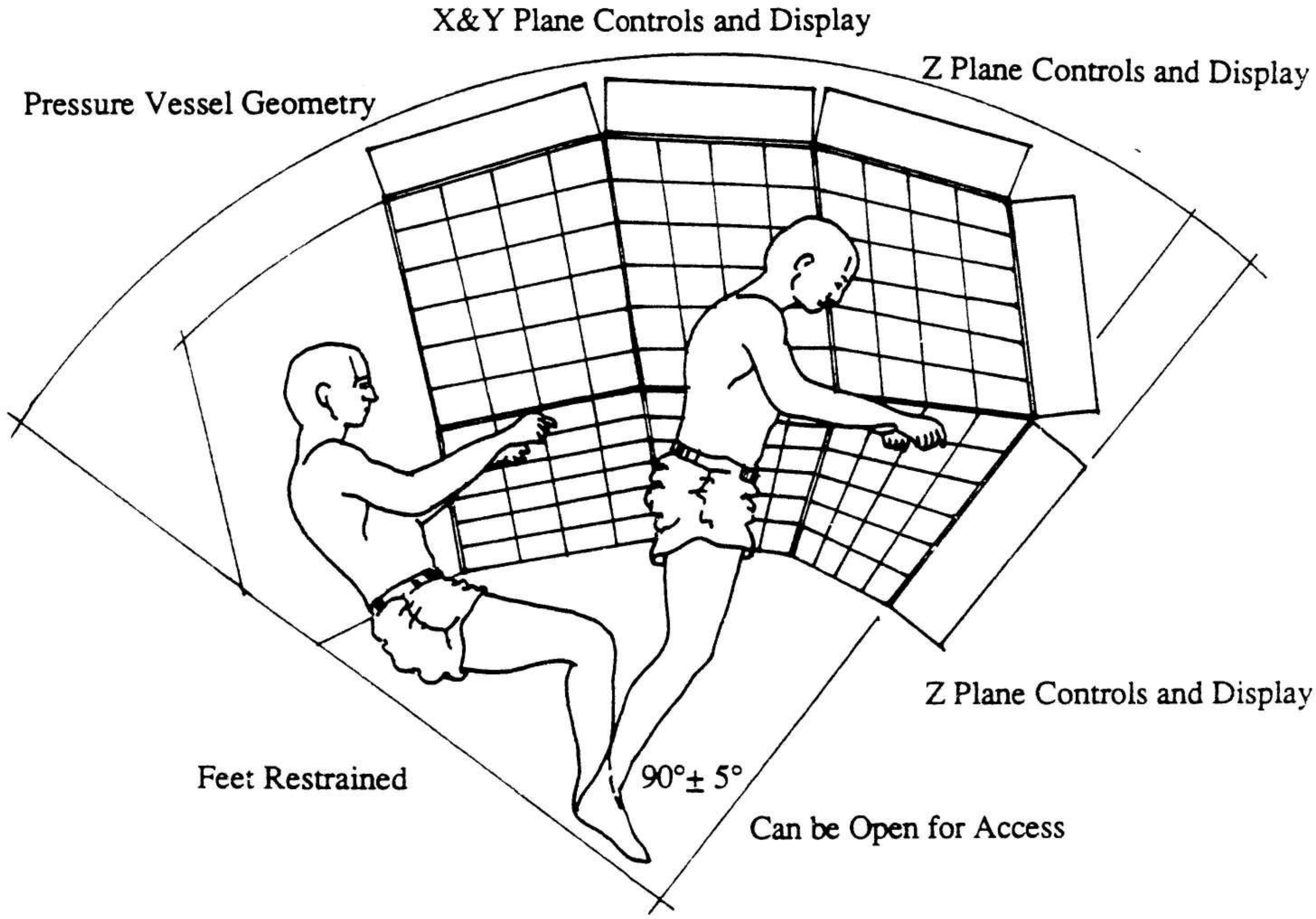


Figure 14: Workstation Diagram Dynamic Zero-G Envelope

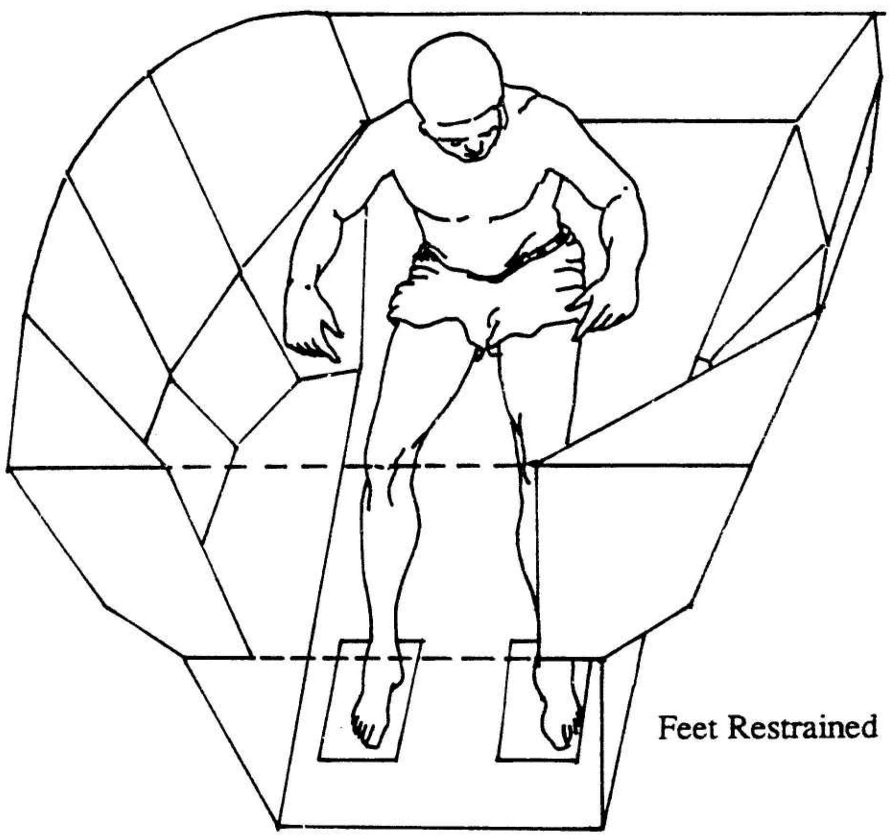


Figure 15: Workstation Diagram for the Dynamic Zero-G Envelope

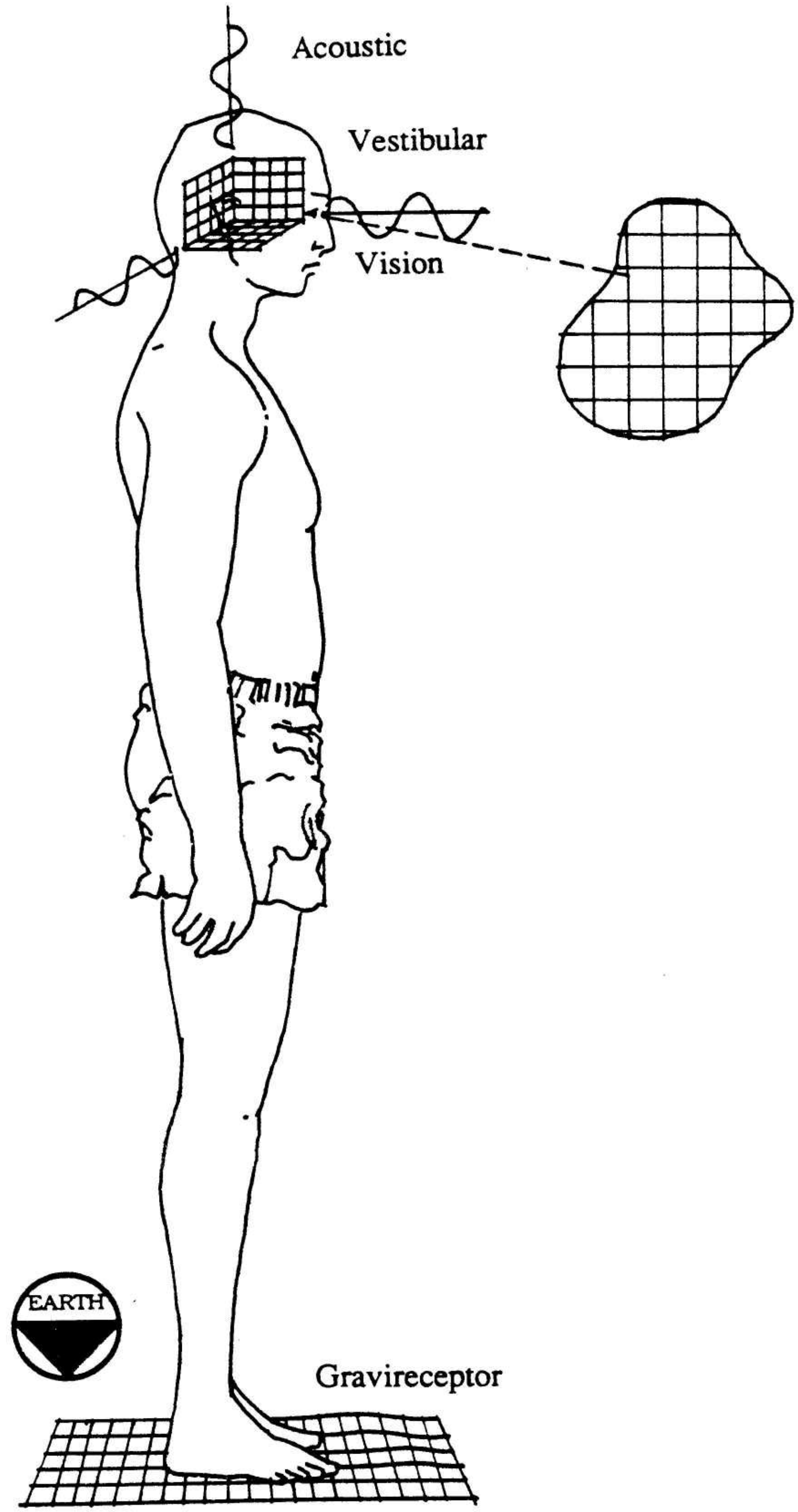


Figure 16: Major Orientation Analyzers

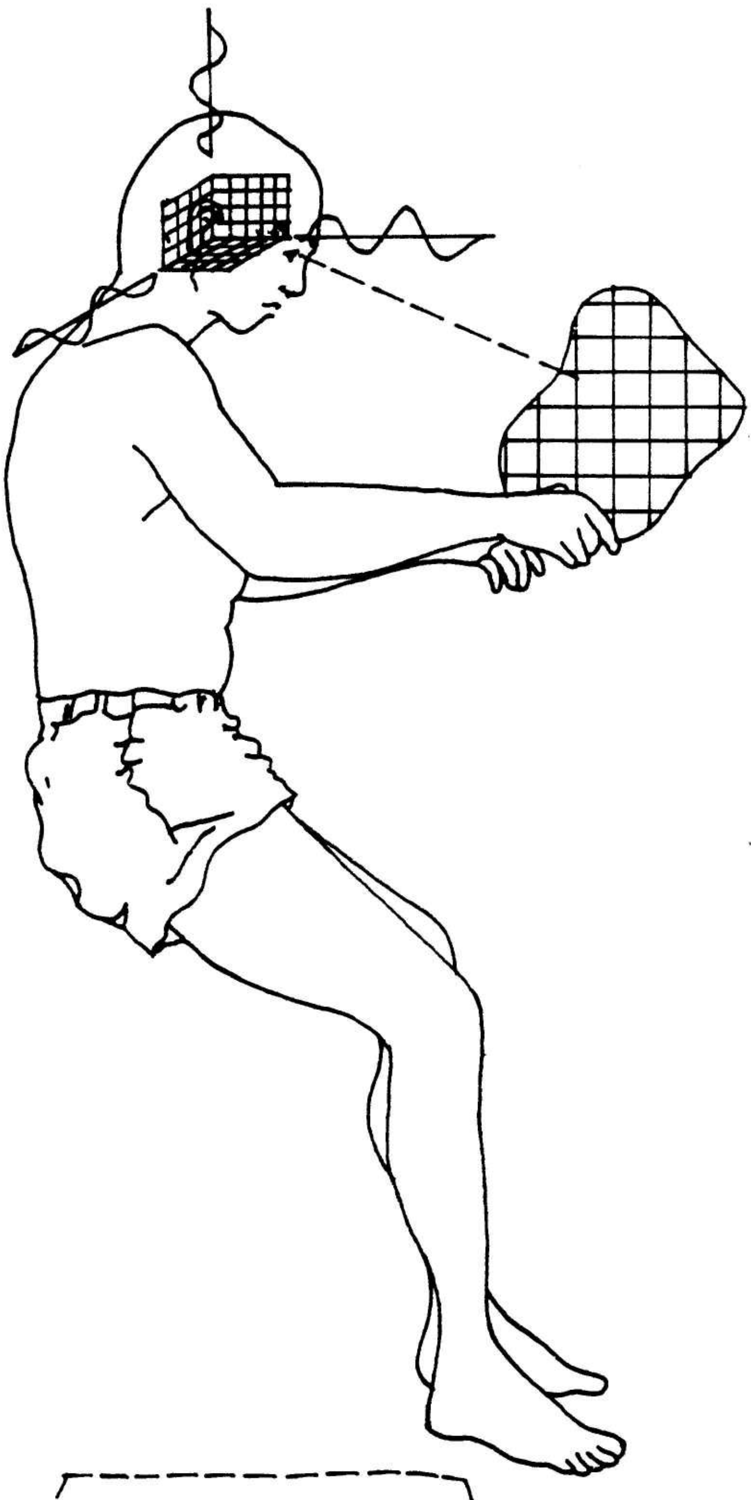
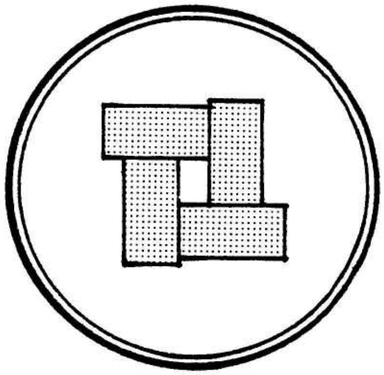
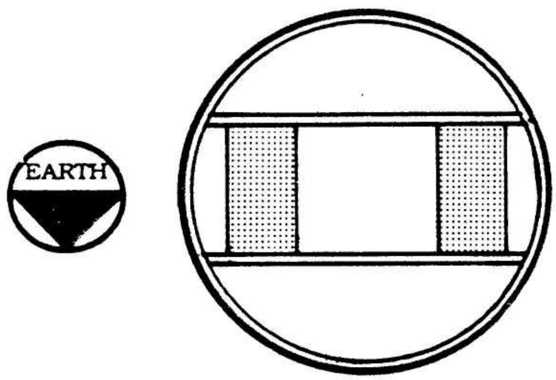


Figure 17: Orientation Analyzers in Zero-G



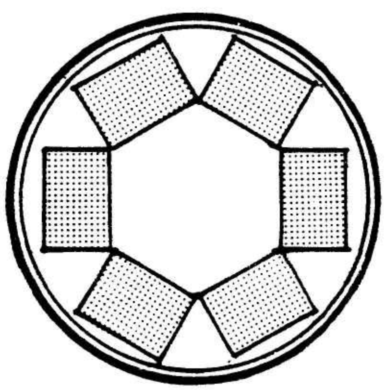
CENTER BEAM

Centrally Mounted Subsystems
• Center "Y"
• Center "T"
• Offset Beam
• Center Pinwheel



INTERSTITIAL

Combination Floor, Wall or Ceiling Subsystems
• Interstitial Standard
• Horizontal Mid Deck
• Vertical Backbone
• Interstitial "Y"



PERIMETER

Perimeter Mounted Subsystems
• Perimeter Pentagonal
• Perimeter Hexagonal
• Perimeter Septagonal
• Perimeter Octagonal

Figure 18: Schematic of Internal Arrangement Strategies

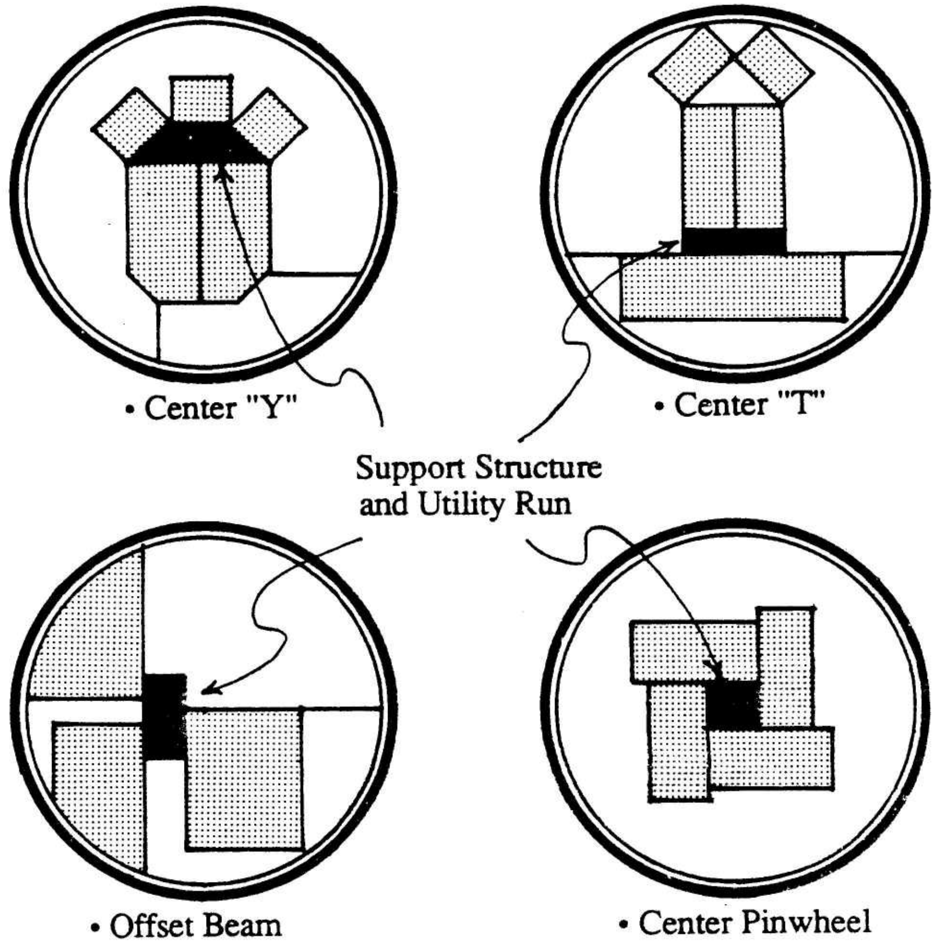


Figure 19: Center Beam Options

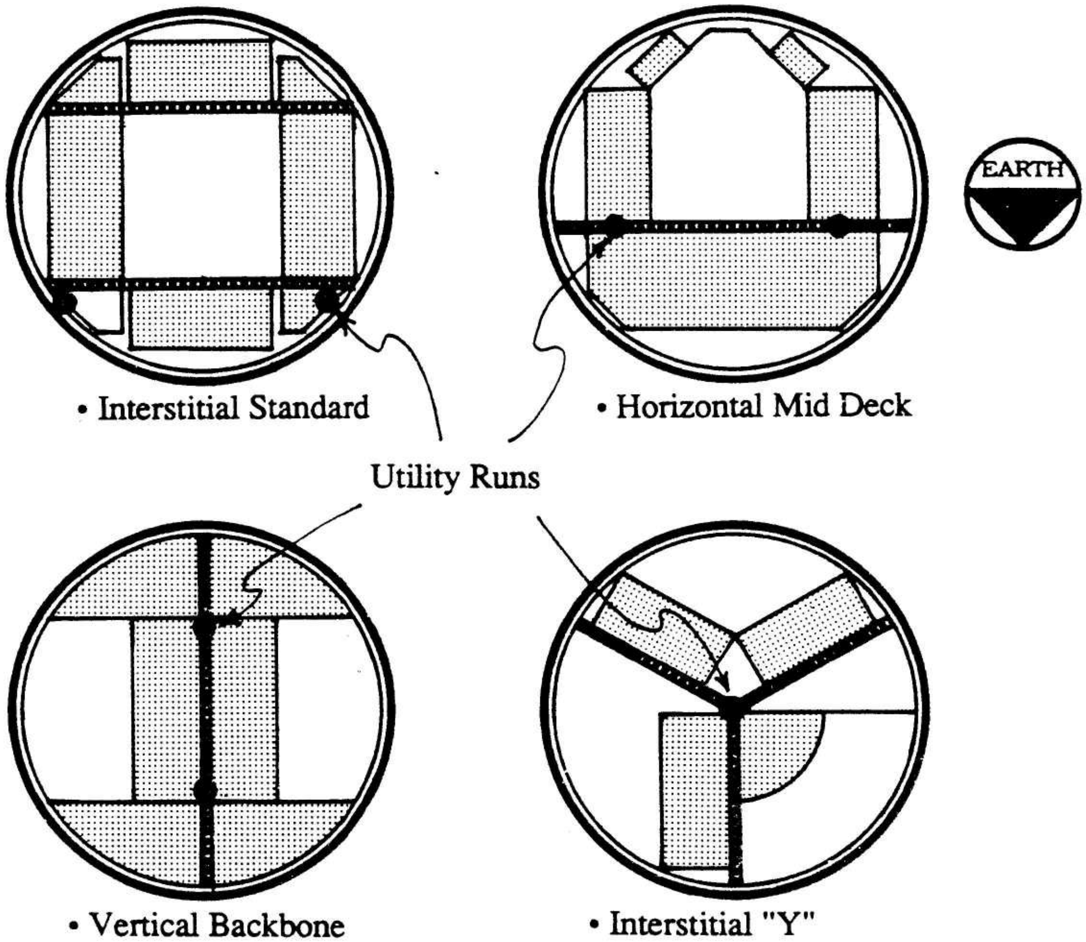


Figure 20: Interstitial Options

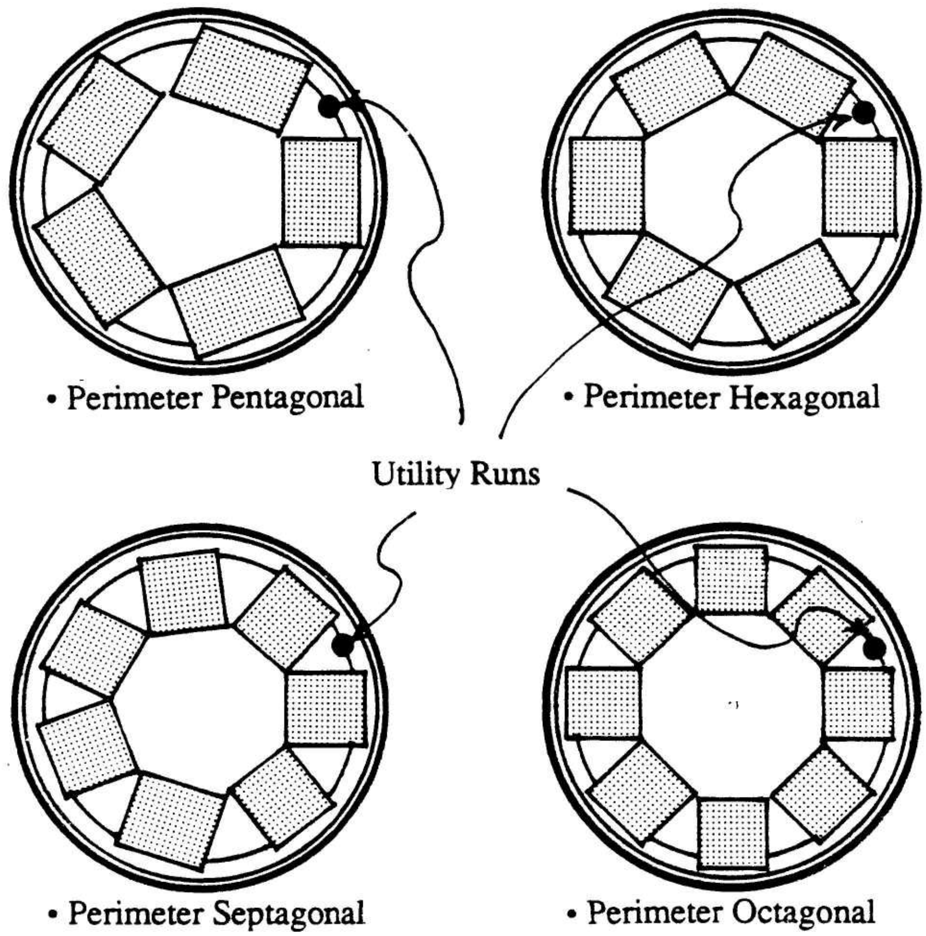


Figure 21: Perimeter Options

	WEIGHT	COMMONALITY	MODULARITY	AIR CIRCULATION	RAD PROTECTION	USABLE VOLUME	ORU ACCESSIBILITY	WALL ACCESS	NOISE CONTROL	CREW TRAFFIC	UTILITIES DIST	RACK FRONT AREA	W/STATION PROFILE	ISOLATION
CENTER "Y"	B	A	B	C	C	C	B	A	A	C	A	B	A	B
CENTER "T"	B	D	B	C	C	C	C	A	A	C	B	B	A	B
CENTER PINWHEEL	B	B	A	D	C	C	C	A	A	D	A	B	C	B
OFFSET BEAM	B	D	C	A	C	C	B	A	A	C	A	B	B	B
INTERSTITIAL STD	C	B	B	A	B	B	C	C	B	B	C	C	A	D
INTERSTITIAL "Y"	C	C	B	B	C	C	B	B	B	C	A	C	B	C
VERTICAL FLOOR	B	B	B	A	C	C	B	A	B	C	B	C	A	B
HORIZ MID DECK	A	A	A	A	B	A	A	B	B	B	B	C	A	A
PERIMETER PENT	B	C	B	A	A	B	C	D	B	A	C	A	C	A
PERIMETER HEX	B	A	A	B	A	B	C	D	B	A	C	A	B	A
PERIMETER SEPT	C	C	B	B	A	B	C	D	B	A	C	A	C	A
PERIMETER OCT	D	C	B	B	A	B	C	D	B	A	C	A	D	A

Figure 22: Evaluation of Internal Arrangement Options

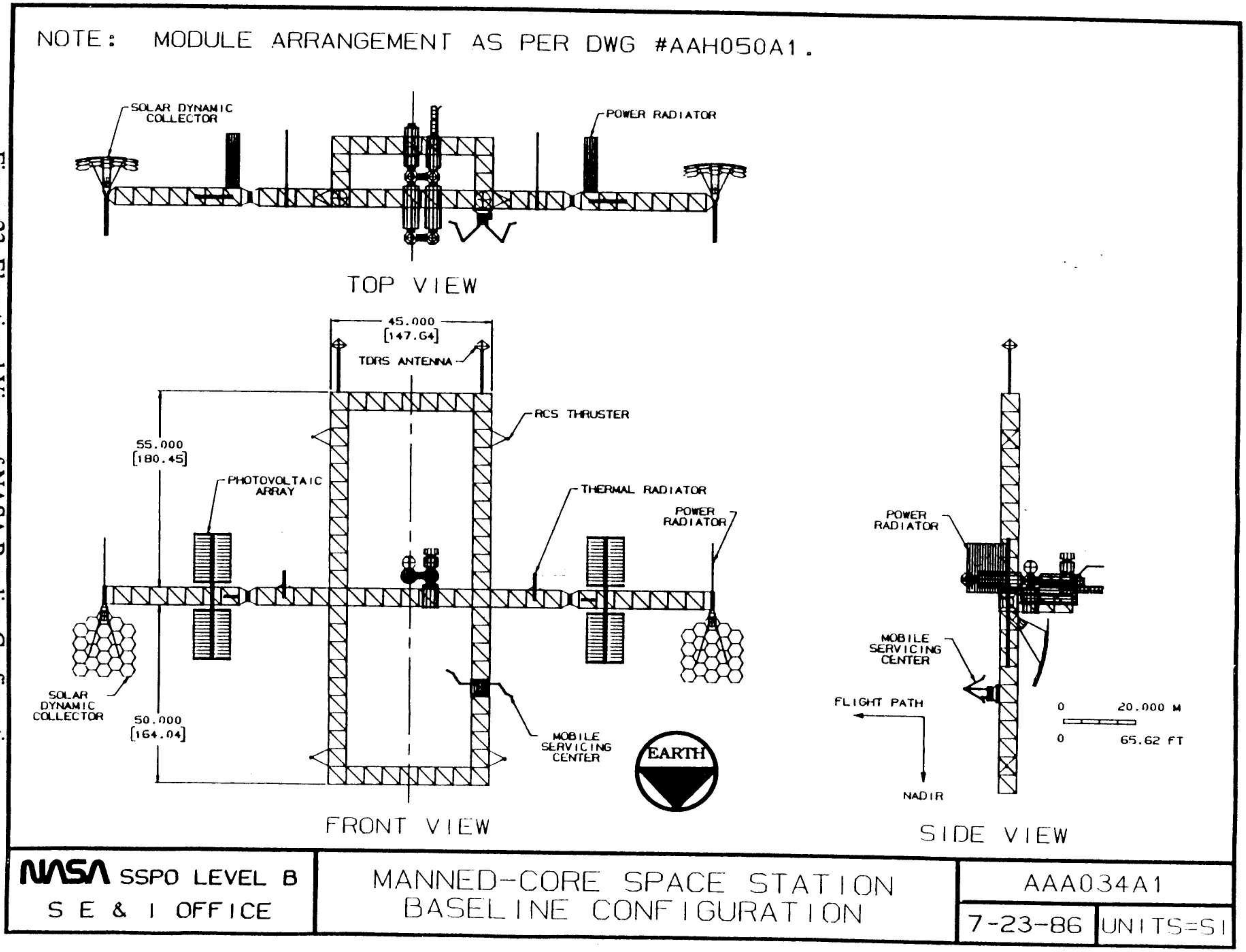


Figure 23: Elevational Views of NASA Baseline Configuration

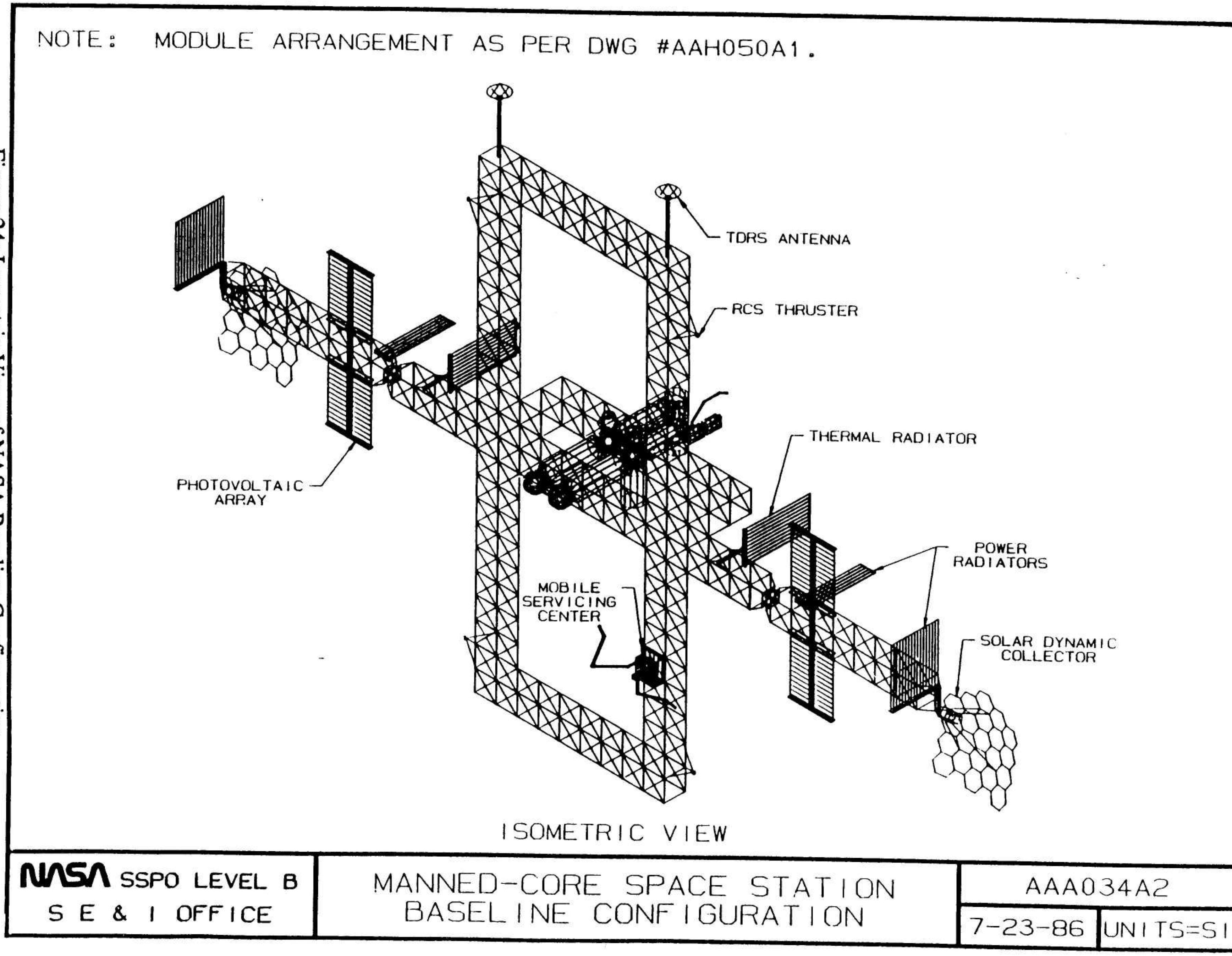


Figure 24: Isometric View of NASA Baseline Configuration

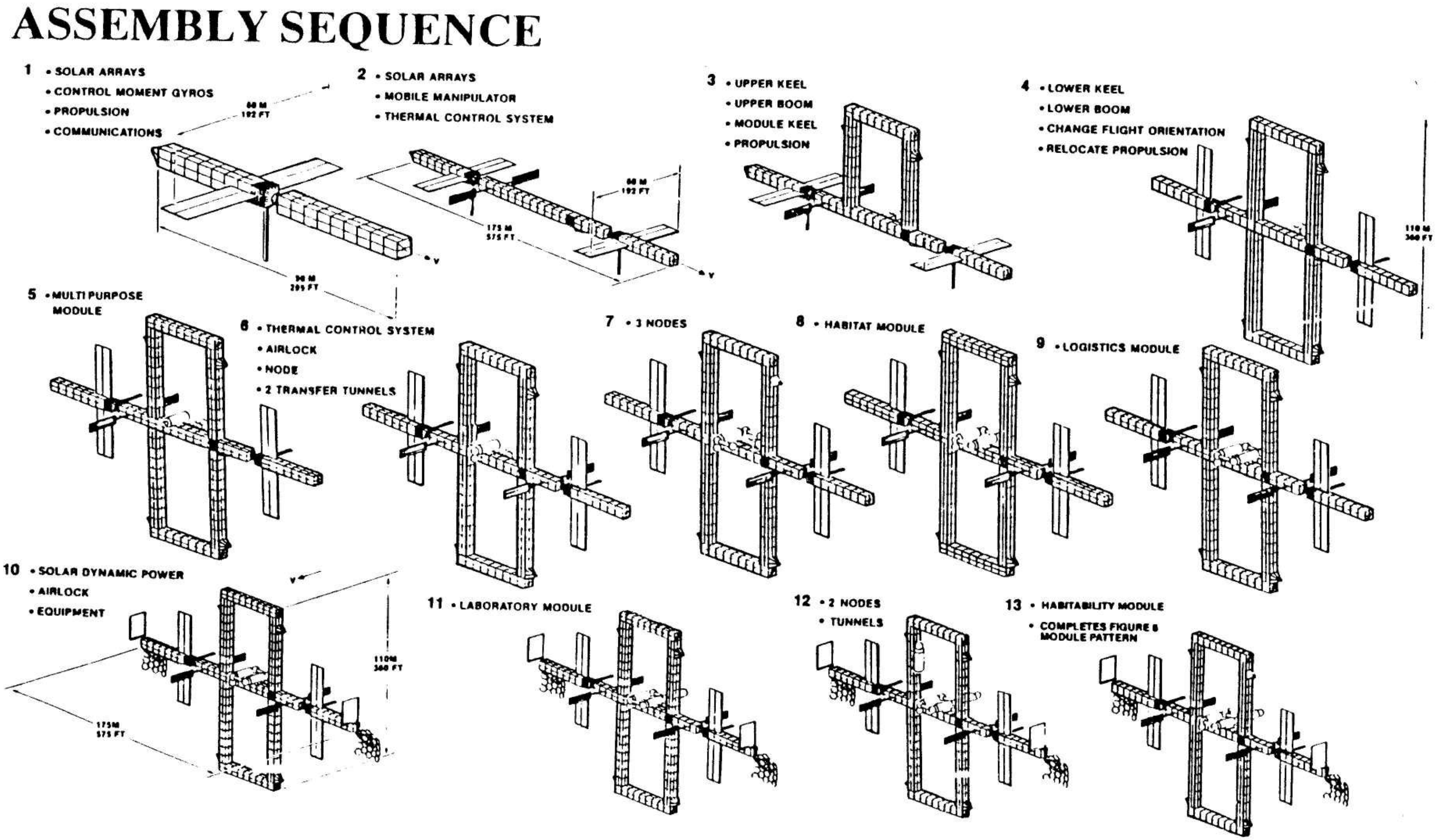


Figure 25: Assembly Sequence of NASA Baseline Configuration

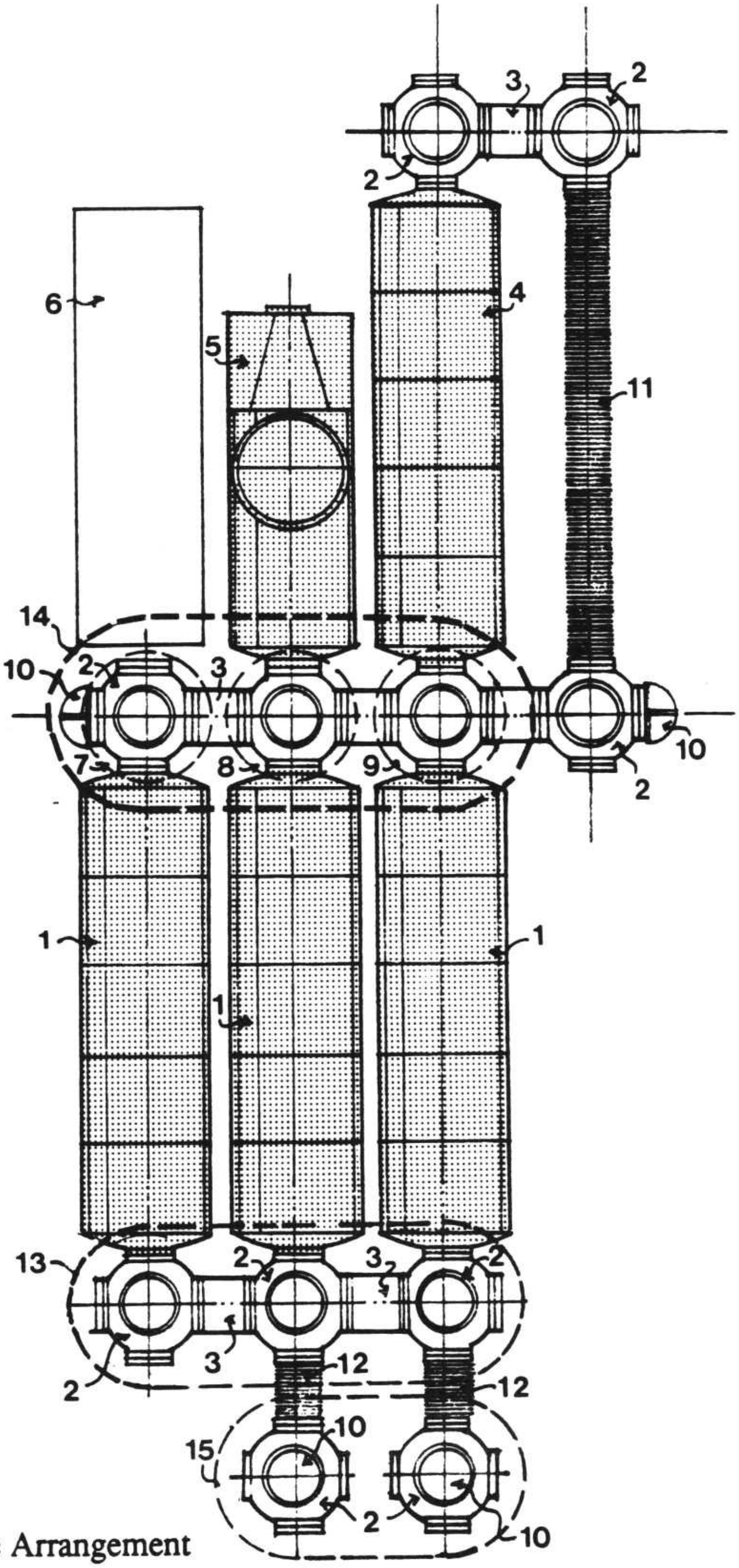


Figure 26: Top View of Proposed Module Arrangement

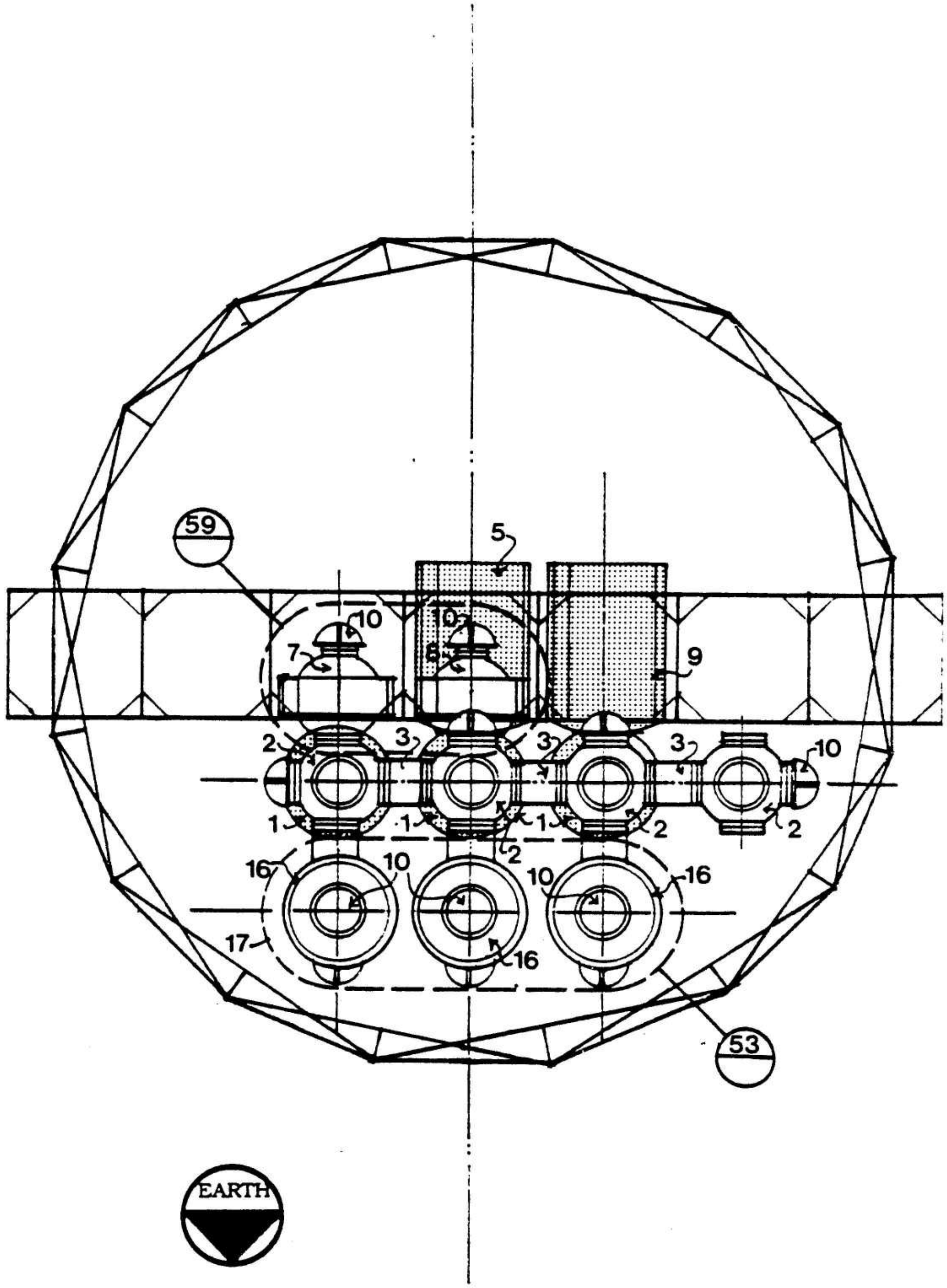


Figure 27: Front View of Proposed Module Arrangement

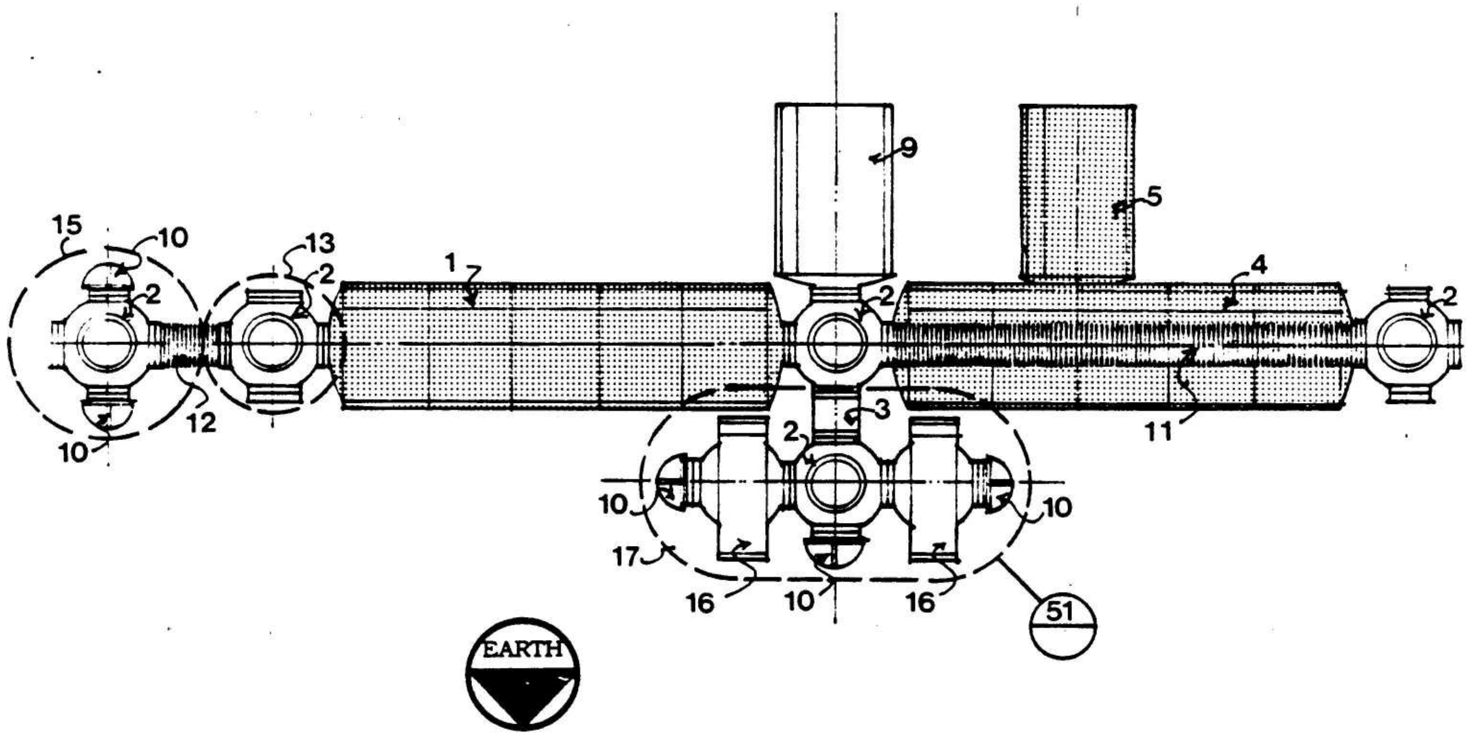


Figure 28: Side View of Proposed Module Arrangement

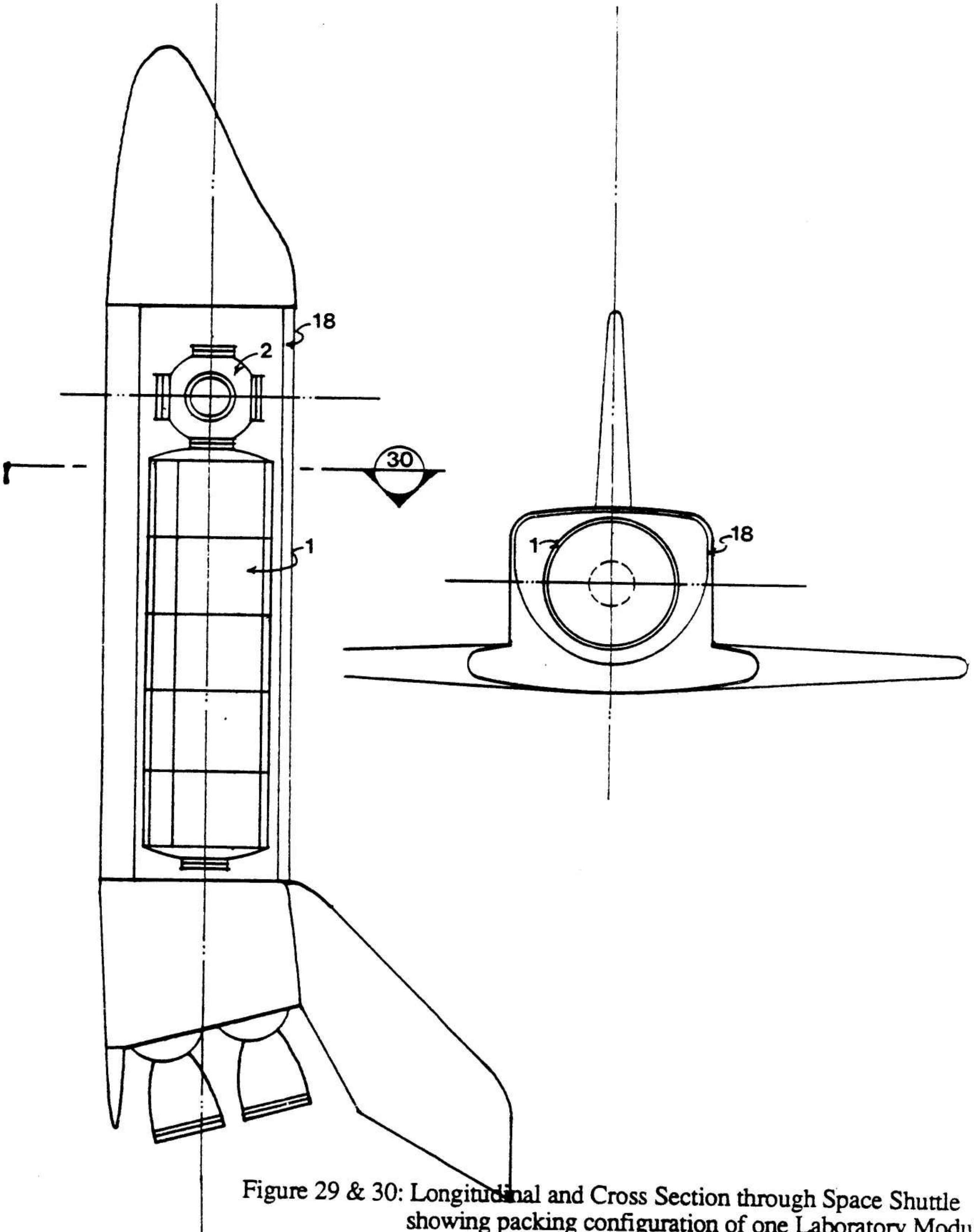


Figure 29 & 30: Longitudinal and Cross Section through Space Shuttle showing packing configuration of one Laboratory Module and one Intermediary Module

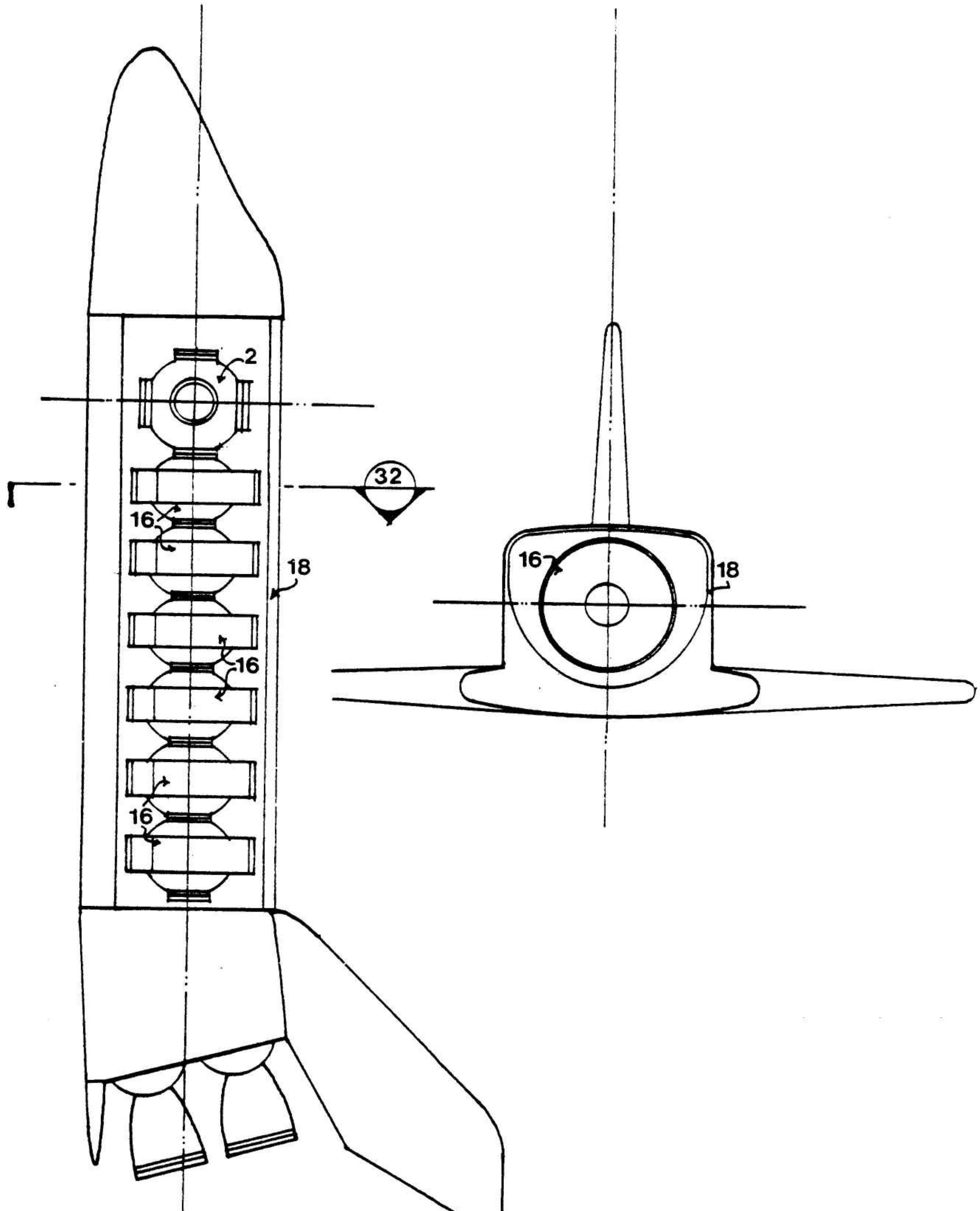


Figure 31 & 32: Longitudinal and Cross Section through Space Shuttle showing packing configuration of six PAD systems and one Intermediary Module

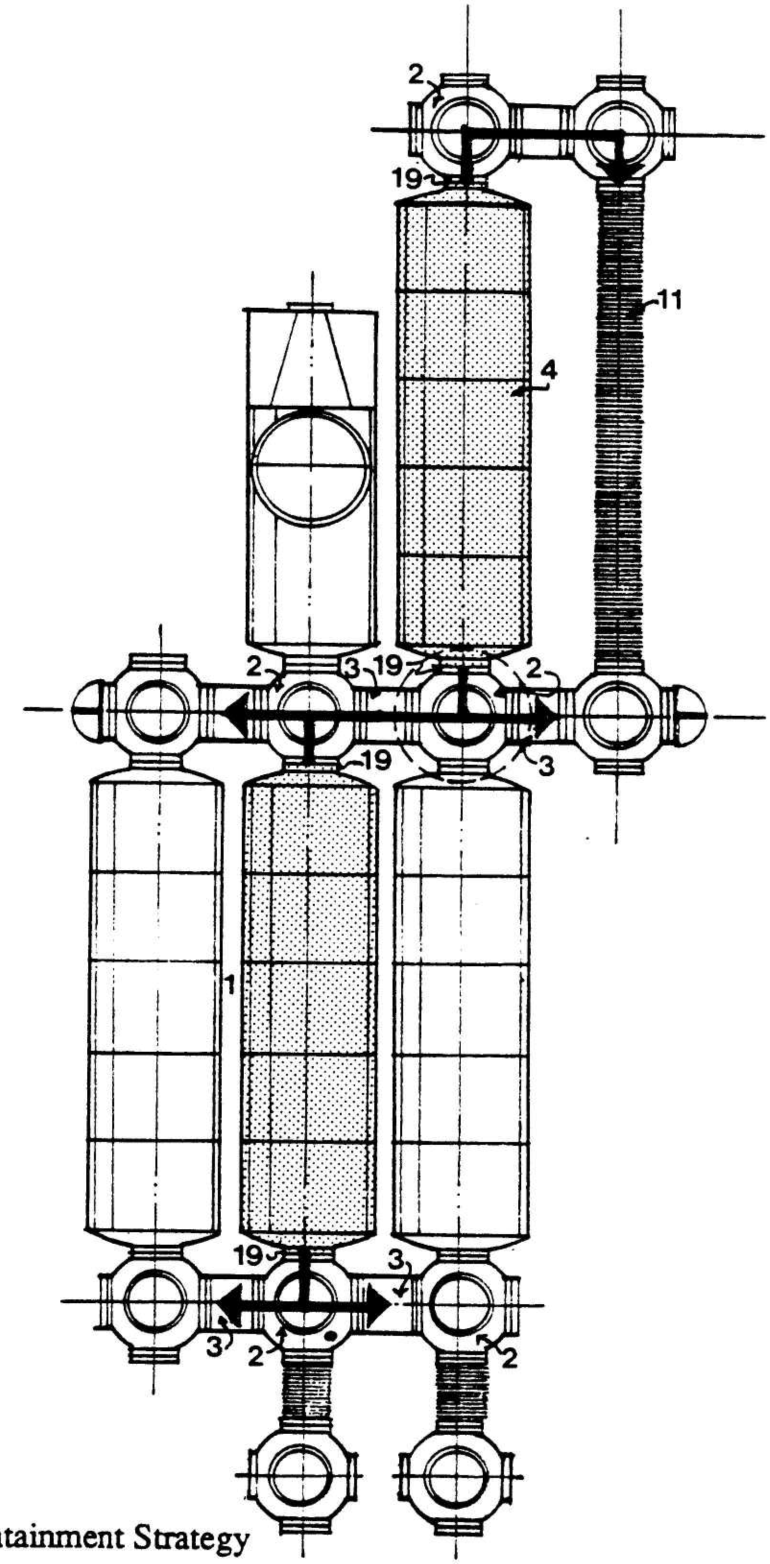


Figure 33: Top View - Emergency Containment Strategy

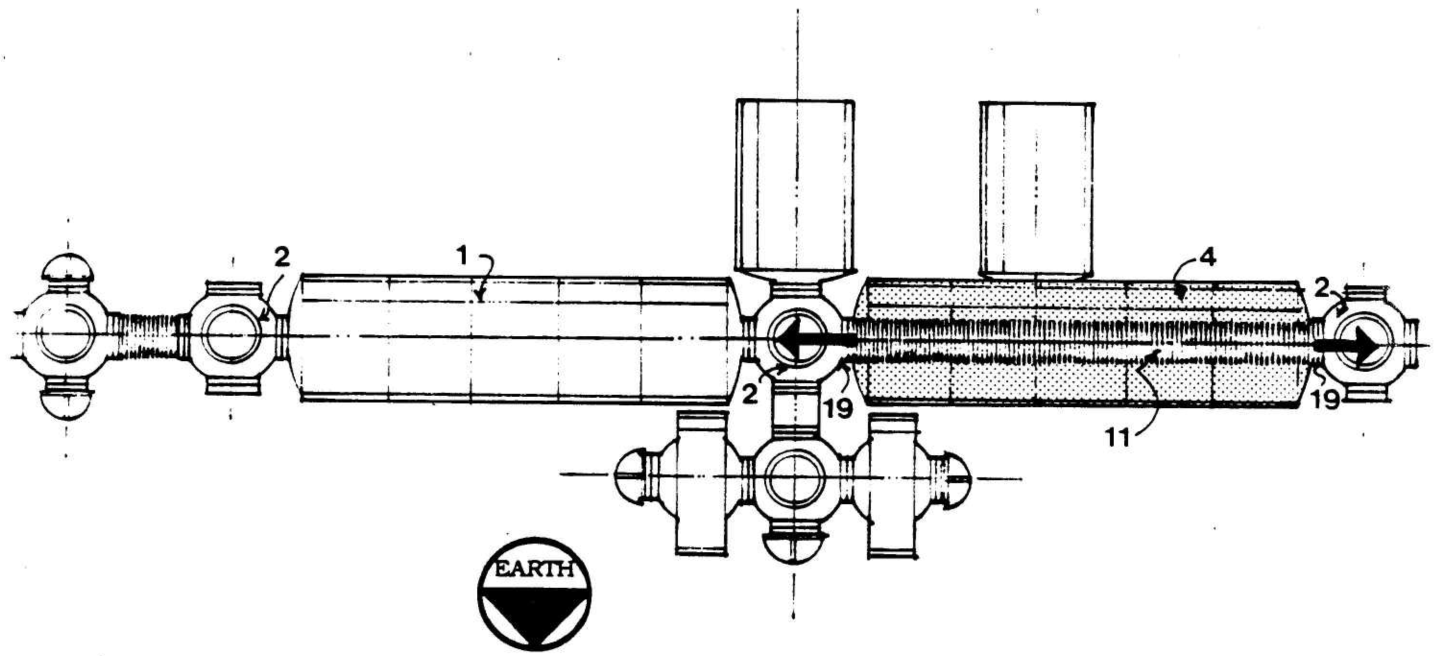


Figure 34: Side View - Emergency Containment Strategy

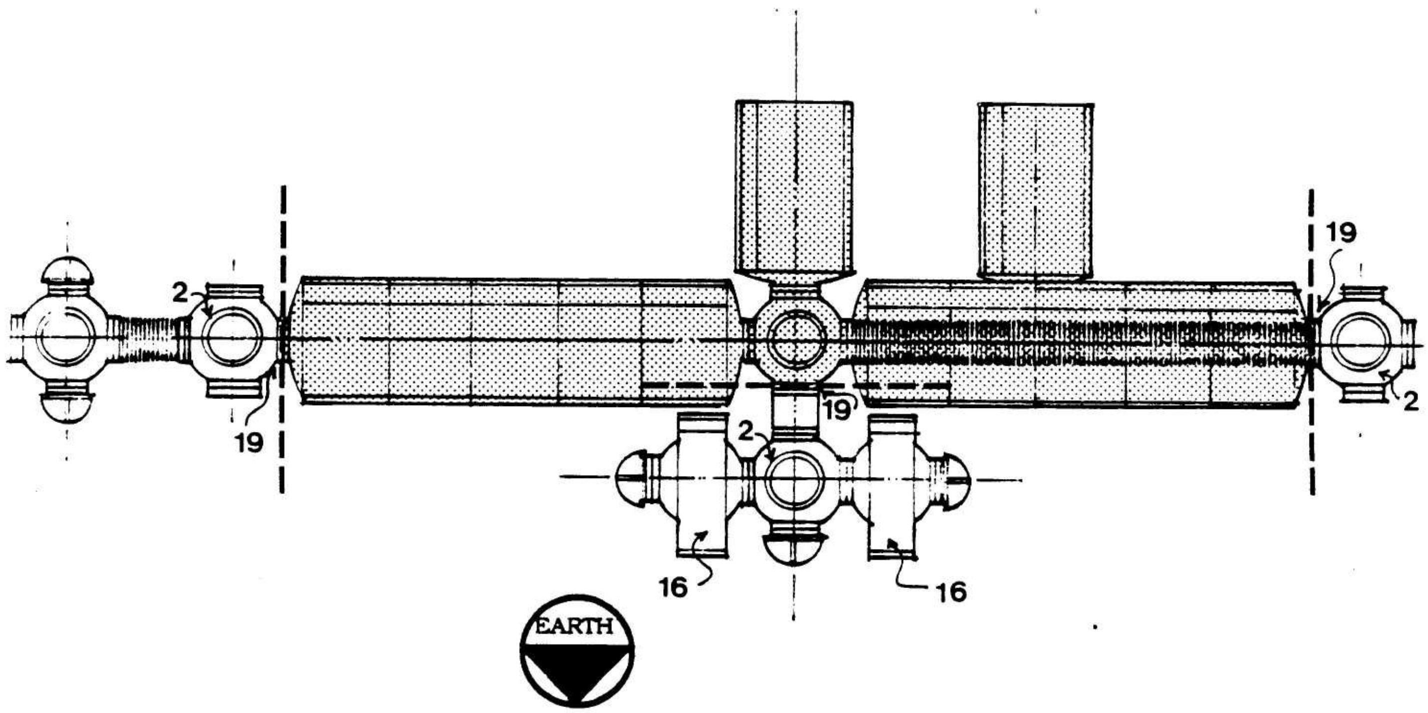


Figure 35: Side View - Emergency Evacuation Strategy

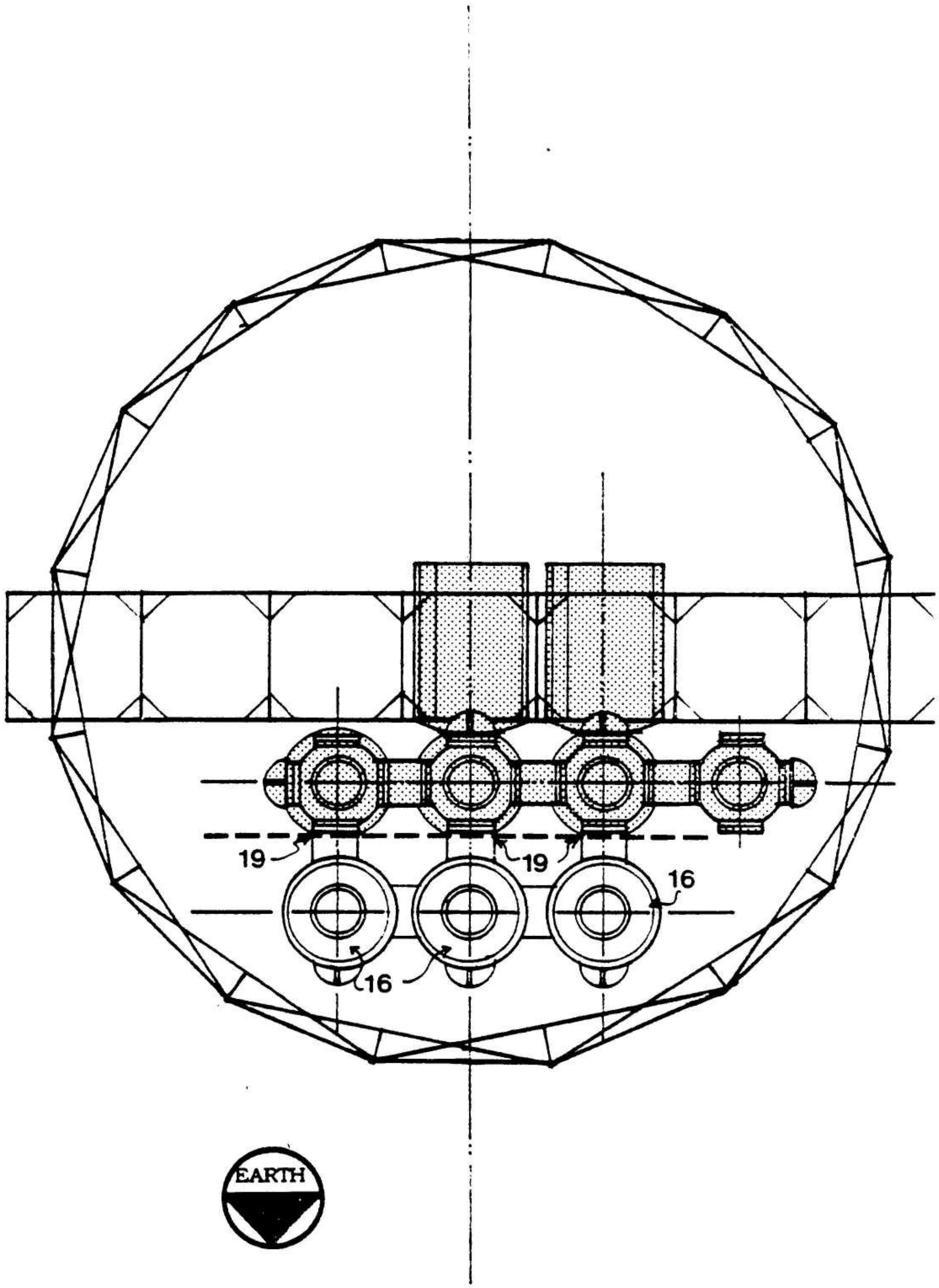


Figure 36: Front View - Emergency Evacuation Strategy

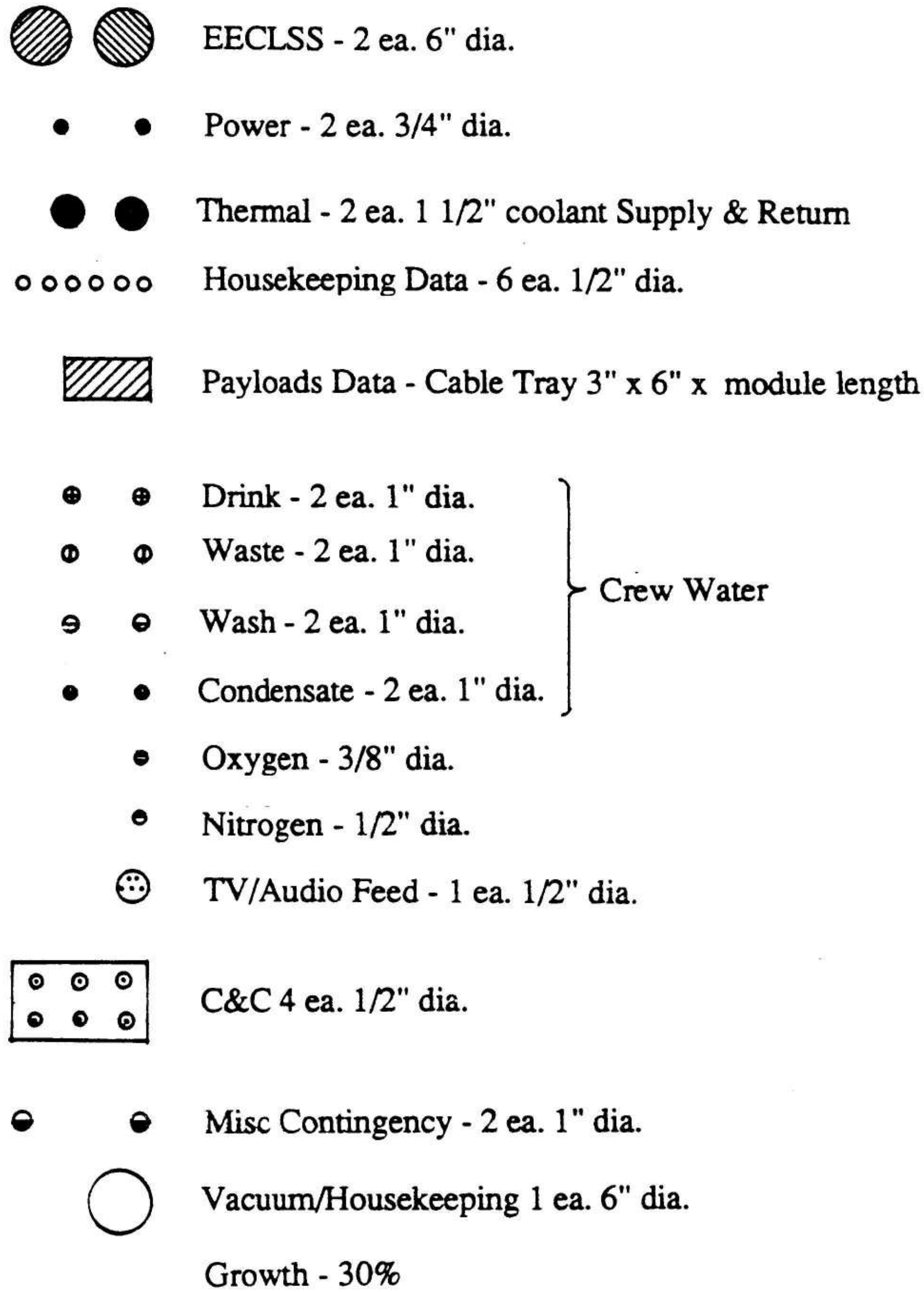


Figure 37: Utility Sizing

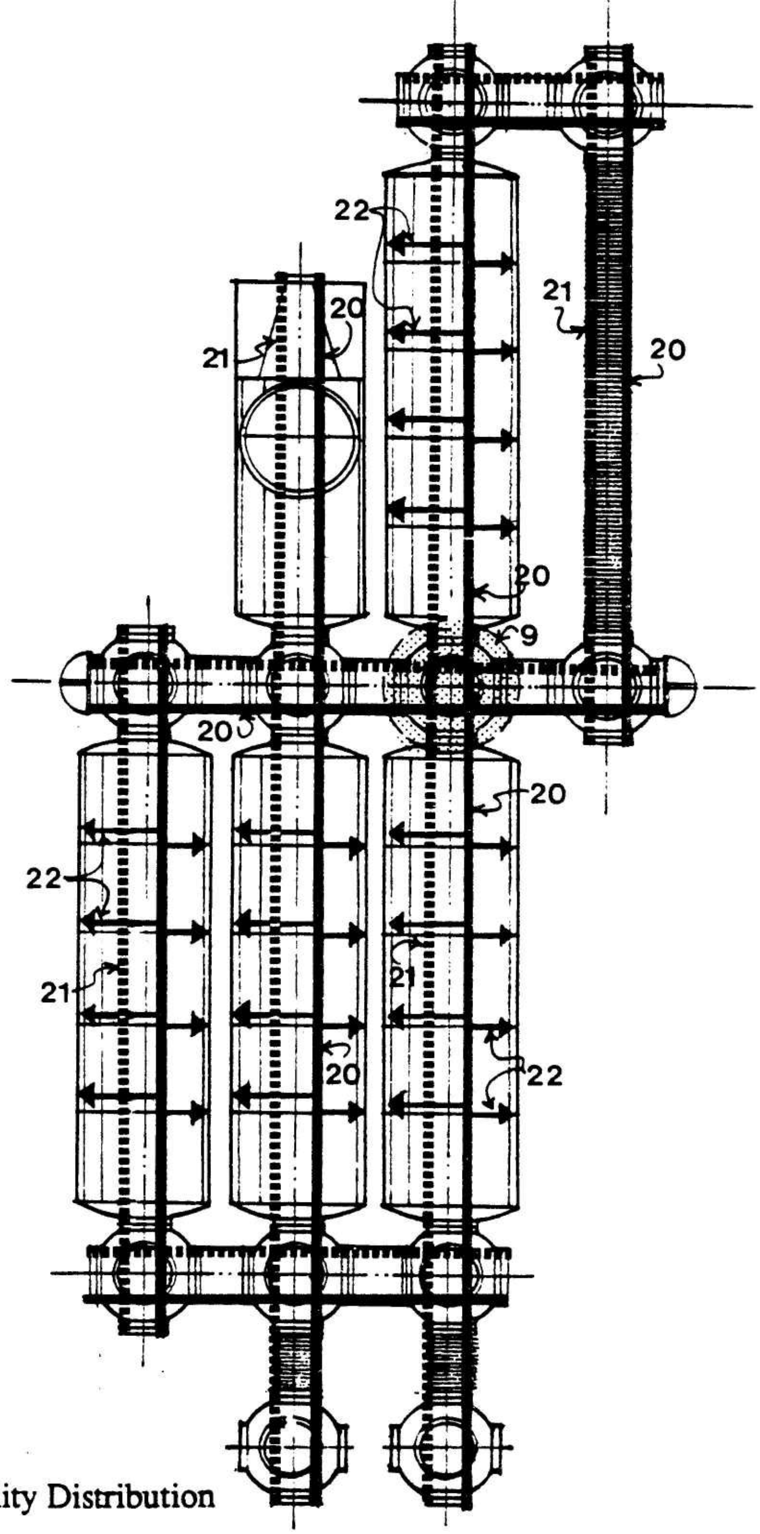


Figure 38: Top View - Module Utility Distribution

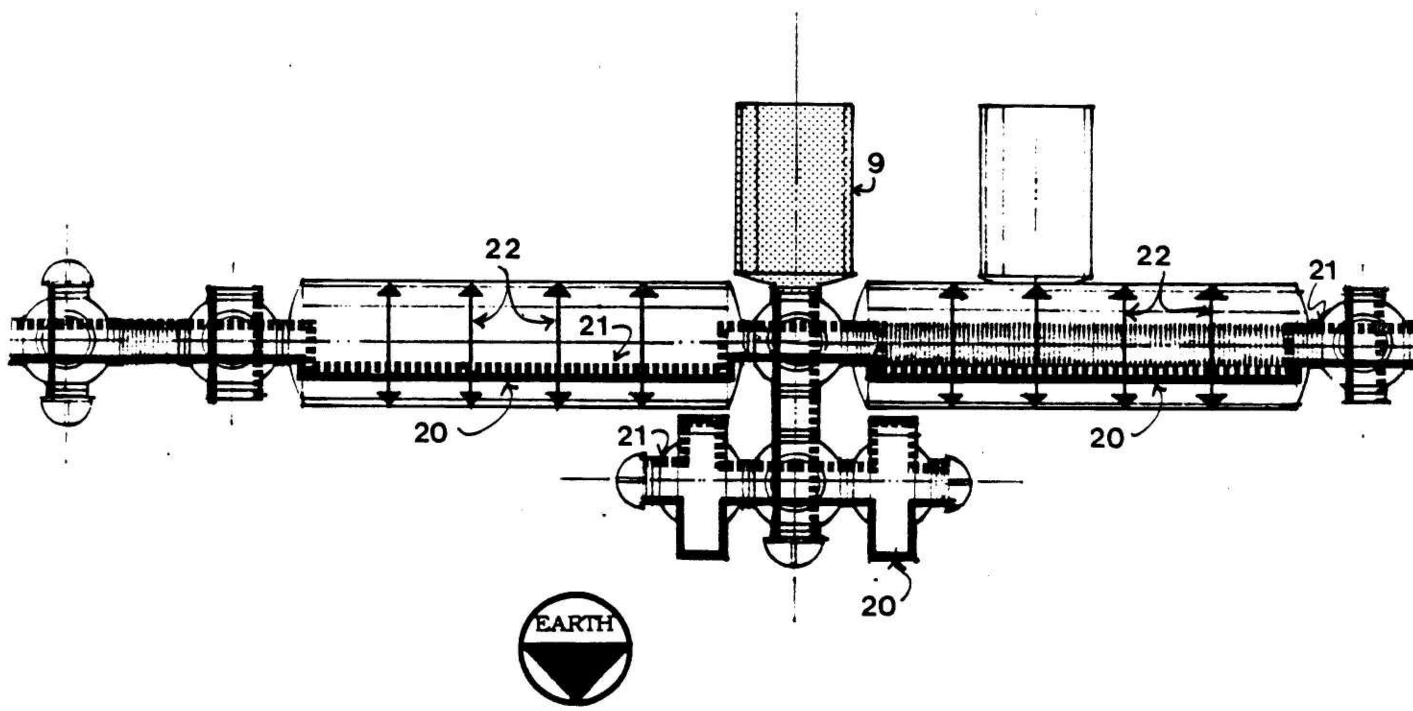


Figure 39: Side View - Module Utility Distribution

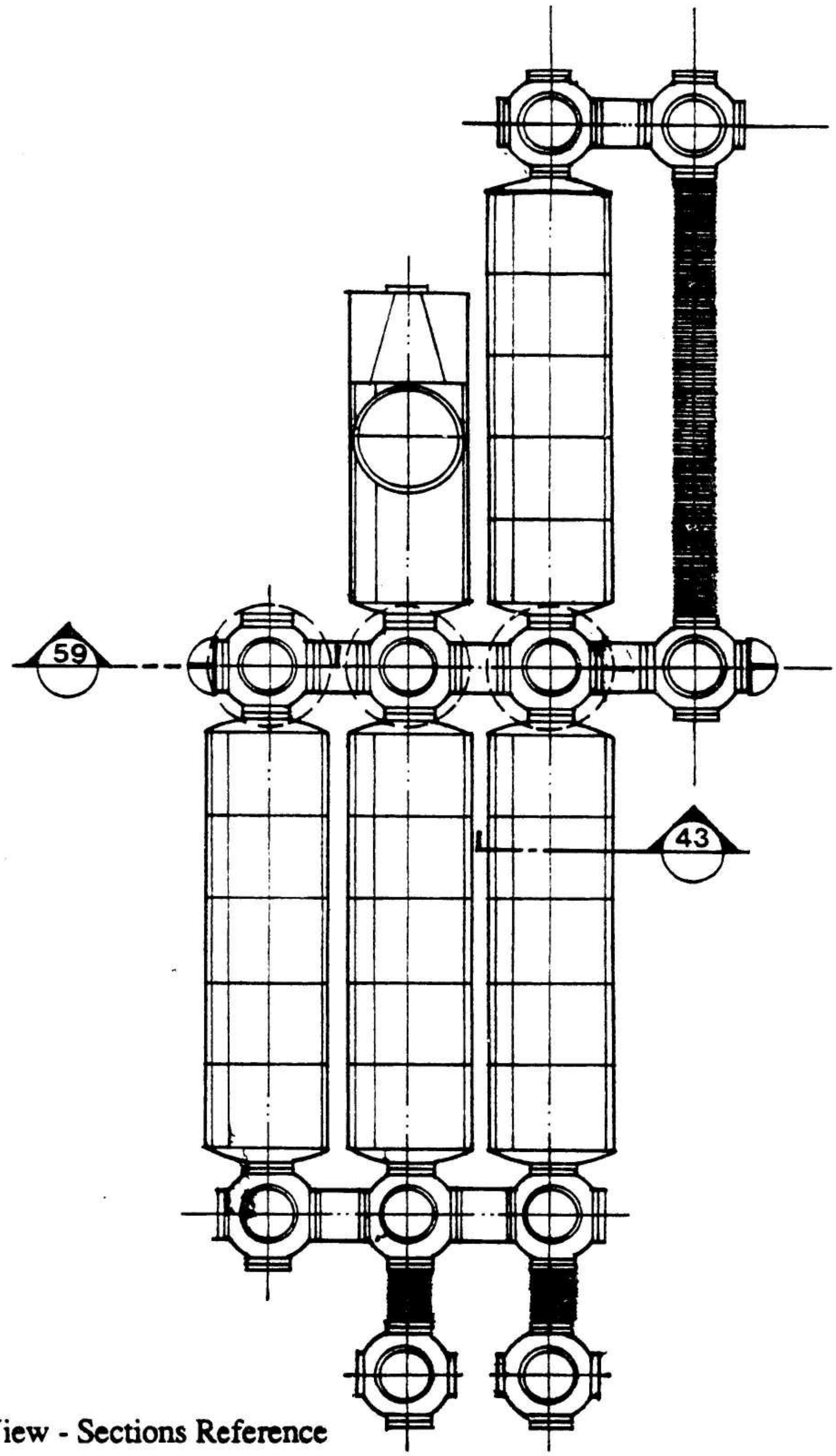


Figure 40: Top View - Sections Reference

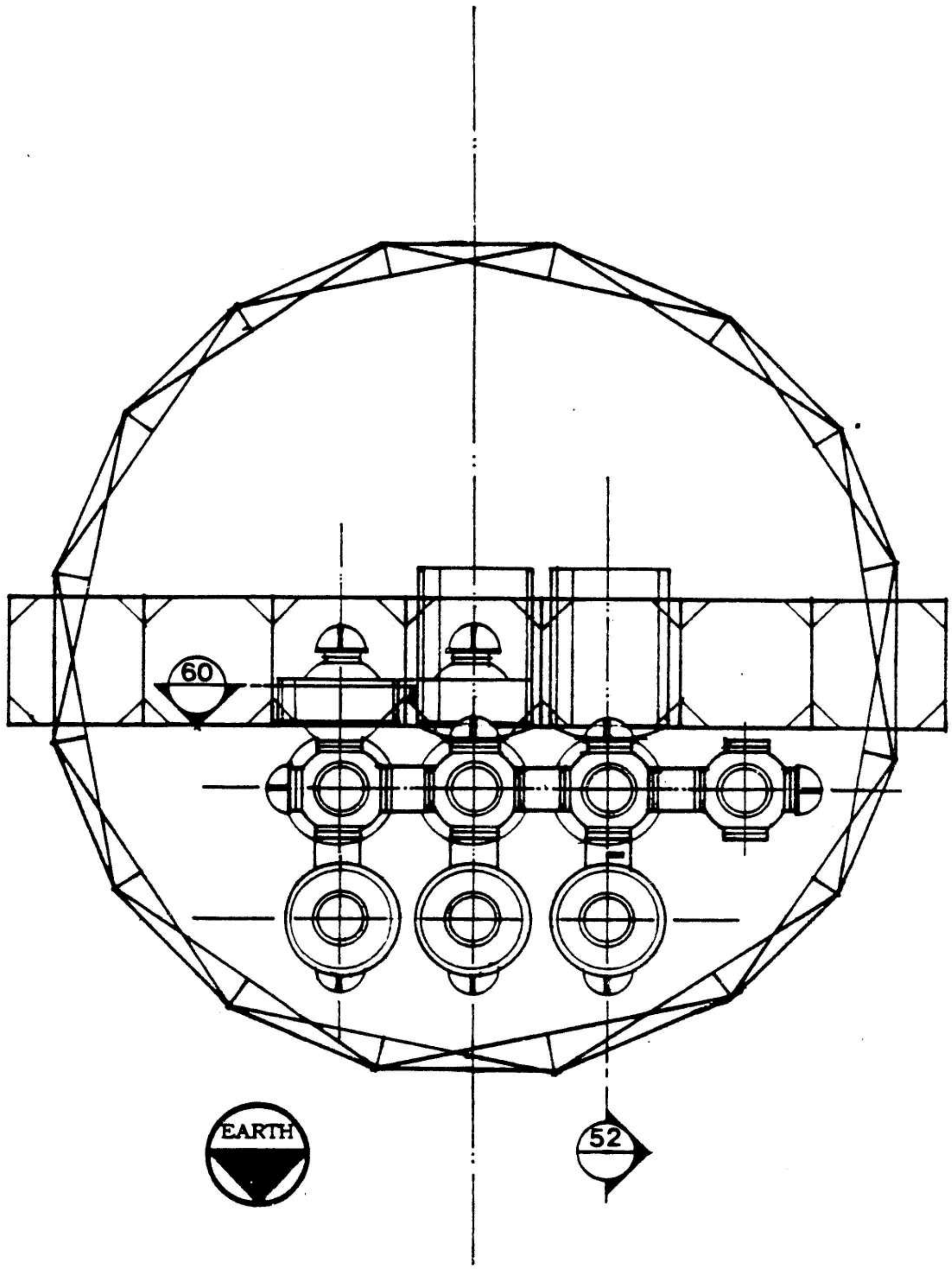


Figure 41: Front View - Sections Reference

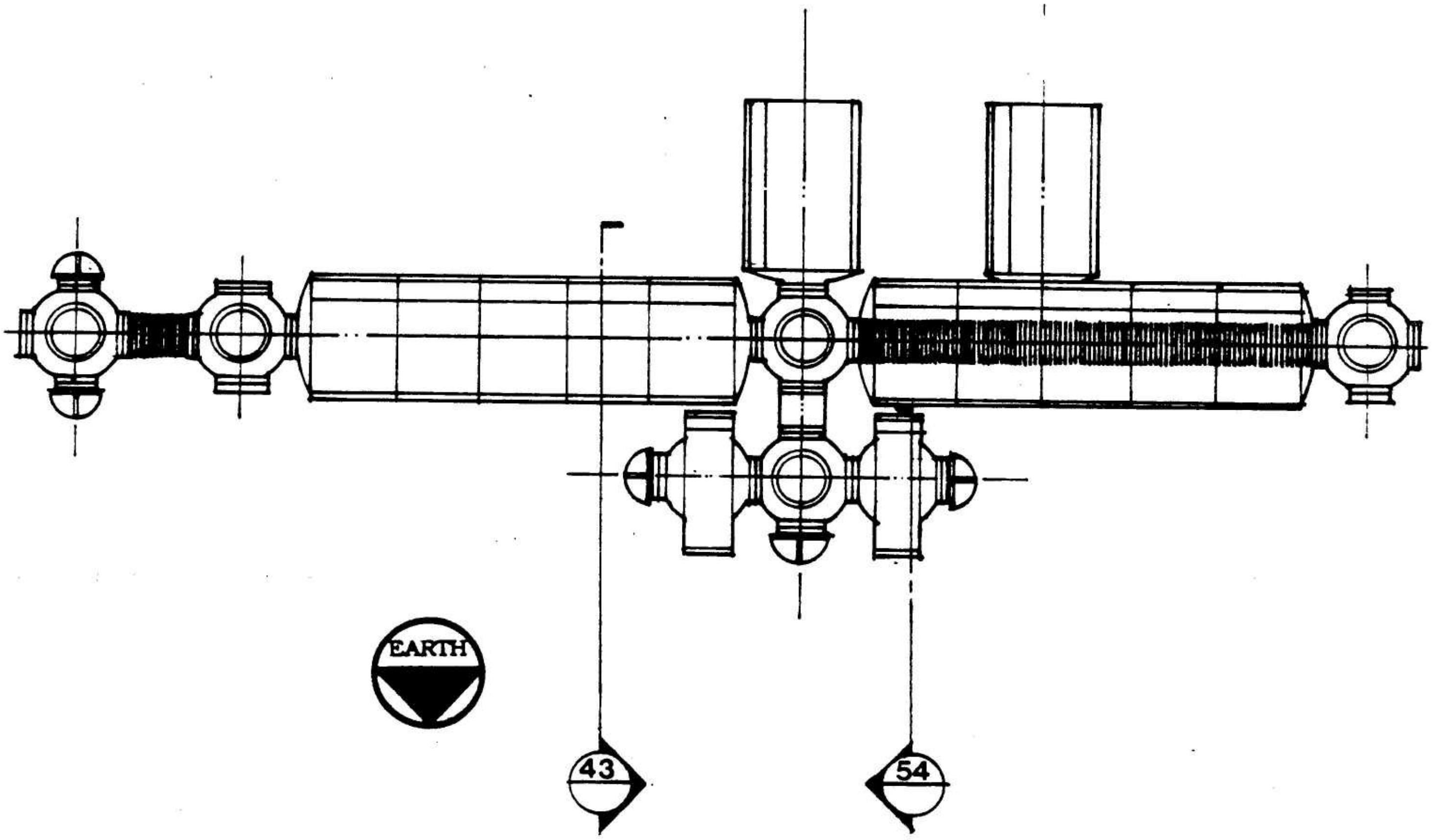


Figure 42: Side View - Sections Reference

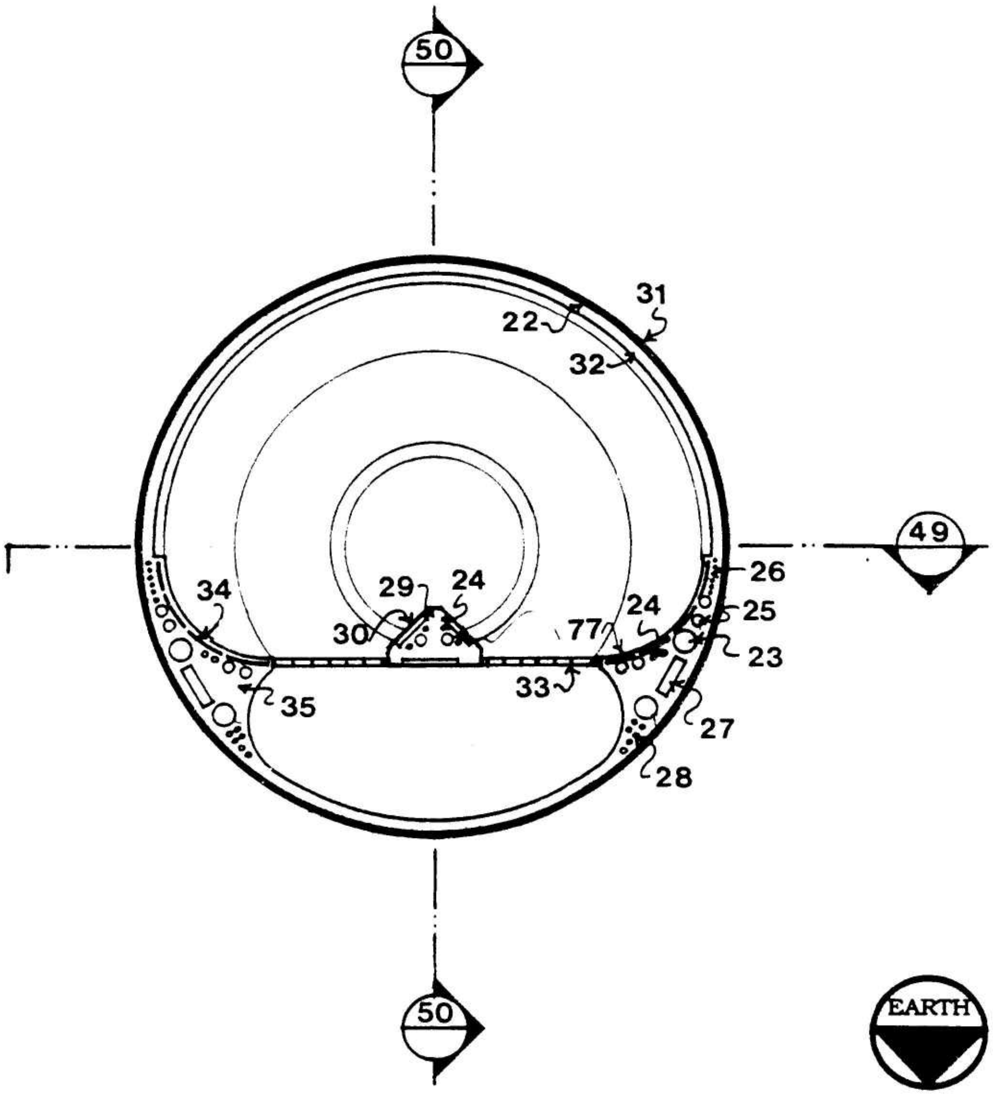


Figure 43: Section - Module Utility Placement, Low Beam

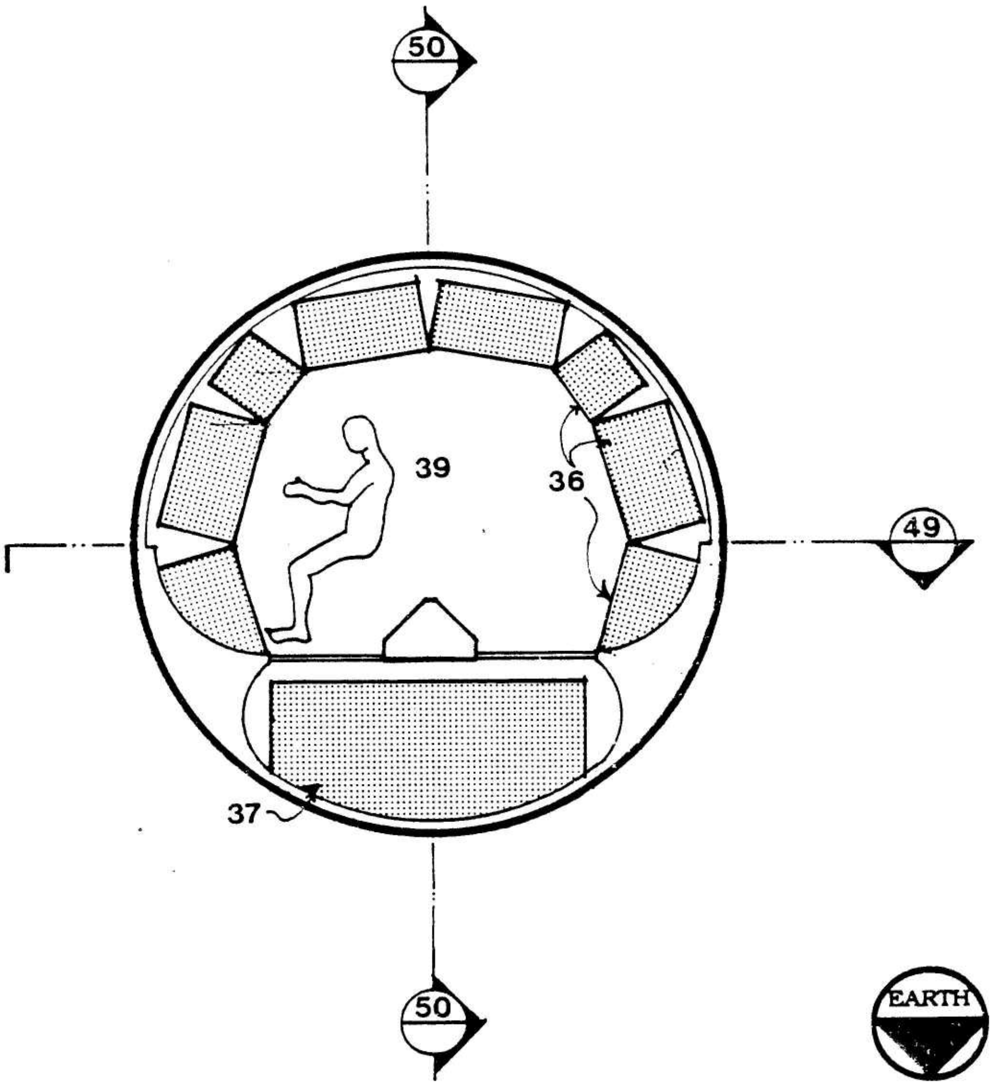


Figure 44: Section - Perimeter Location of Equipment, Low Beam

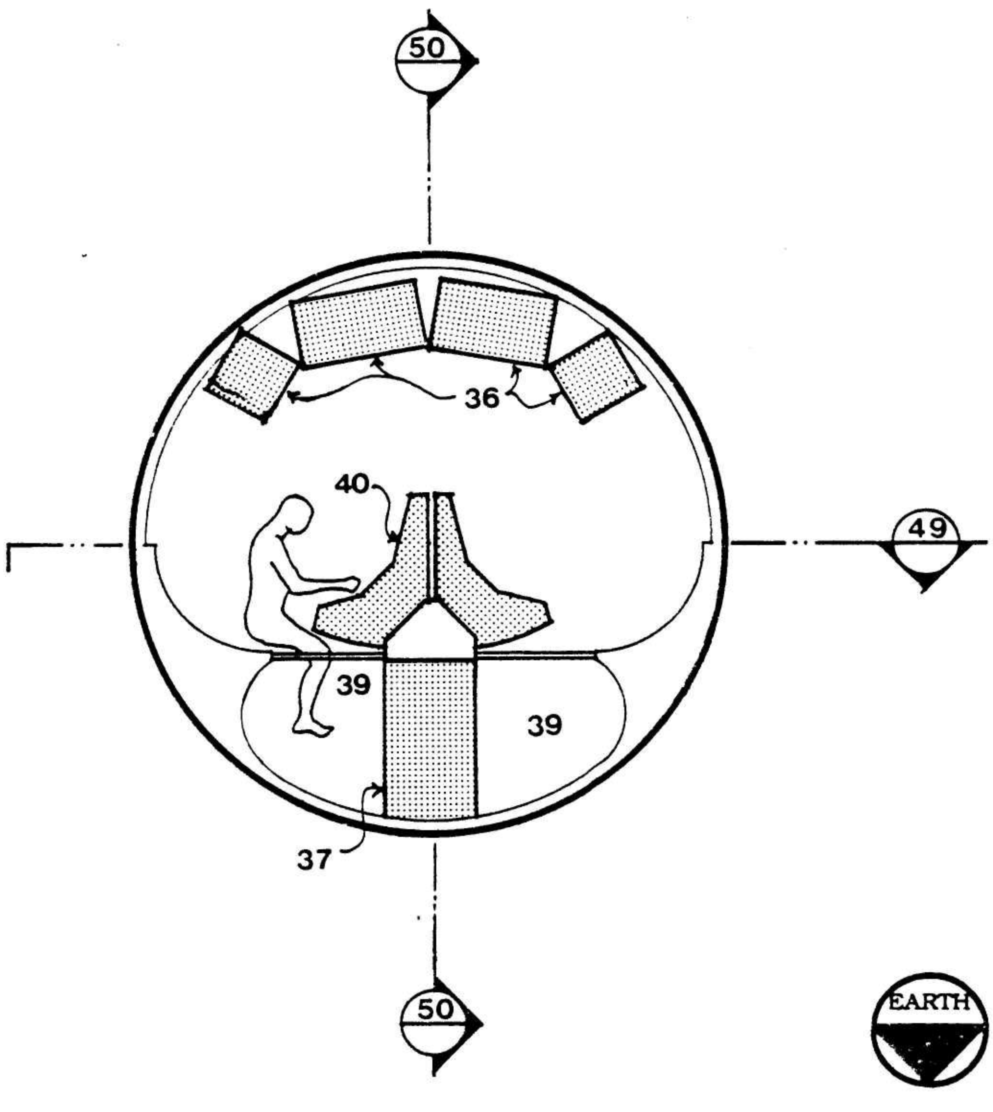


Figure 45: Section - Center Beam Location of Equipment, Low Beam

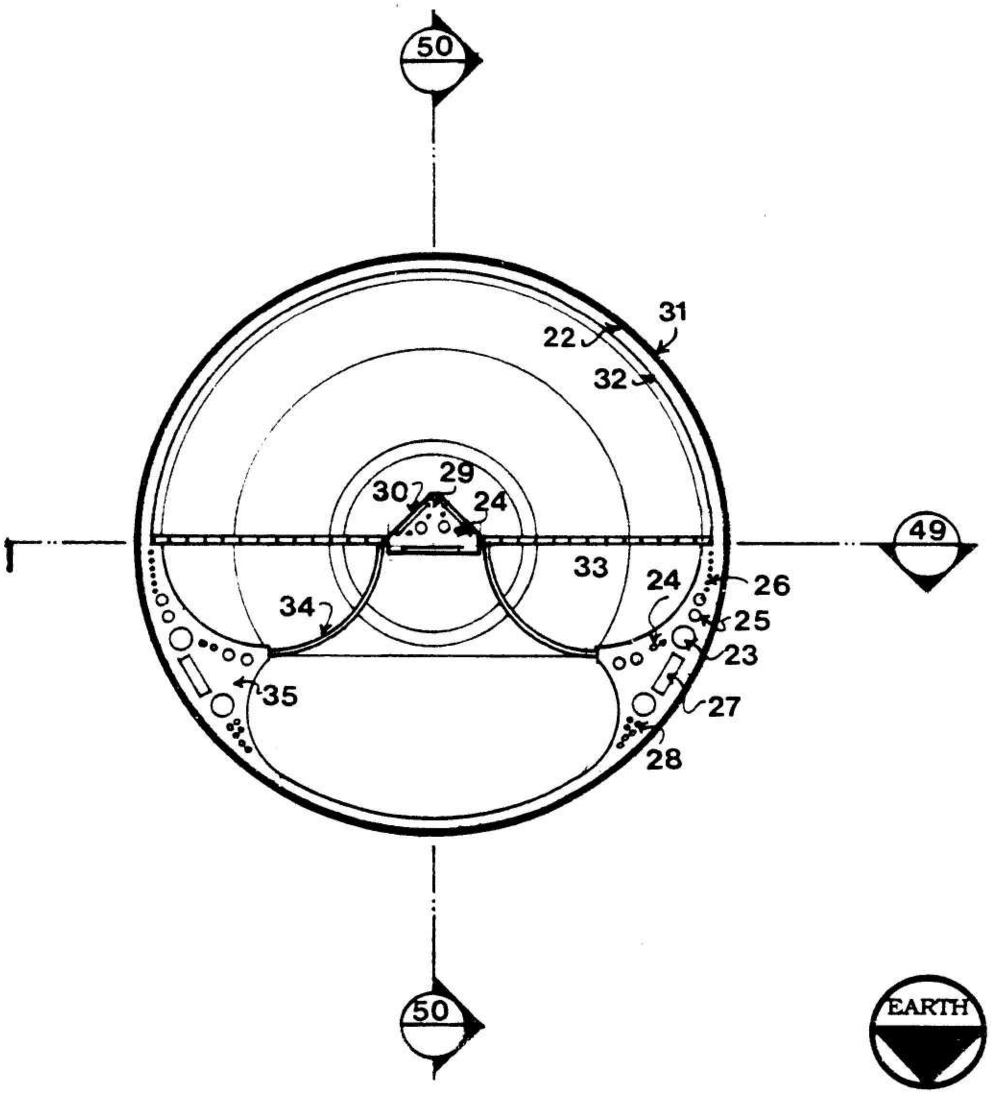


Figure 46: Section - Module Utility Placement, High Beam

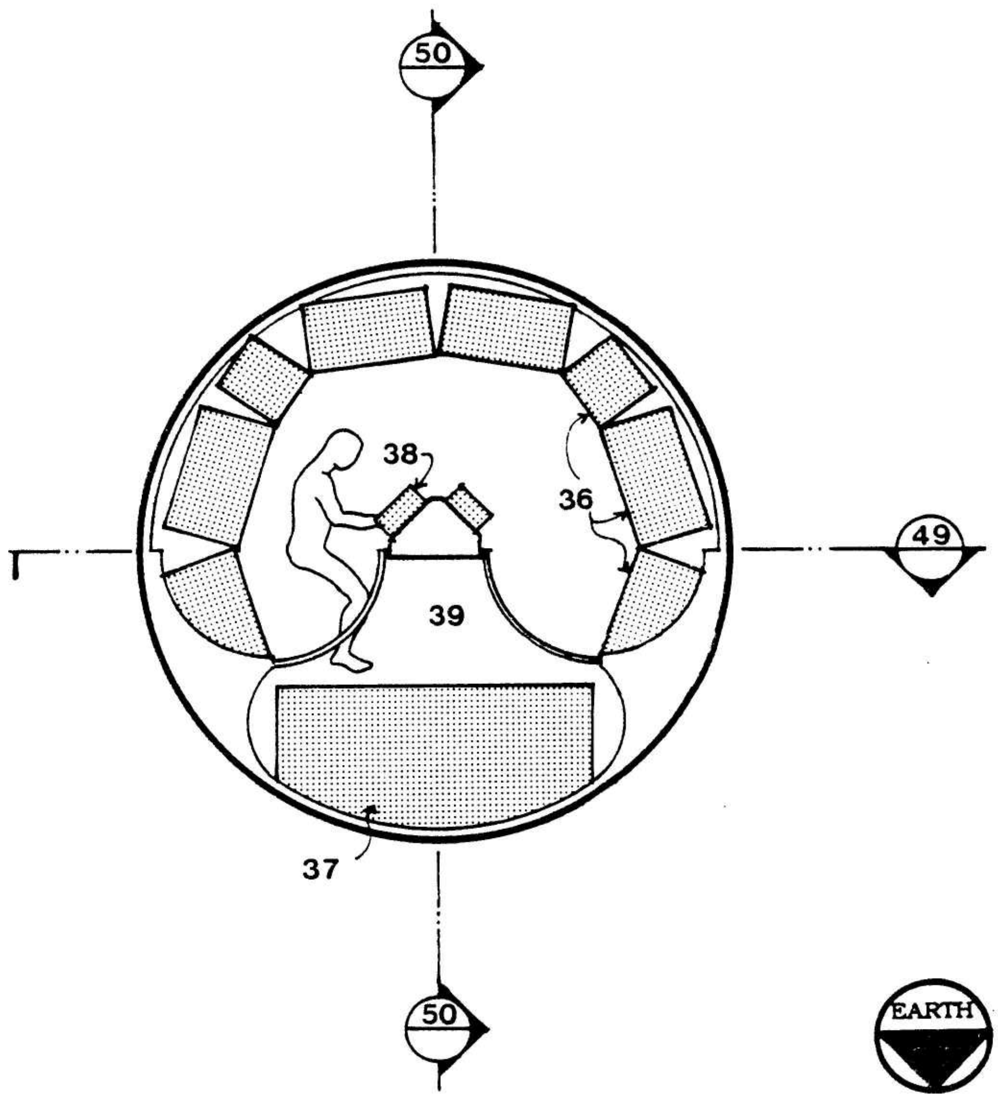


Figure 47: Section - Perimeter Location of Equipment, High Beam

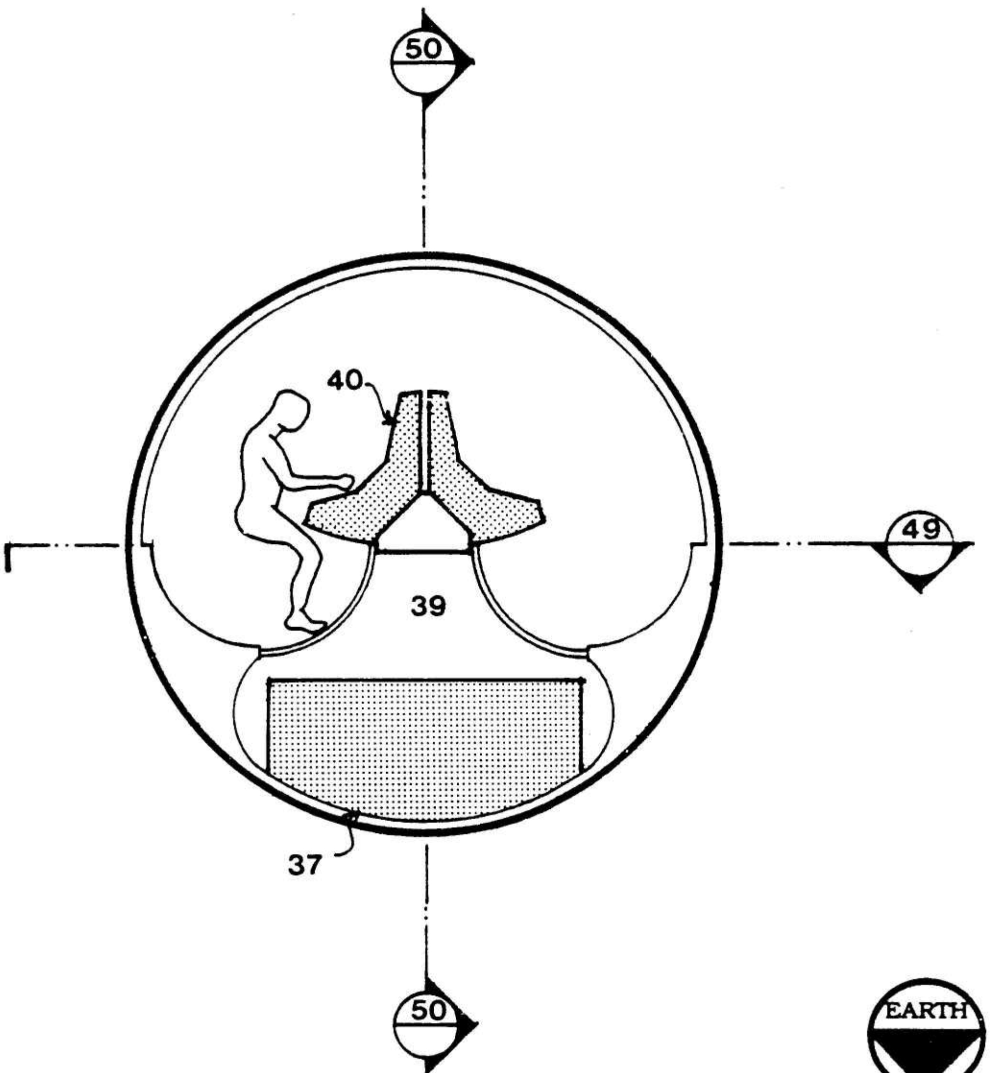


Figure 48: Section - Center Beam Location of Equipment, High Beam

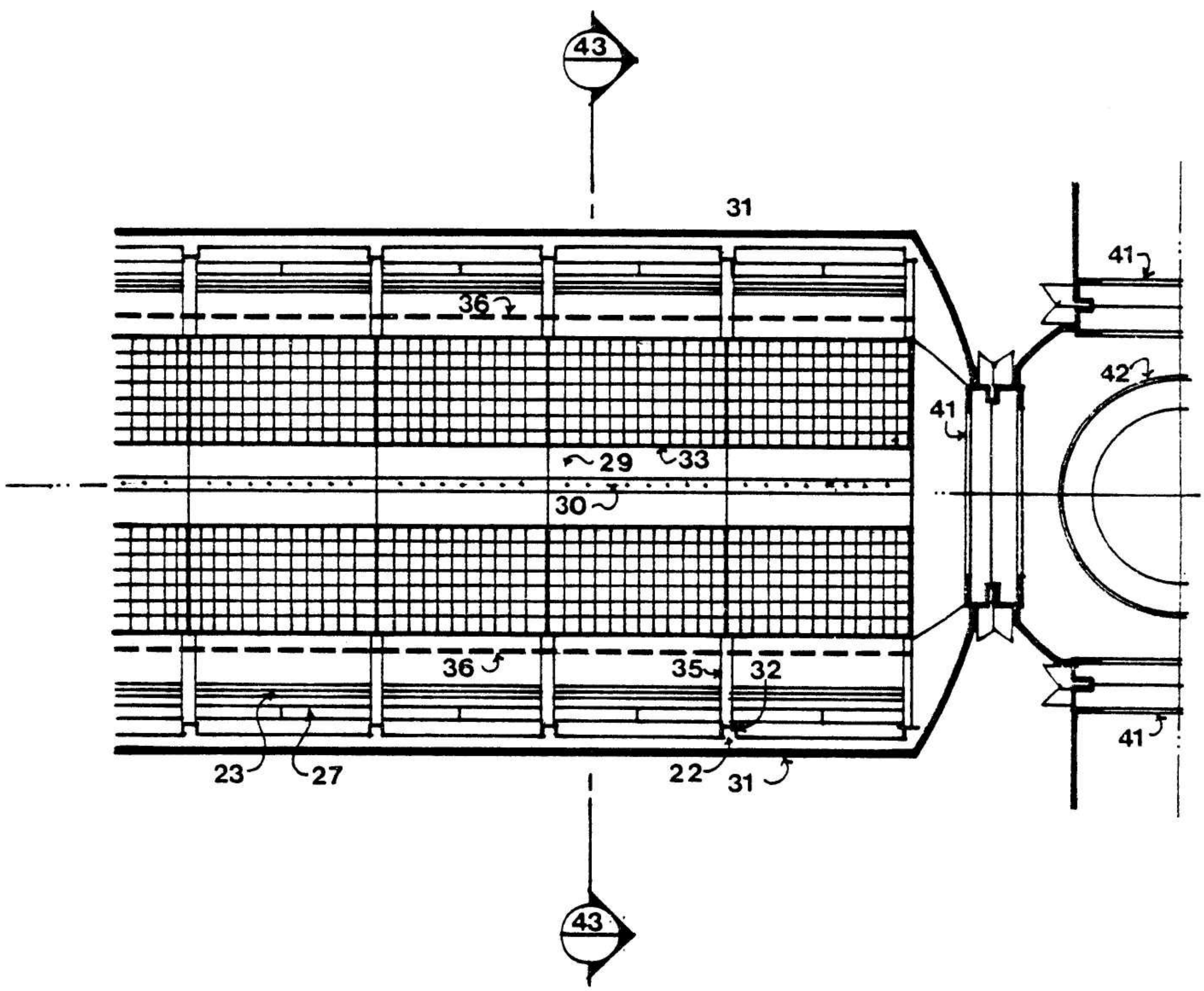


Figure 49: Plan - Perimeter Location of Equipment, Low Beam

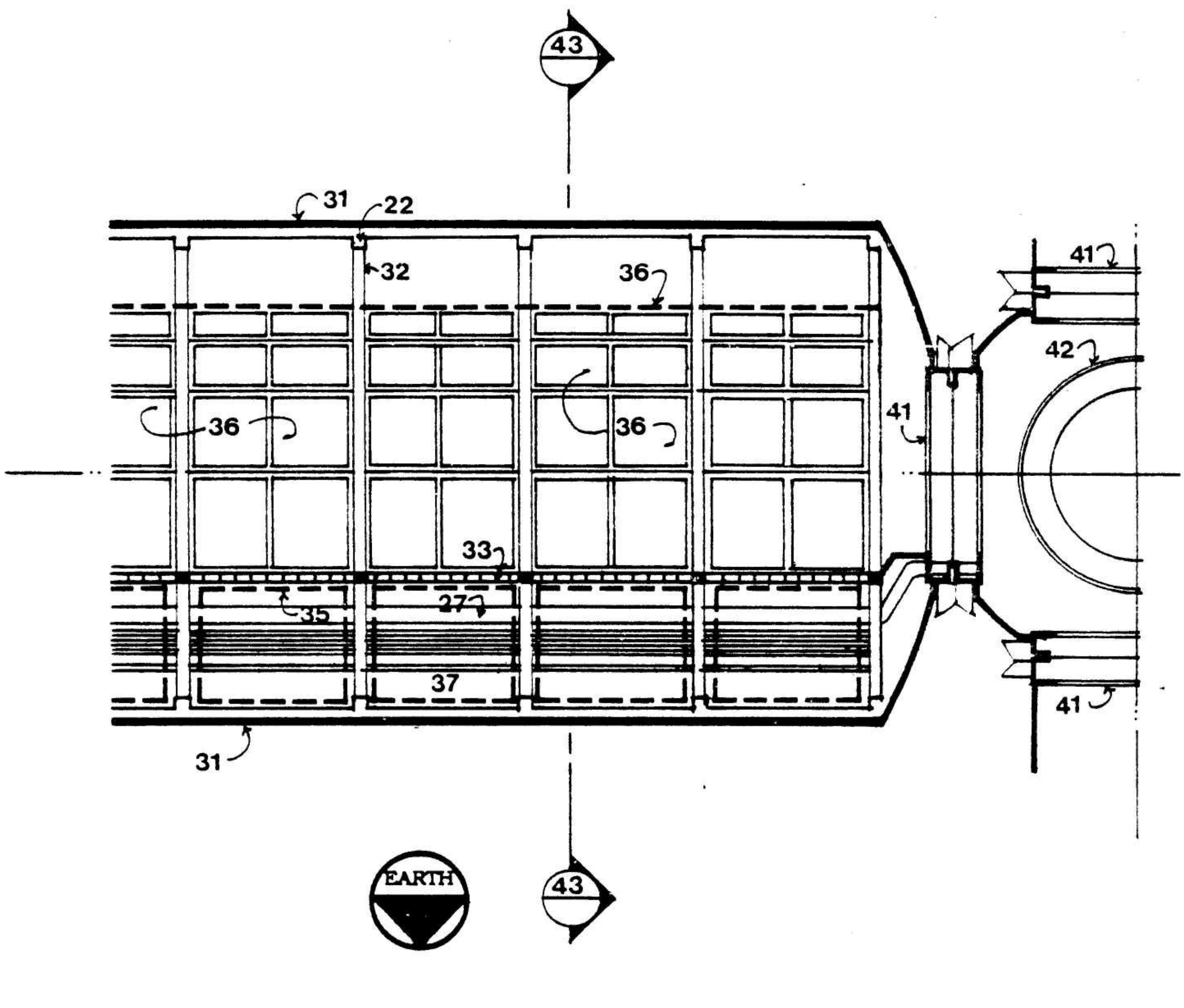


Figure 50: Interior Elevation - Perimeter Location of Equipment, Low Beam

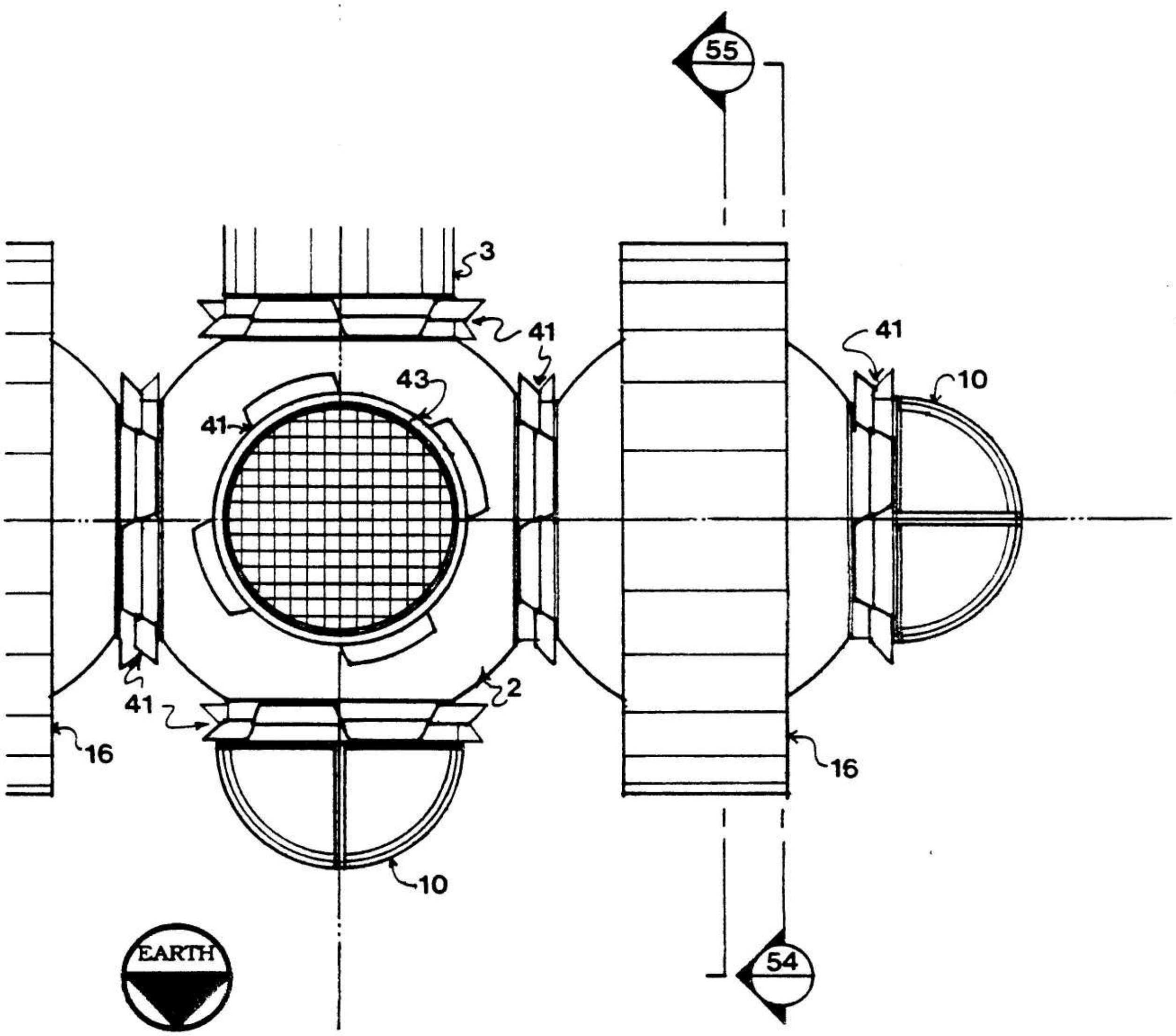


Figure 51: Side View - PAD Module

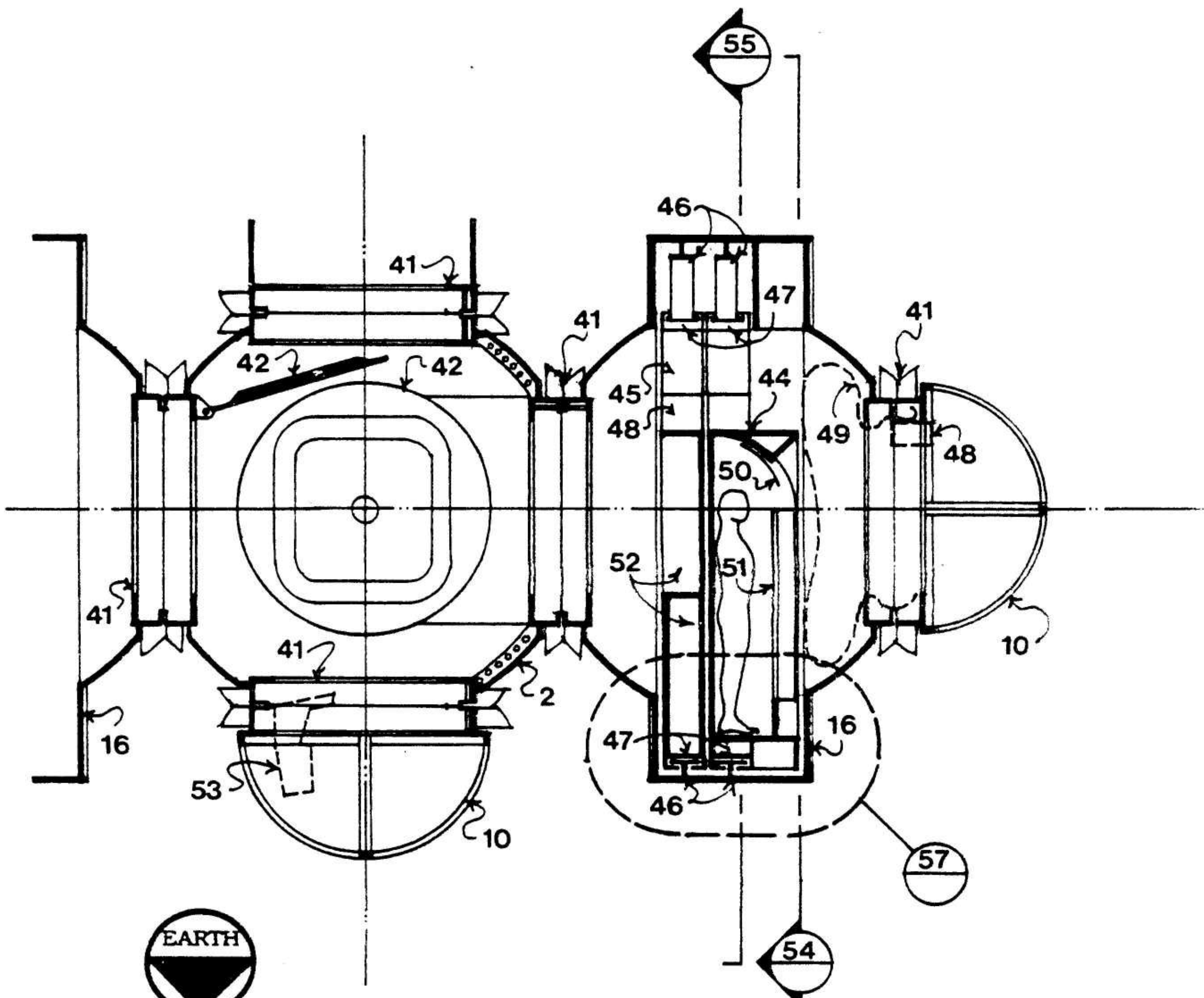


Figure 52: Interior Elevation - PAD Module

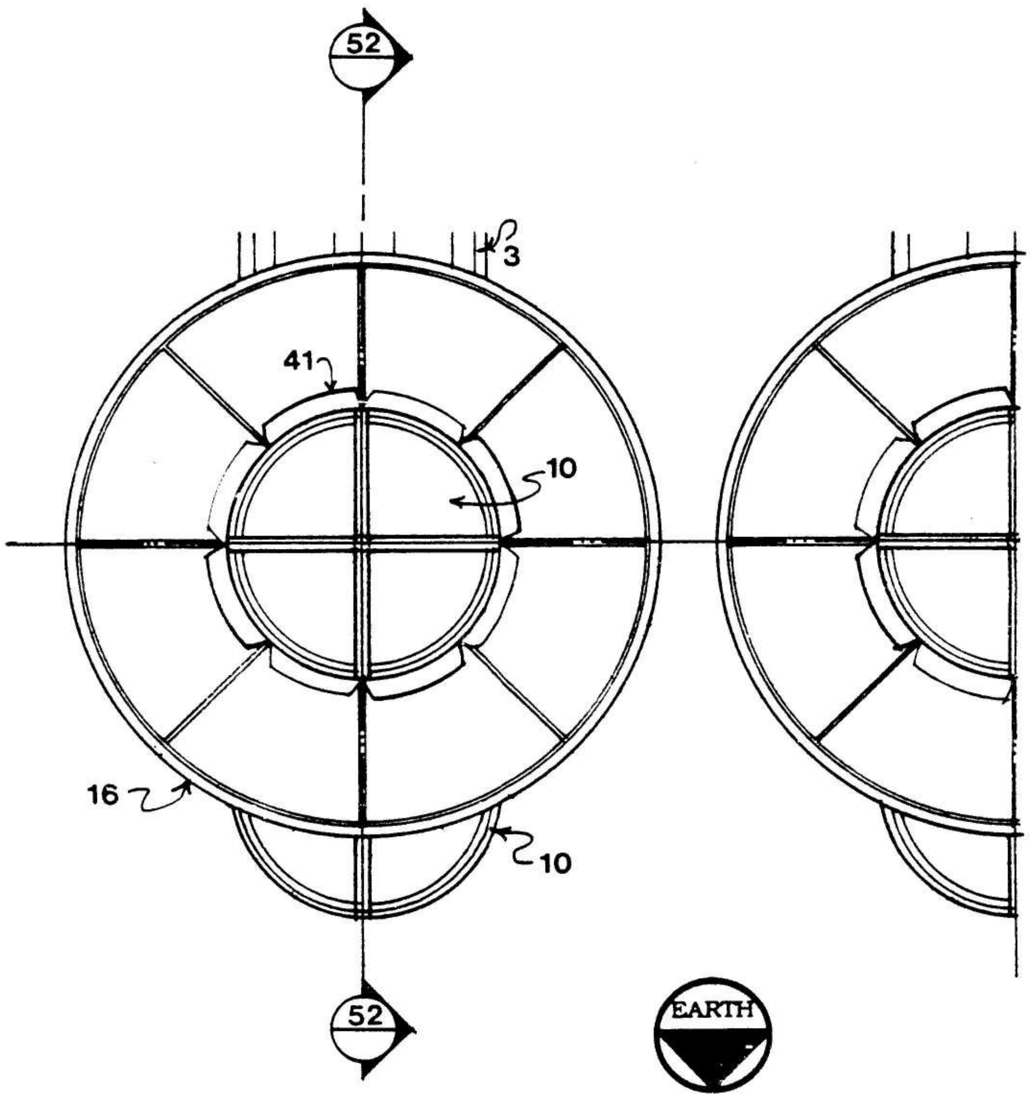


Figure 53: Front View - PAD Module

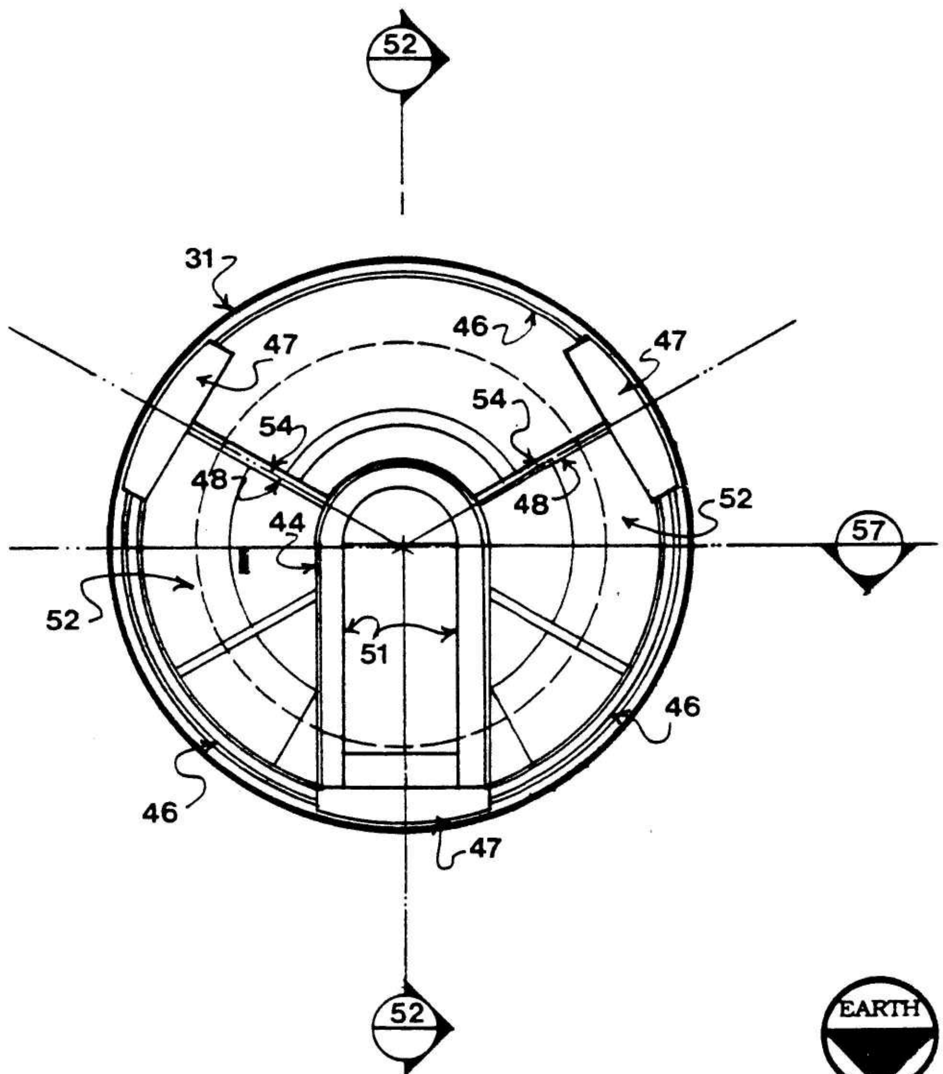


Figure 54: Interior Elevation - PAD Module

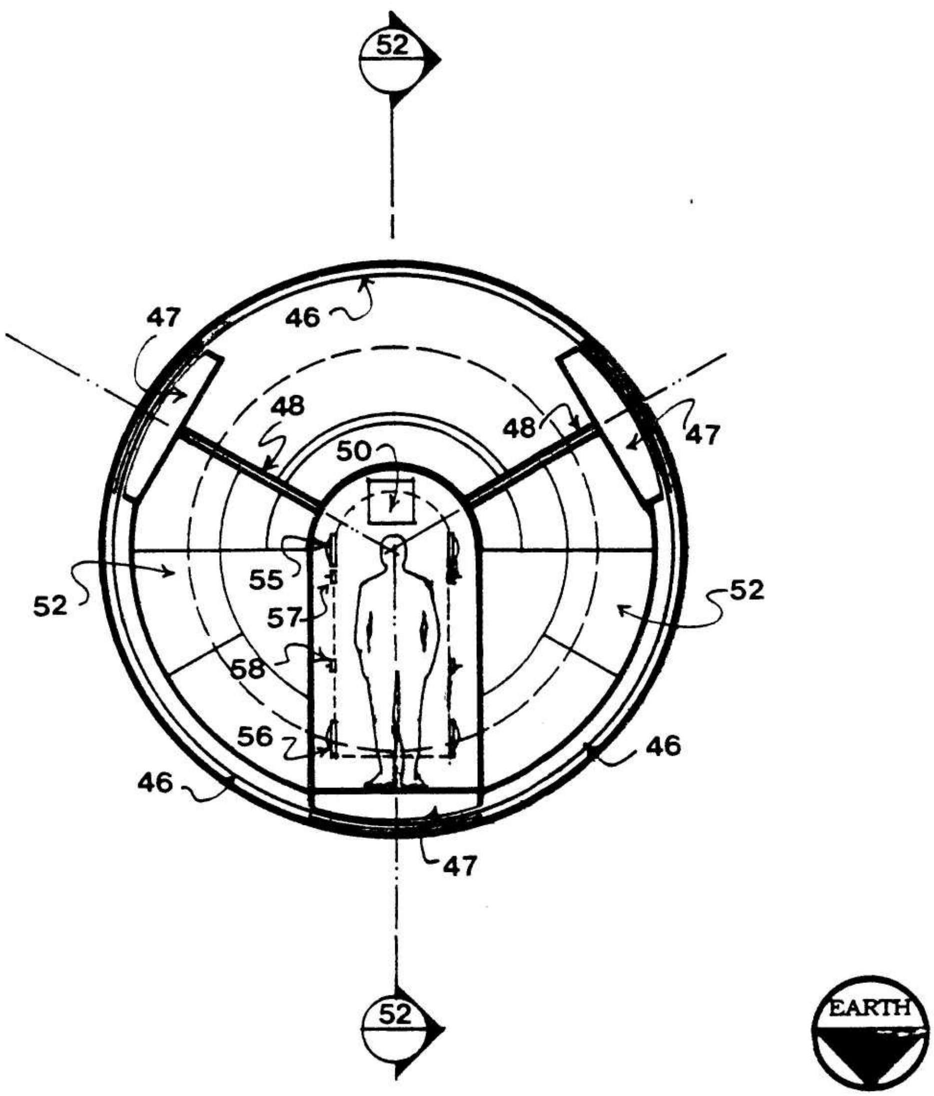


Figure 55: Interior Elevation - PAD Module

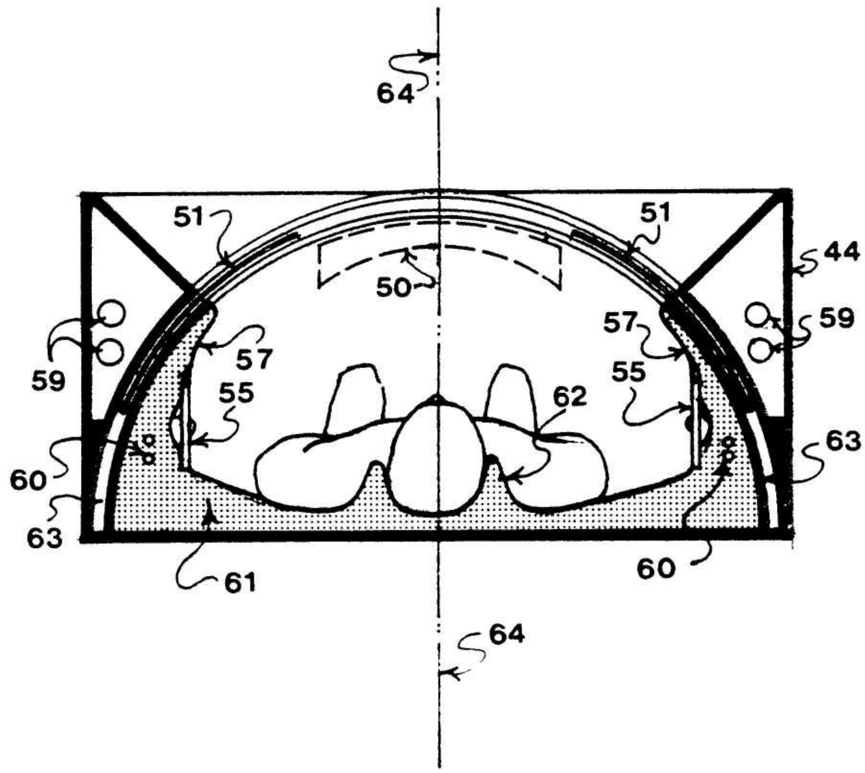


Figure 56: Section - Sleep Platform

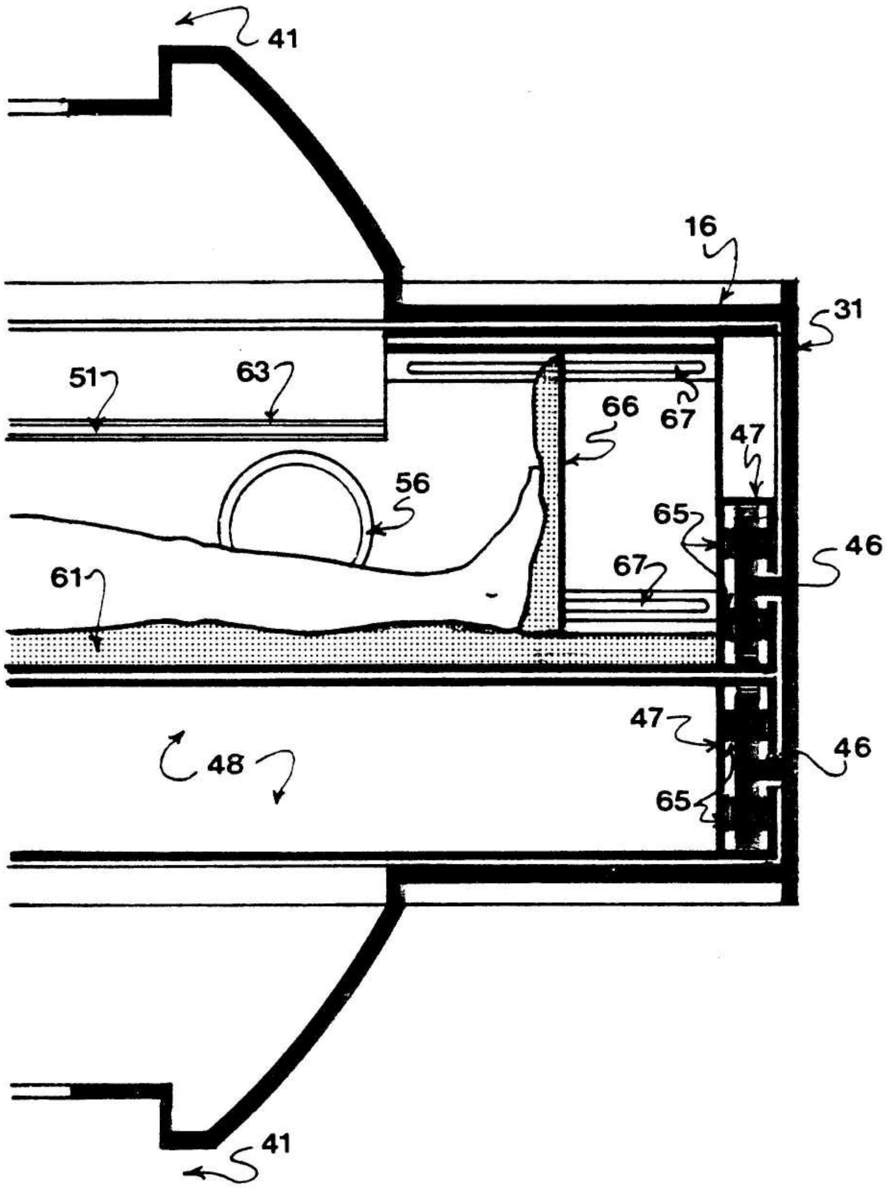


Figure 57: Section - Sleep Platform

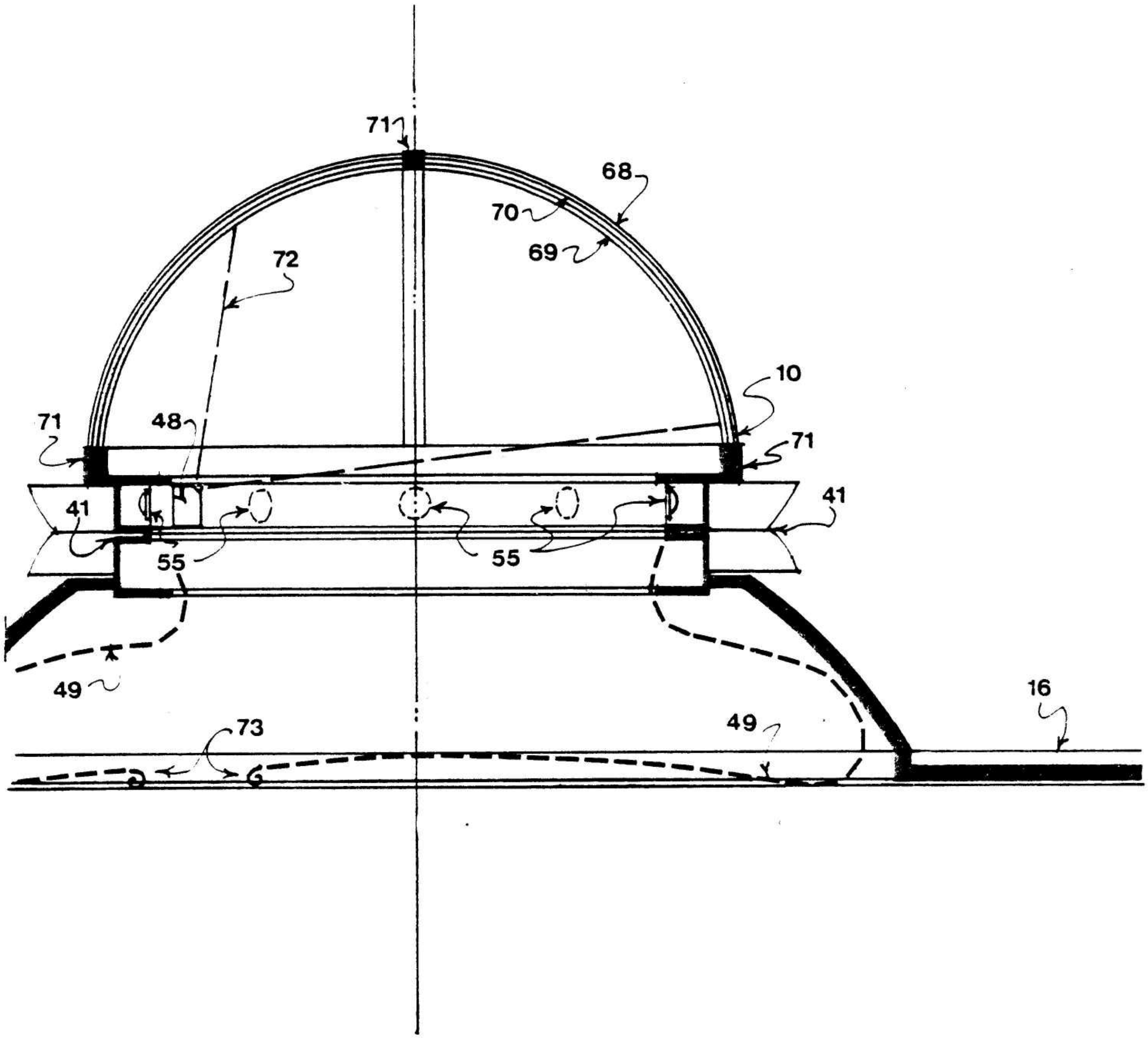


Figure 58: Section - DEPE System and Projection Unit

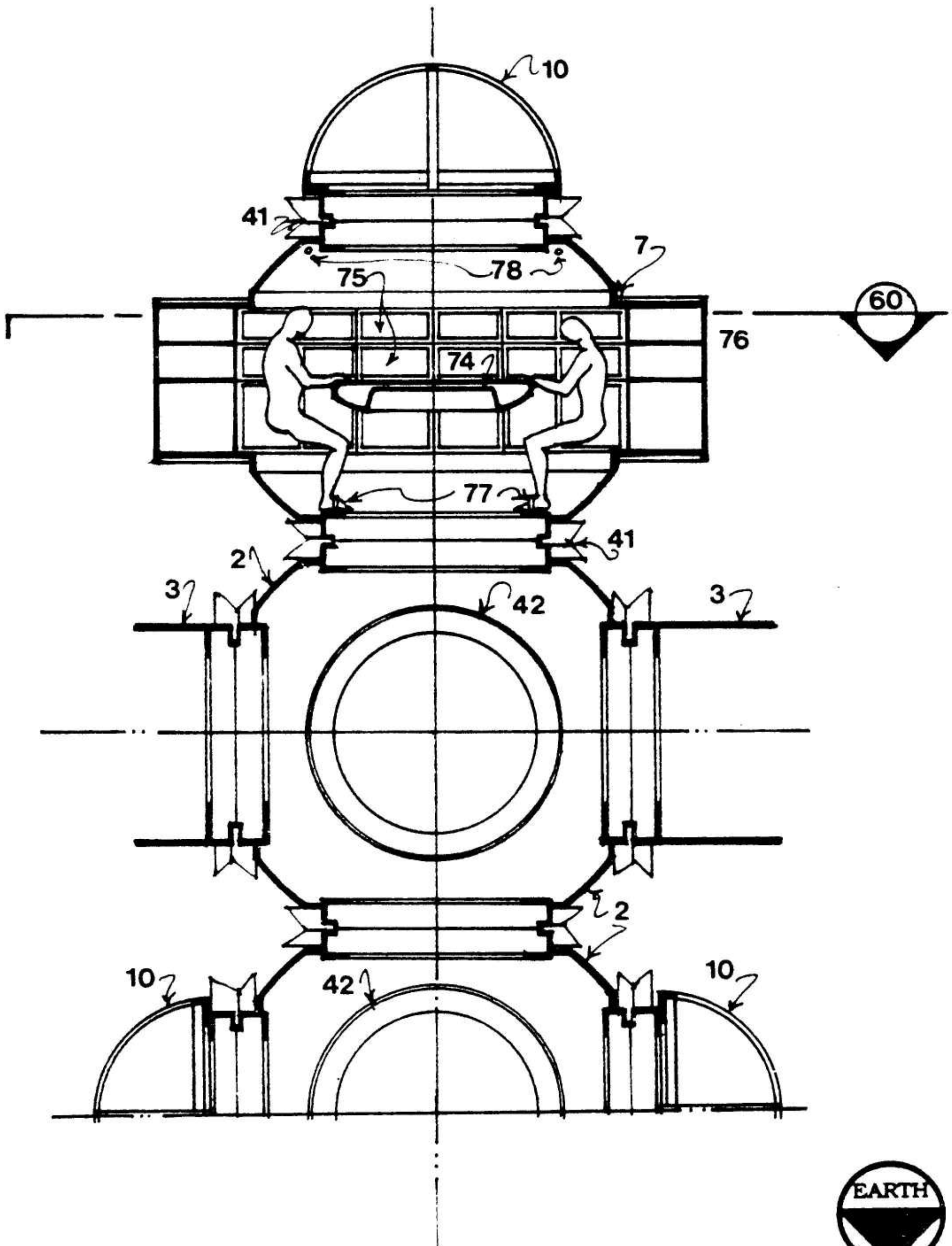


Figure 59: Interior Elevation - Galley/Conference Room

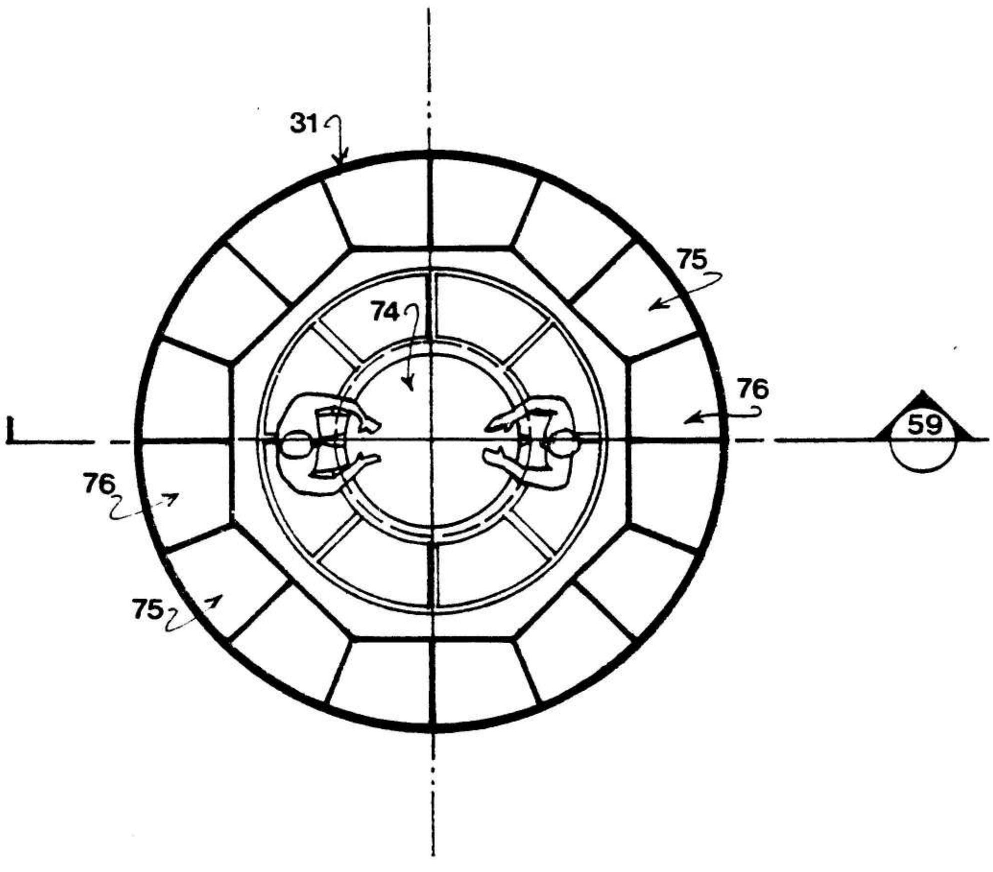


Figure 60: Plan - Galley/ Conference Room

15.0 GLOSSARY

15.1 Acronyms and Abbreviations

ALS	Advanced Logistic System
AME	Air/Lock Manipulator Element
CAE	Central Aseembly Element
DEPE	Digitally Enhanced Psychoacoustic Environment
ECLSS	Environmental Control and Life Support System
ECS	Emergency Containment Strategy
EEC	Emergency Evacuation Strategy
EOS	Earth Orbit Shuttle
EPB	Electrical Power Boom
EPS	Electrical Power System
EVA	Extravehicular Activity
G	One Gravity
GCS	Guidance and Control System
IMS	Information Management System
IVA	Intravehicular Activity
LEO	Low Earth Orbit
MOL	Manned Orbital Laboratory
NASA	National Aeronautics and Space Administration
OWS	Orbital Workshop
ORU	Orbital Replacement Unit
PAD	Personal Autonomous Domain
SOSI	Space Operations and Scientific Investigation
SSDW	Space Station Design Workshop

15.2 Definitions

Absorption Coefficient - The sound absorption coefficient of a surface which is exposed to a sound field is the ratio of the sound energy absorbed by the surface to the sound energy incident upon the surface.

Acoustic Impedence - The complex ratio of the effective (rms) sound pressure over a surface to the effective volume velocity through it.

Analogous Color Scheme - A scheme utilizing two or more hues next to each other on the spectrum, e.g., blue with blue-green or blue-violet.

Area per Man - Area per man refers to the numerical figure arrived at by dividing the gross area of a space by the number of occupants the space is designed to hold.

Articulation Index - A predictive measure of speech intelligibility. Formulation of the articulation index is based upon the fraction of the total speech band-width to the listener's ear and the signal-to-noise ratio at the listener's ear.

Attentuation - Attentuation is the term used to express the reduction in decibels of sound intensity at a designated point A as compared to sound intensity at point B which is acoustically farther from the source.

Brightness - That which the eye actually sees and is the result of light being reflected or emitted by a surface directly into the eye. Measured in foot lamberts or candelas per inch.

Candela - Unit of luminous intensity of a light source in a specified direction. Defined as 1/60 the intensity of a square centimenter of a black body radiator operated at the freezing point of platinum (2047°K).

Conduction - Conduction is a process by which heat flows from a region of higher temperature to a region of lower temperature within a medium (sòlid, liquid or gas), or between different mediums in direct physical contact. In conduction heat flow, the energy is transmitted by direct molecular communication without appreciable displacement of the molecules.

Contrast - A measure of the brightness of an object compared to its immediate surroundings.

Convection - Convection is a process of energy transported by the combined action of heat conduction, energy storage, and mixing motion. The transfer of energy by convection from a surface whose temperature is above that of a surrounding fluid takes place in several steps. First, heat will flow by conduction from the surface to adjacent particles of a fluid. The fluid particles will then move to a region of lower temperature in the fluid, due to the increase in temperature and internal energy of of the fluid particles, where they mix with, and transfer a part of their energy to, other particles. This is known as free convection, as the change in density is the motivationg force causing the mixing motion. When the mixing motion is induced by some external agency, such as a pump or a blower, the process is called forced convection. An increase in humidity increases heat transfer to the body for a given temperature difference and air velocity, since water vapor has a heat absorptive capacity twice that of air.

Comfort Zone - The area enclosed by the bounderies of the effective temperatures and relative humidity that induces a feeling of comfort to humans. All factors affecting the thermal condition of man are used in determining the comfort zone.

Decibel - The decibel is a dimension used for expressing the ratio of two powers and is referred to a reference level of 0.0002 dynes per square centimeter. Mathematically, the number of decibels is 10 log10 of the power ratio. Since sound pressure is proportional to the square root of sound power, the number of decibels in sound pressure level ratios is expressed as 20 log10 of the ratio of the two sound pressures.

Energy Density - The average energy unit per unit volume in a medium due to the presence of a sound wave.

Foot Candle - The measure of illumination at any point that is a distance of one foot from a uniform point source of one candle power. It is also equivalent to a density of one lumen uniformly distributed over an area of one square foot.

Frequency - The rate of repetition in cycles per second of the sound wave. Frequency is equal to the ratio of the speed of sound to the wavelength of sound. It is normally expressed as Hertz (Hz).

$$\text{Approximate frequency} = \frac{\text{speed of sound}}{\text{wave length of sound}}$$

Gross Area - Gross area is the approximate area required to attain the minimum tabulated net area. Gross area is found by deducting only large ventilation trunks, access trunks and other similar items. No deduction should be made for normal access ladders or main passageways within the space. This area represents the entire wall to wall area.

Illumination - Amount of light incident upon a surface measured in foot candles.

Intensity - The average rate at which sound energy is transmitted through a unit area perpendicular to the direction of wave propegation.

Minimum Desirable Volume - That volume provided for a specific activity which man will perceive as adequate. A minimum desirable volume provides adequate space to support the dynamic envelope man describes in performing the activities related to that space, the volume in which man feels comfortable in regard to distance between himself and others, and the volume which man visually perceives as adequate during all activity conditions.

Noise - Noise is any undesirable sound. As used broadly in accoustics, this may include not only aircraft noise and industrial sounds, such as traffic and machinery, but also speech and musical sounds if they are undesired at any particular location.

Net Area - Net area is defined as deck area that can actually be walked upon. Deck areas occupied by trucks, hatches, fixed berths, lockers, installed furniture, etc., are excluded.

Reverbation Chamber - An enclosure in which all the surfaces have been made as sound reflective as possible.

Reverbation Time - The time required for the average sound pressure level, originally in a steady state, to decrease 60 db after the source has stopped.

Sound Waves - Sound waves can be described by any of several characteristics, such as displacement of particles of the medium, the particle velocity, or the sound pressure measurements under certain conditions. The passage of a sound wave is accompanied by a flow of sound.

Visual Space - Visual area is the amount of space visually perceived as usable. This space is related to physical objects in a room, e.g., furniture and partitions, and the placement of these objects relative to the observer's eye level (sitting and standing).

SOURCE NOTES AND BIBLIOGRAPHY

Source Notes

1. The original design for a rotating gravity-inducing sleep platform was conceived by Peter Diamandis, M.D./Ph.D. candidate Biomedical/Aero-Astro Engineering.
2. From research compiled by Jack W. Stuster, Ph.D. *Space Station Habitability Recommendations based on a Systematic Comparative Analysis of Analogous Conditions*. December 1984, pp. 7 - 8.
3. From research compiled by Taylor and Associates, Inc. *Space Station Architectural Elements Model Study*. February 1986, pp. 3 - 4.
4. Taylor and Associates, Inc. See note 3, p. 7.
5. Ibid., p. 13.
6. Jack W. Stuster, Ph.D. See note 2, pp. 8 - 9.
7. Ibid., p. 9.
8. Ibid., p. 9.
9. Ibid., p. 10.10.
11. Ibid., pp. 10 - 11.
12. Ibid., pp. 20 - 21.
13. Taylor and Associates, Inc. See note 3, pp. 12 - 14.
14. Rambaut and Johnson. From the article "Humane Space Station", as it appeared in *Autonomy and the Human Element in Space*. August 1983, p.68.
15. Ibid., p.68.
16. Ibid., p.68.
17. The Space Station Task Force. *Book 2: Mission Decsription Document.* March 1984, pp. 6-1 to 6-4.
18. Ibid., p. 5 - 4.
19. Ibid., pp. 5 - 5 to 5 - 6
20. Ibid., p. 5 - 7.
21. Ibid. , p. 6 - 1.

Drawing Credits

1. Figures 1 - 5 taken from research compiled by Jack W. Stuster, Ph.D. *Space Station Habitability Recommendations based on a Systematic Comparative Analysis of Analogous Conditions*. December 1984.
2. Figures 6 - 17 adapted from Brand Norman Griffin. *The Influence of Zero-G and Acceleration on the Human Factors of Sacecraft Design.* 1978.
3. Figures 18 -20 adapted from Martin Marietta document. *Internal Arrangement Options.* August 1985.
4. Figures 23 - 25 as noted on drawings.
5. Appendix B computer generated drawings by Constantin Cavoulakis S.M.ARCH S. '87, structural details by Carlos Hernandez, S.M.ARCH S. '87.

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- Book 2
- Book 3
- Book 4
- Book 5
- Book 6

Taylor and Associates, Inc. *Space Station Architectural Elements Model Study.* February 1986.

Appendix A

Summary of the Invention:

System Deployment Operations and System Descriptions

The space station construction operations begin with the deployable platform (1)(Figure 4 - 1.1). The platform is based upon a five module by seven module deployable system, whereby each module is a 5m x 5m x 5m cubic structure (Figure 5a). The 35m x 25m platform in its transport configuration (Figure 5b) is secured in the shuttle bay utilizing restraining supports at each of its ends (25).

The platform's spring loaded deploying operation consists of one continuous deployment in three directions whose rate is regulated by a cicumferential banding system (27). A motorized mechanism slowly opens the restraining band, allowing the platform to open at a controlled rate, thereby reducing any sudden, uneven movements which would cause undesirable vibrations within the system.

Each module in the platform, (Figure 6) consists of 5m rigid struts which are in the position of the assumed vertical when deployed (23), 5m collapsible struts (24) hinged at (21) that pivot in relationship to (23) at connection point (20). Corner bracing between (24) and (23) is achieved with strut (22) which also incorporates the spring mechanism (28) that fascilitates deployment. Upon strut (24)'s complete assumption of the horizontal, the spring (29) loaded collar (30) mechanism (Figure 7a) at (21) moves into position securing the bi-pivotal linkage assembly shown in (Figure 7b).

The hub assembly at (20) consists of an aluminum housing assembly (32)(Figure 8b, plan view), (Figure 9b, section view), and four pivotal points (31) for the connection of four struts (24)(Figure 8a, plan view), (Figure 9a, side view). The knob assembly (20) is used as a universal attachment point for the various living and operational components of the space station utilizing the cup (46) and locking sleeve (45) mechanism in (Figure 14a).

The rigid corner bracing struts (22) in the vertical plane are pin connected at (22) to the flanged collar assembly at (34)(Figure 9a).

The deployable corner bracing struts (35) in the horizontal plane are pin connected at (22) to the flanged collar assembly at (34)(Figure 8a). The struts (35) are hinged at (33) which is a spring loaded collar and linkage assembly analogous to the system described in (Figure 7b).

All sliding collar assemblies (21)(33)(34) have a high visibility colored marking system on their respective struts to indicate by visual inspection whether or not complete deployment has been achieved. If collar assemblies have been successfully locked into place, no color markings will be visible, thereby indicating full deployment.

Next in overall construction operations is the deployment of the circular MMRMS truss system which consists of an upper half (2)(Figure 4 - 1.2) and a lower half (3)(Figure 4 - 1.3). The 30m diameter truss deploys by means of a hydraulic system in the manner shown in (Figure 10).

Connection of the circular MMRMS truss to the main platform (1) is achieved through a series of crossed tensioning cables, each with a vibration dampening coupler system that will prevent major vibrations produced by the MMRMS when it is in motion, from reaching the platform (1) and modules (18)(19).

The transport configuration of the MMRMS trusses(2)(3) is similar to the platform (1) configuration shown in (Figure 5b).

Each half of the deployable MMRMS assembly consists of an inner configuration of struts (41) pinned at (39)(Figure 11a, side view), (Figure 11c, detail). Each of these cross struts are joined at (40) on the inner diameter and at (37)(Figure 11a, side view), (Figure 12a, top view detail), (Figure 12b, side view detail). Also making a connection at (37) and (39) are the cross struts (43) which form the 7m width of the fully deployed MMRMS truss. At full deployment these cross struts (43) pull a network of cables (Figure 11b) into tension thus providing greater stability and rigidity across the truss.

At the outer diameter of the MMRMS truss is a T-section rail (44) connected at (37), hinged at (38)(Figure 11a, side view), (Figure 11b, top view), (Figure 12c, cross section detail), which is the track that the manipulator arm 's (17) wheel and carriage assembly (45) travels on.

Next in overall construction operations is the deployment of the solar dynamic's (6) arms (4)(Figure 4 - 1.4) which are connected to the main platform (1) via step-down truss assemblies and alpha joints (5). The 2.5m x 2.5m x 2.5m modules of these trusses (4) are deployed utilizing the method shown in (Figure 13). The rigid square frame comprised of members (76) is rotated thereby raising members (77) from the parallel transport position while pivoting at connections (75) and (78). This rotating and locking procedure is repeated for each of the four 2.5m x 2.5m x 2.5m modules that comprise (4).

Next in the overall construction operations is the assembly of the solar dynamics (6) and radiators (7), (Figure 4 - 2.1). These are connected to the ends of the trusses at (4), (Figure 2a, left side view),(Figure 2b, right side view).

Next in the overall construction operations is the deployment of the lower mast truss (9), (Figure 4 - 2.2), which is connected to the main platform (1) via a step-down truss assembly, and to the lower half of the circular MMRMS truss (3) via a system of crossing tensioning cables and vibration dampening couplers analogous to those used to attach the MMRMS truss (2)(3) to the main platform (1). The lower mast's 18 modules are structurally identical to the solar dynamic's arms (4), and are deployed in the same manner as described in (Figure 13).

Next in overall construction operations is the deployment of the upper half of the mast truss (10) (Figure 4 - 2.3), which is connected to the main platform (1) and the upper half of the circular MMRMS truss (2) in the same manner as the lower mast (9) described in operation (Figure 4 - 2.2).

Next in overall construction operations is the delivery and connection of the first habitability module (8) to the underside of the main platform (1) (Figure 4 - 3.1). The module (8) is connected to the platform (1) at the knob assembly (20)(Figure 14c) utilizing the Y-strut mechanism (49)(Figure 14b) and the slotted (47) cup (46) and locking sleeve (45) mechanism illustrated in (Figure 14a). (Figure 14a) is threaded into (Figure 14b) at (48).

Next in overall construction operations is the delivery and connection of a second habitability module (8) to the underside of the main platform (1) (Figure 4 - 4.1). This procedure is the same as the one described in operation (Figure 4 - 3.1).

Next in overall construction operations is the connection of the left TDRS frame assembly (11)(Figure 4 - 5.1) which is connected to the upper deployable mast (10), via an alpha joint (12). Located at the end of this 4.5m x 18m U-shaped frame system is the the upper left stabilizing thruster (16).

Next in overall construction operations is the connection of the right Earth observation equipment support frame (13) (Figure 4 - 6.1), to the end of the lower mast (9). The support frame is identical in size and structure to the system described in (Figure 4 - 5.1) .

Next in overall construction operations is the connection of the right TDRS frame assembly (11)(Figure 4 - 6.1) which is connected to the upper deployable mast (10), via an alpha joint (12).

Next in overall construction operations is the connection of the left Earth observation equipment support frame (13) (Figure 4 - 7.1), to the end of the lower mast (9).

In the remaining overall construction operations, the satellite servicing hangar (15), (Figure 16) is connected to the upper side of the main platform (1), via cup and sleeve connection points (68) similar to the connection described in (Figure 14a). The 5m x 10m frame (67) of the hanger has a series of brackets (70) every 2.5m along each of its two 10m sides which support the right half of a deployable partially circular truss (69) while in transport configuration, and the corresponding left half of a deployable partially circular truss (72) while in transport configuration.

Each half of this truss is similar in operation and deployment to the circular truss system described in (Figure 10). Trusses (69) and (70) are covered with a resilient reflective membrane (71) and (73) respectively, which enlose and shield the inside of the hanger from ultra-violet rays when fully deployed and connected together at (74).

Finally, the remaining habitability modules (8) are delivered and connected in their appropriate configuration. A docking hub (18), interhabitability connection hubs (19) are added. Additional Earth observation equipment (14) and modules can be plugged into the frame system (13) described in (Figure 4 - 6.1) and (Figure 4 - 8.1). More TDRS equipment modules can also be plugged into the frame system (11) described in (Figure 4 - 5.1) and (Figure 4 - 7.1).

The connection of various apparatus at any point along the structure (1)(2)(3)(4)(9)(10)(11)(13), can be achieved using the mechanism shown in (Figure 15a), in the manner illustrated in (Figure 15b). The mechanism (Figure 15a) is connected to the particular apparatus needing attachment at (50) and secured with the locking latch at (51). Halves (52) and (53) are placed around the particular strut where attachment is needed, and the hooking mechanism (55), pivoting at (57), is tightened by mechanism (58) which is creating leverage at point (56) as manual force is applied in a clockwise direction at lever (65). This in turn tightens halves (52) and (53) around the strut, compressing the elastic seal (54) to achieve a firm hold. This entire mechanism is then locked into place at (61) with (60), pivoting at (63) and held fast with spring assembly at (62).

To release the mechanism in (Figure 15a) from the strut, manual pressure is applied at (64), causing pivot at (63), thereby releasing (60) from (61). At the same time, manual counter-clockwise force is applied at (65), thereby reversing the procedures outlined above.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a frontal view of the space station at the completion of assembly.

Figure 2a is a left side view of the space station at the completion of assembly.

Figure 2b is a right side view of the space station at the completion of assembly.

Figure 3a is a top view of the space station at the completion of assembly.

Figure 3b is a top view of a typical module and hub assembly at or near the completion of assembly.

Figure 4 shows axonometric views which demonstrate the sequential assembly of the space station.

Figure 4 - 1.1 Platform deployed

Figure 4 - 1.2 Top half of MMRMS track deployed

Figure 4 - 1.3 Bottom half of MMRMS track deployed

Figure 4 - 1.4 Solar dynamic arms deployed

Figure 4 - 2.1 Solar dynamics erected

Figure 4 - 2.2 Lower mast deployed

Figure 4 - 2.3 Upper mast deployed

Figure 4 - 3.1 United States habitability module

Figure 4 - 4.1 United States life sciences module

Figure 4 - 5.1 TDRS assembly (R)

Figure 4 - 6.1 Geo-study assembly (L)

Figure 4 - 7.1 TDRS assembly (L)

Figure 4 - 8.1 Geo-study assembly (R)

Figure 4 - 9.1 European Space Agency Module

Figure 4 - 10.1 Japanese Experimentation Module

Figure 5a shows one platform module deployment operation.

Figure 5b shows the deployable platform structure in the transport configuration with shuttle bay mounting supports.

Figure 6 shows a longitudinal section through one module of the platform.

Figure 7a shows a linkage detail at one of the platform's deployable struts (side view).

Figure 7b is a longitudinal section of 7a.

Figure 8a shows a plan view of the hub and corner bracing of the platform structure.

Figure 8b is a cross section through the hub assembly in 8a.

Figure 9a is a side view of the hub and corner bracing assembly of the platform structure as shown in 8a.

Figure 9b is a longitudinal section through the hub assembly in 9a.

Figure 10 shows the circular MMRMS system deployment operation (schematic).

Figure 11a shows a frontal view of the circular MMRMS system.

Figure 11b shows a top view of the circular MMRMS system.

Figure 11c shows a detail at joint 39.

Figure 12a is a top view of the strut and joinery point at a typical connection in the circular MMRMS ring as shown at 37

Figure 12b is a side view and partial section of the strut and joinery point at a typical connection in the circular MMRMS ring as shown in 10a.

Figure 12c is a cross section through the T-section MMRMS rail showing the locking mechanism.

Figure 13 shows the structural operation of the upper and lower deployable masts, and the deployable solar dynamic arms.

Figure 14a is a section through the cup and sleeve connection employed to fasten objects to the knob assembly shown in 9a.

Figure 14b shows the strut connection assembly utilizing the cup and sleeve design in

14a to connect the habitability modules to the deployable truss platform at the connection point detailed in Figure 9a.

Figure 14c shows the systems described in 14a and 14b in operation.

Figure 15a shows a longitudinal section through an intermediary connection system used to attach various apparati and assemblies to any of the deployable truss systems throughout the space station at any point along a strut.

Figure 15b shows several possible operations of the system described in 15a.

Figure 16 shows an axonometric view of the deployable service hanger which is mounted to the upper plane of the deployable platform utilizing the cup and sleeve connector described in 14a and the ball connecter at 20.

Appendix B

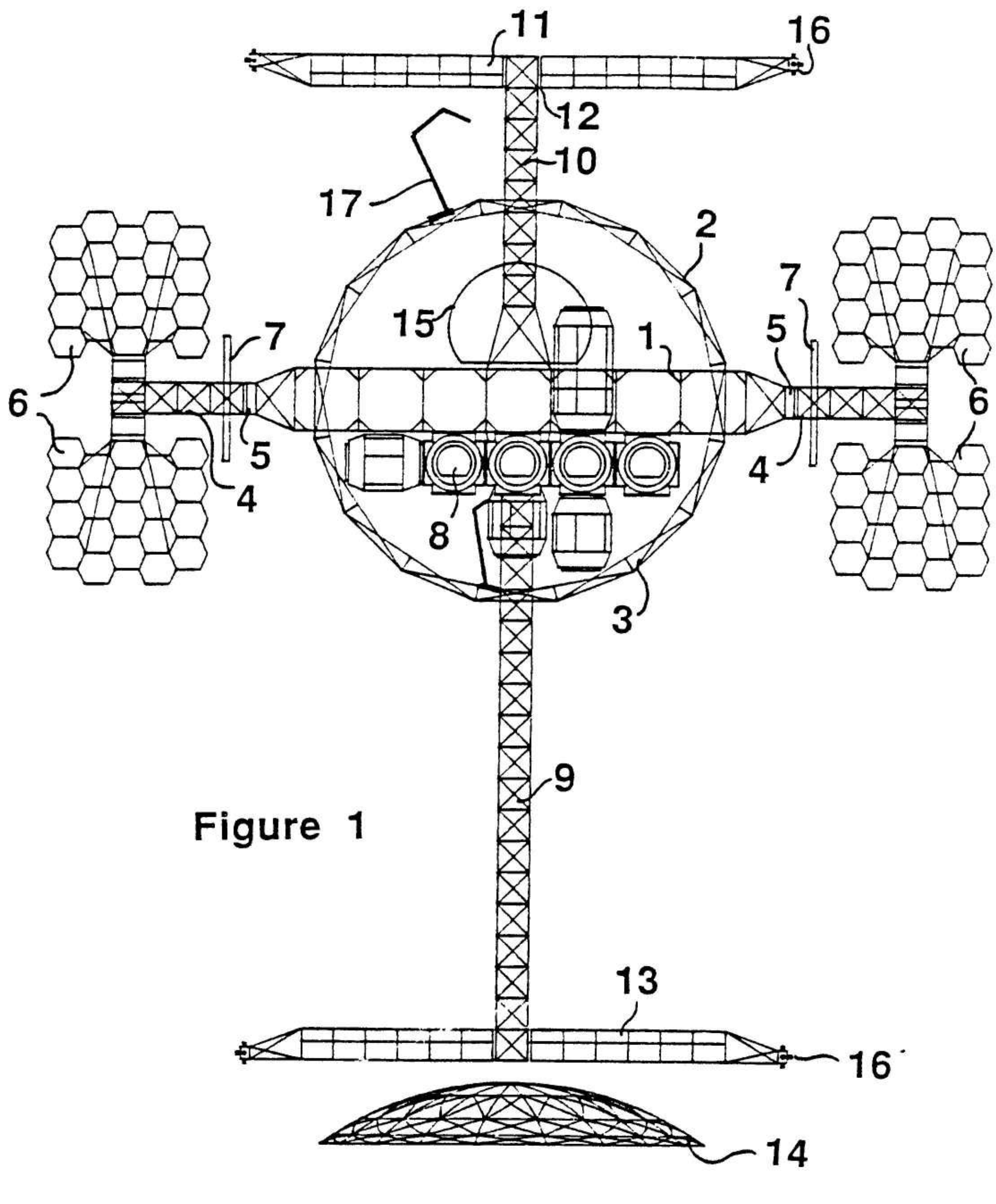
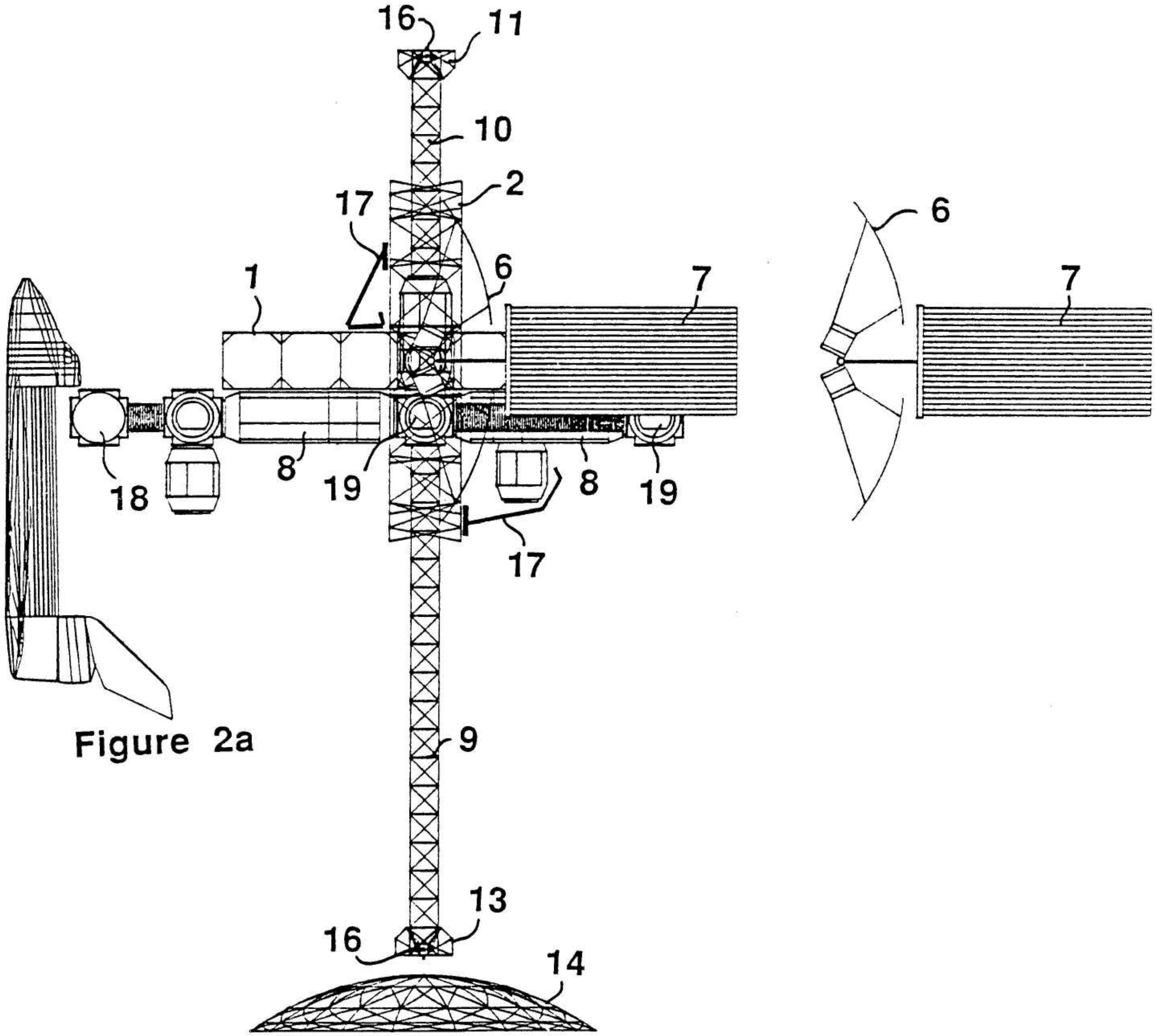


Figure 1



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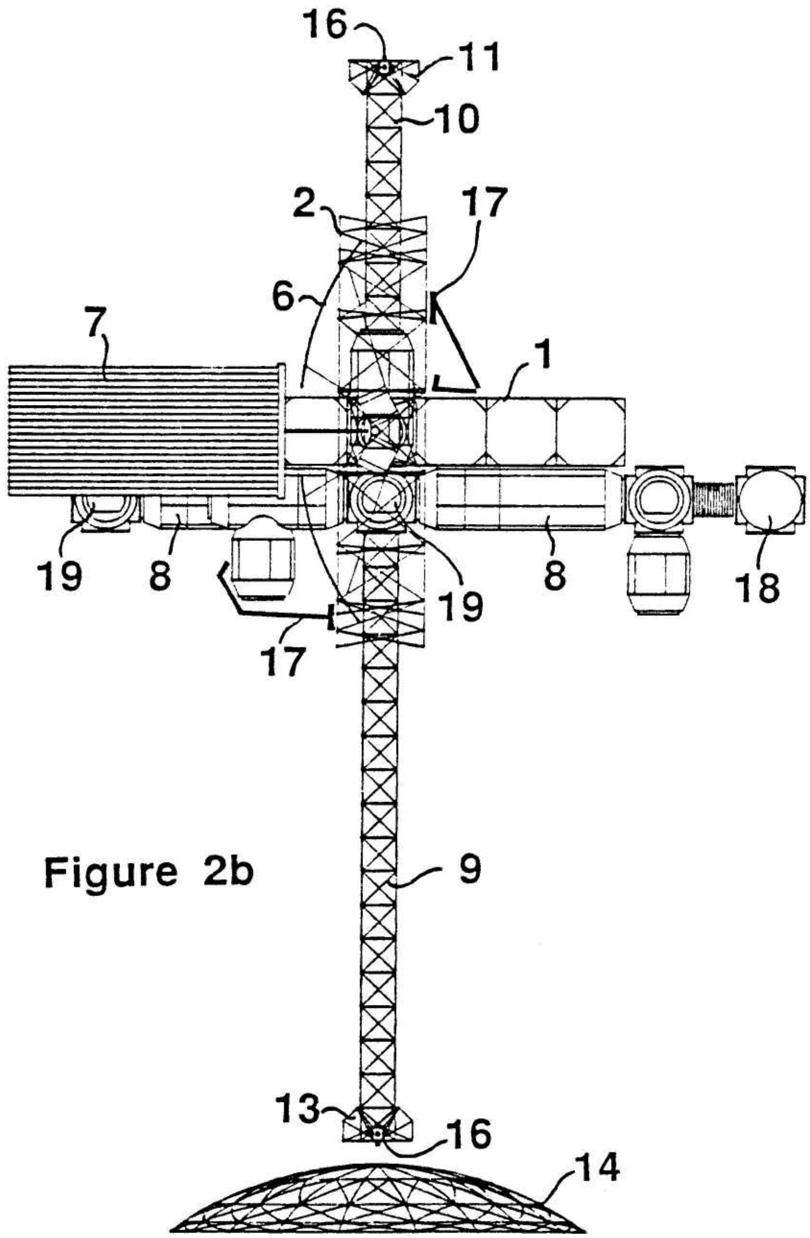


Figure 2b

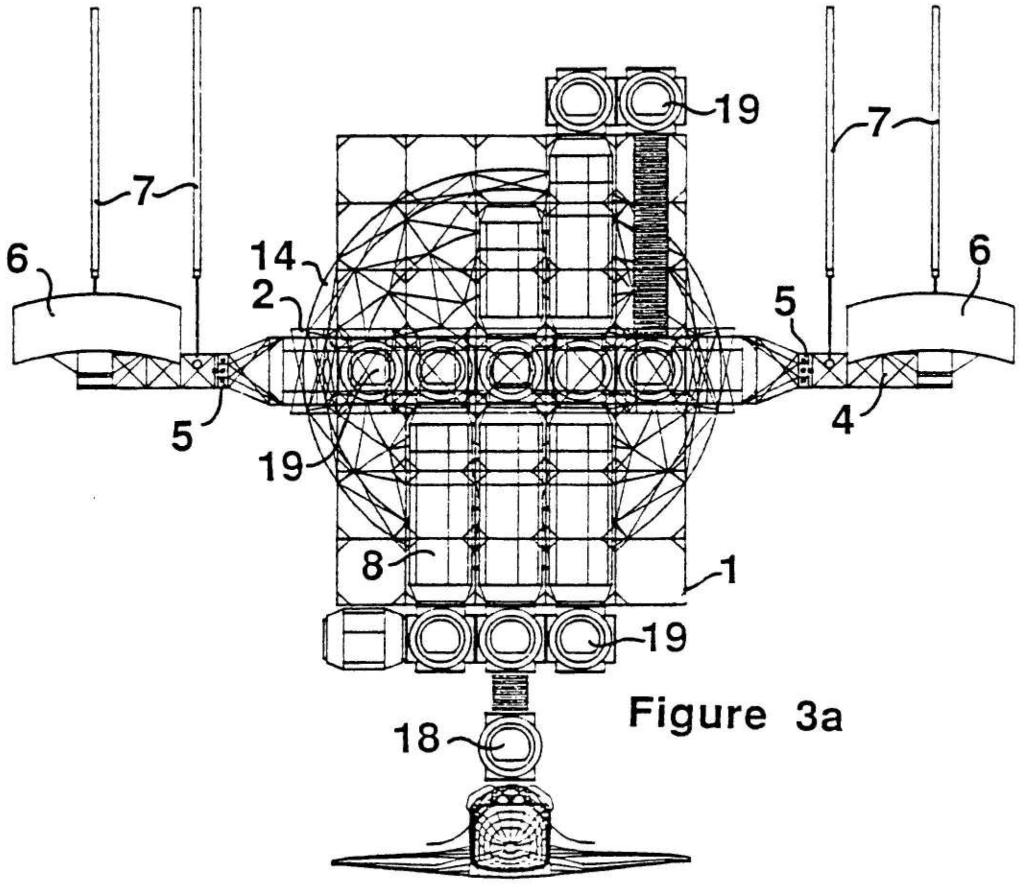


Figure 3a

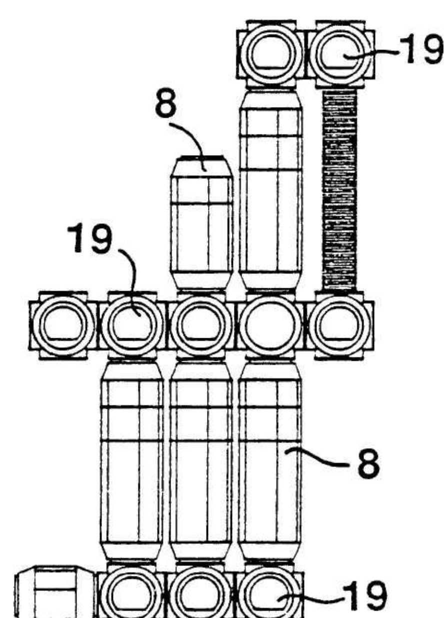


Figure 3b

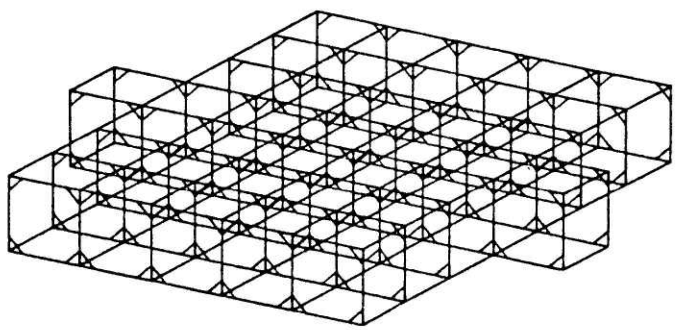


Figure 4 - 1.1

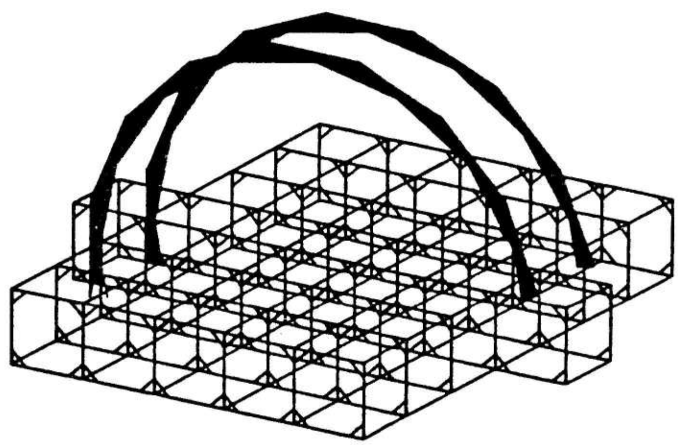


Figure 4 - 1.2

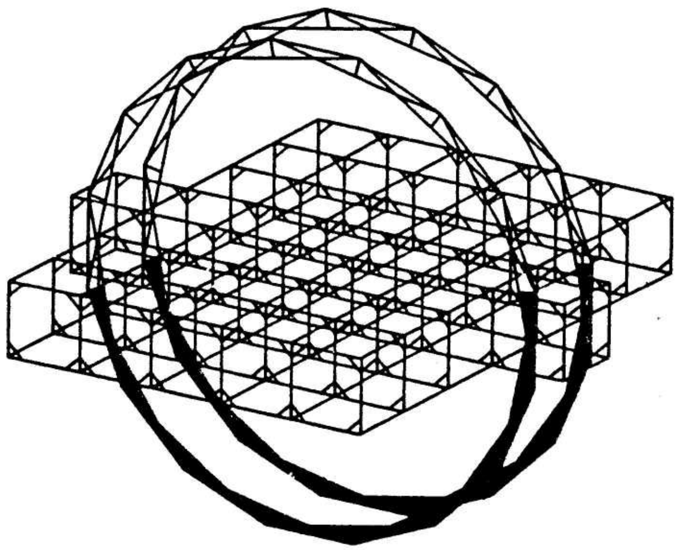


Figure 4 - 1.3

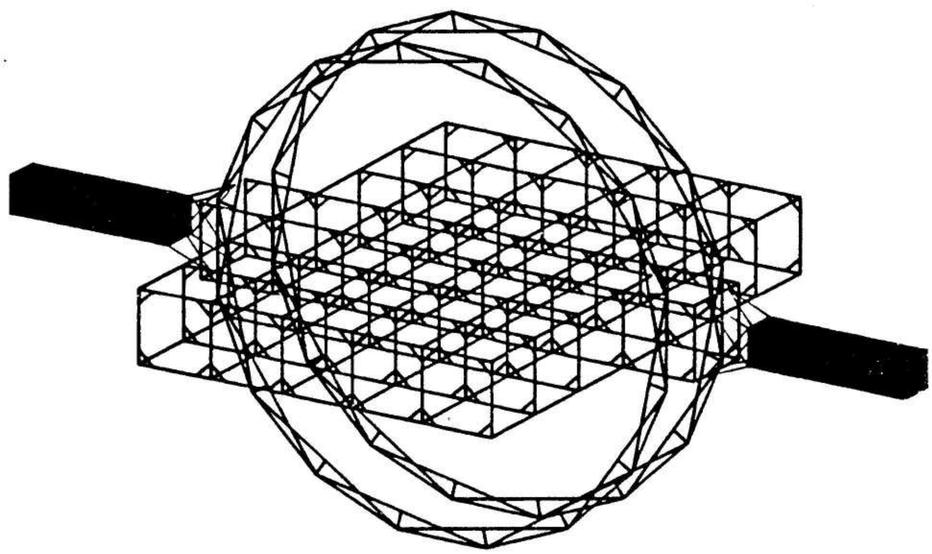


Figure 4 - 1.4

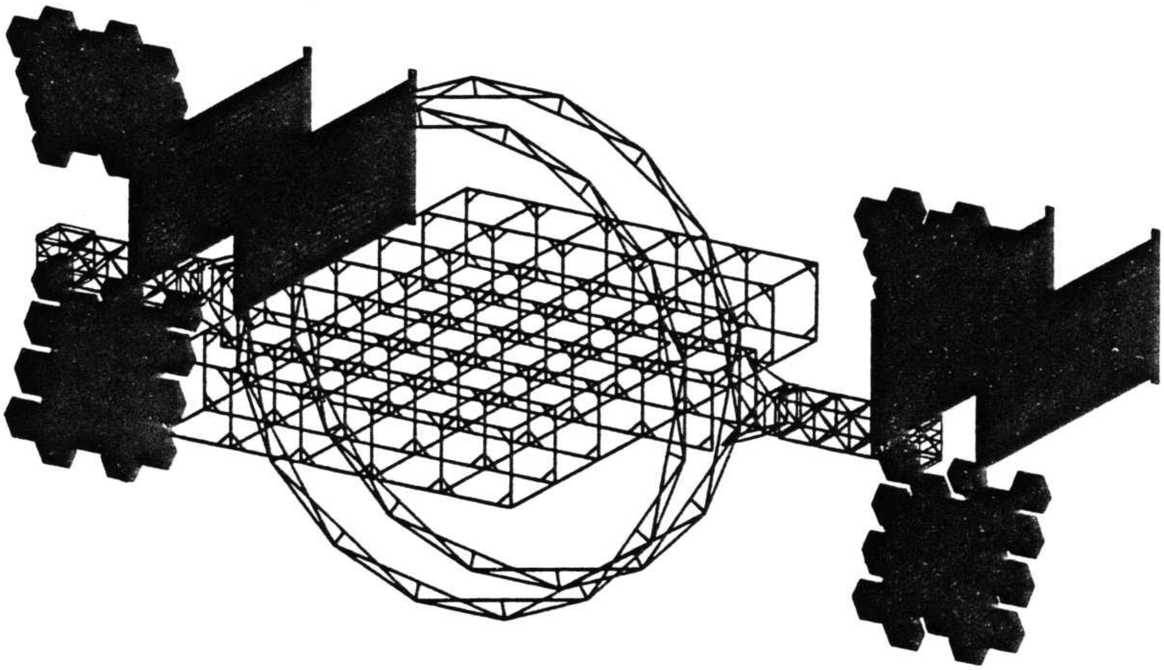
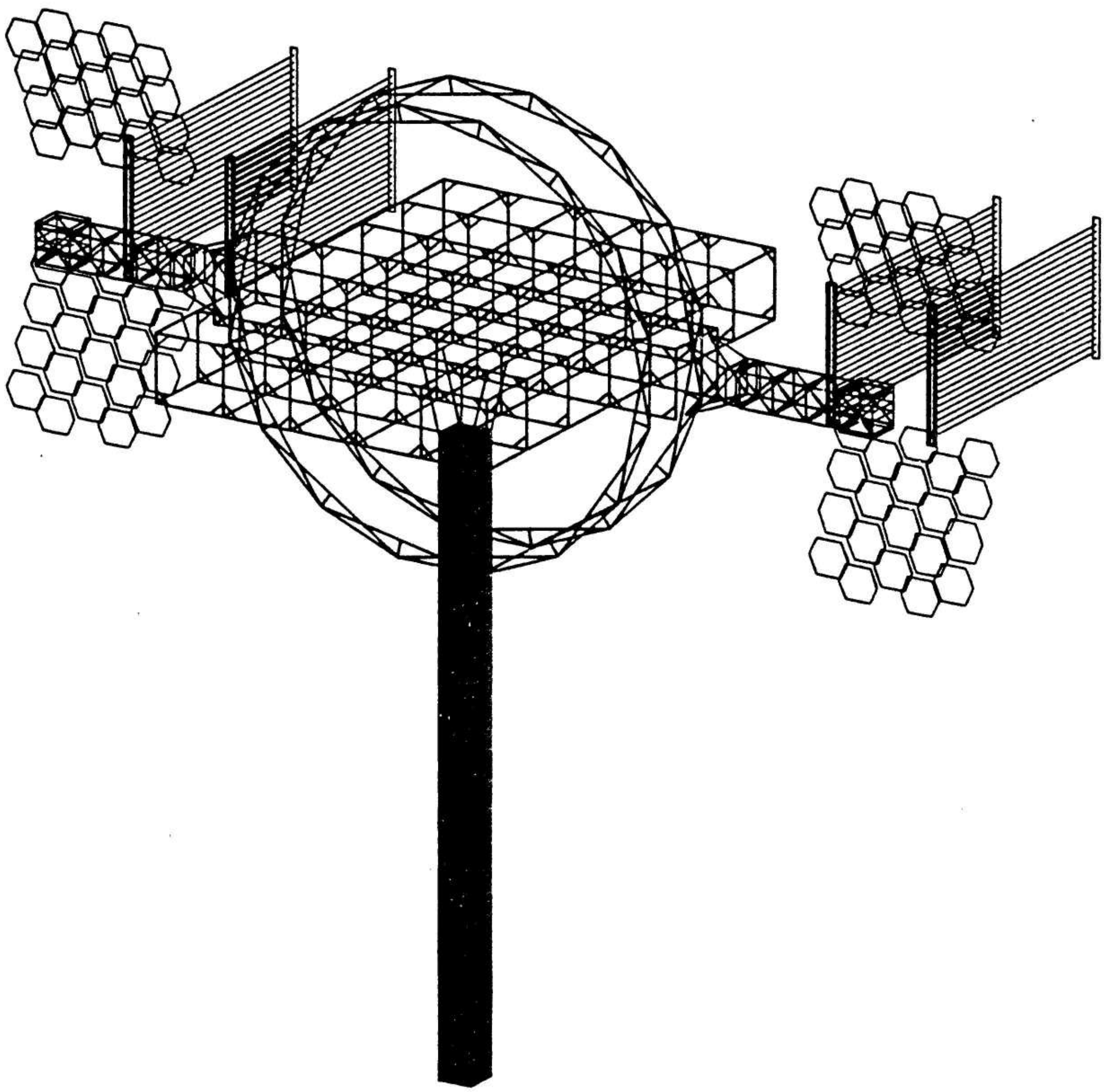


Figure 4 - 2.1



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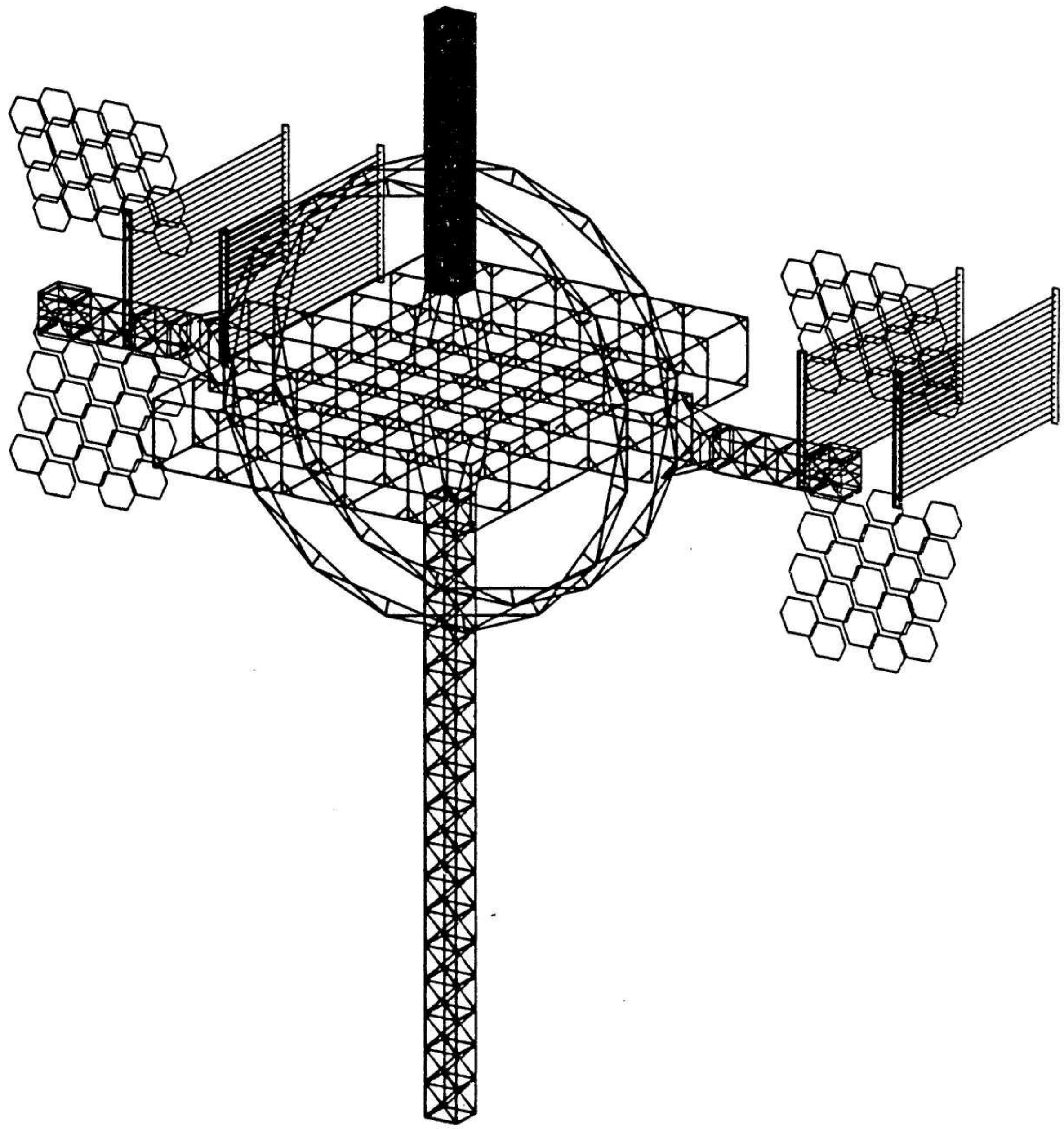

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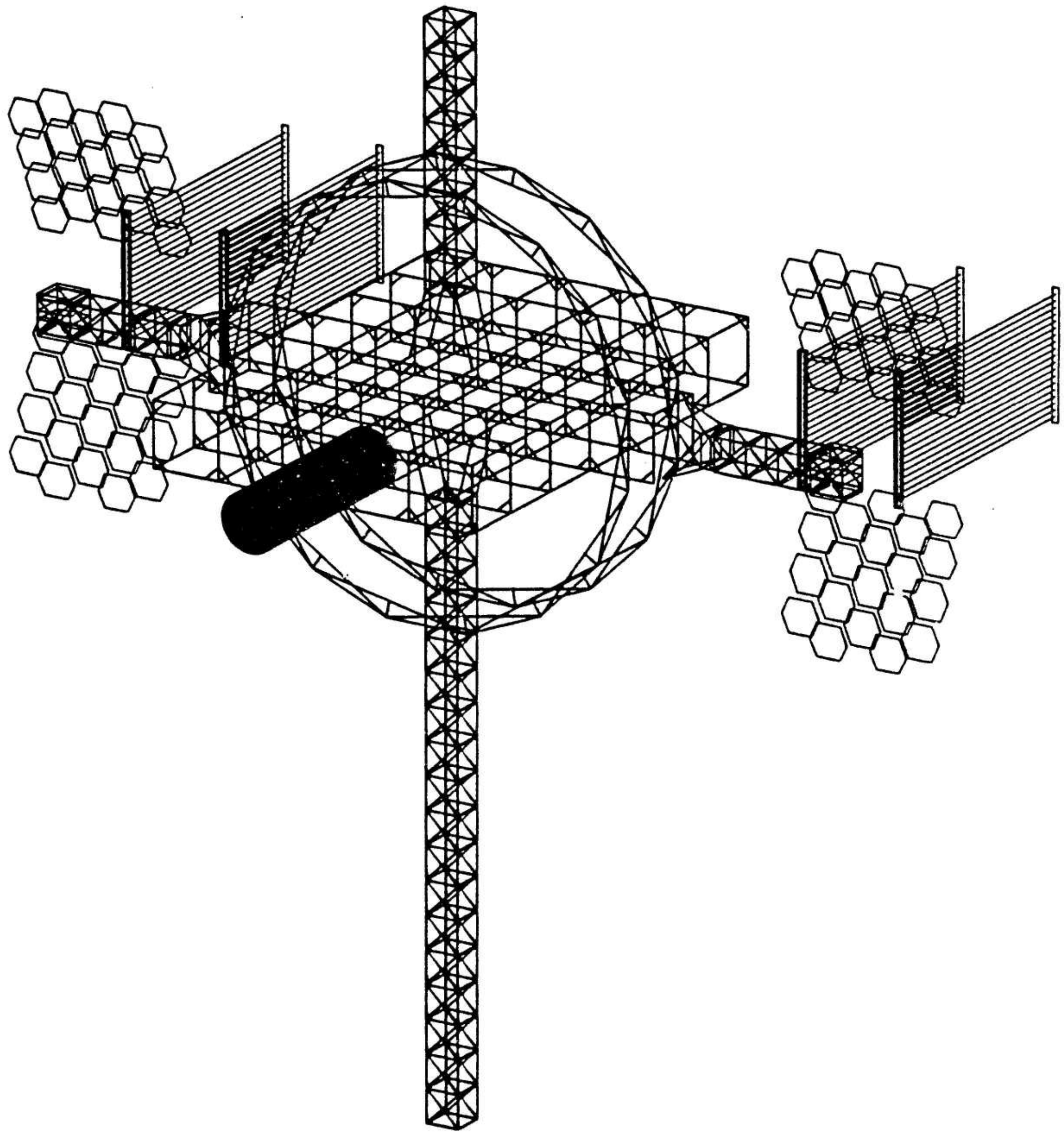

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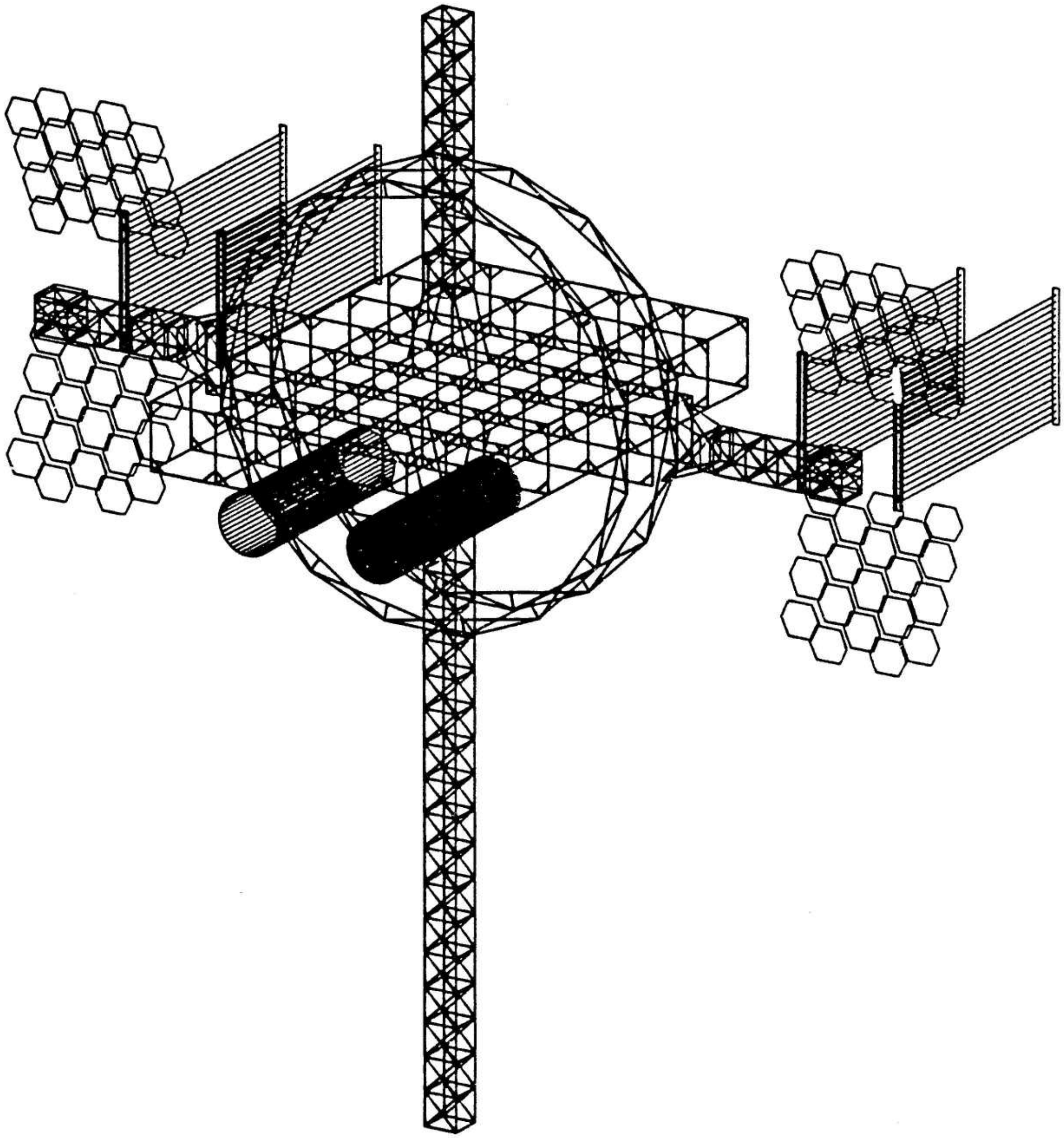


Figure 4 - 4.1

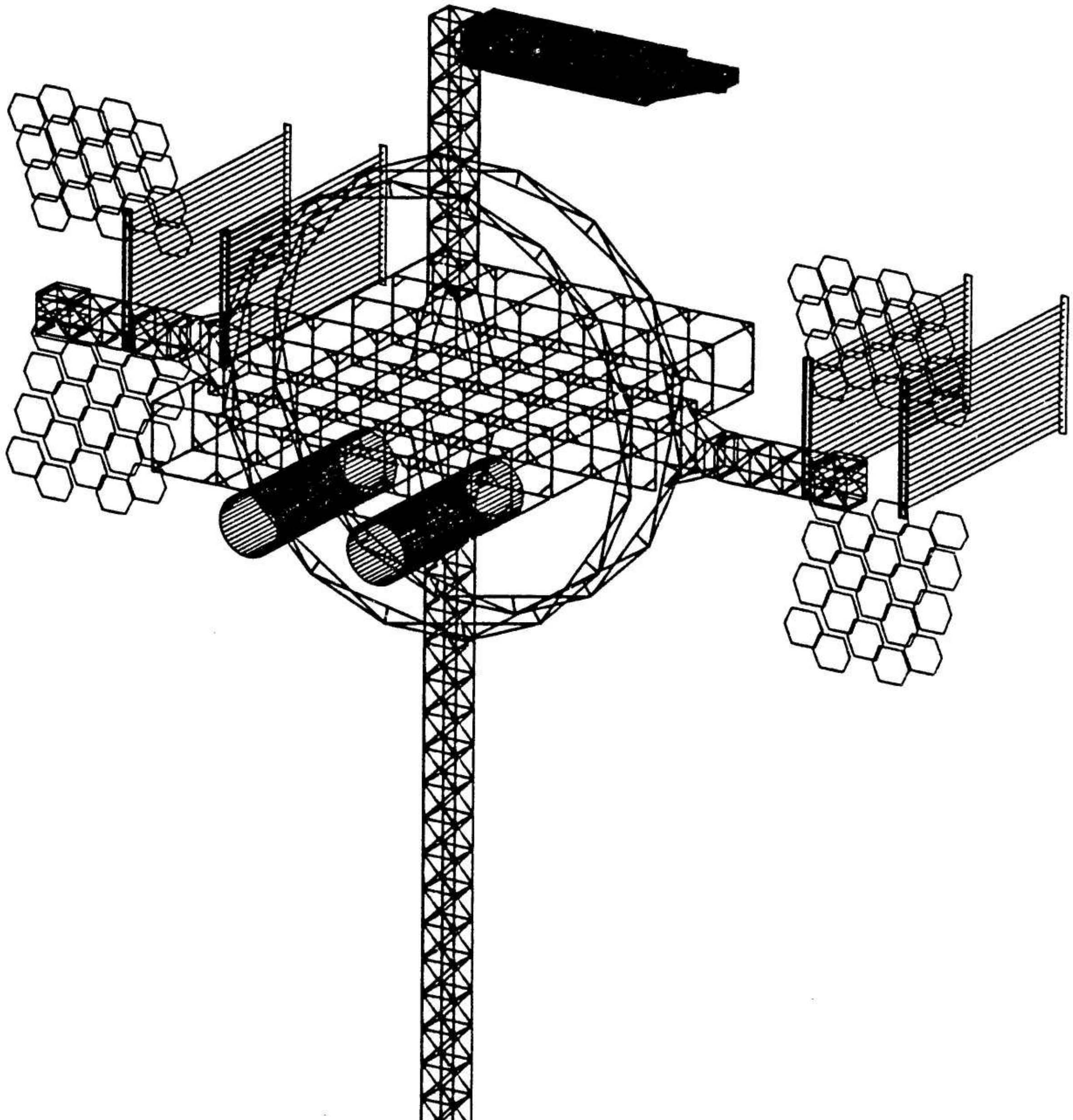


Figure 4 - 5.1

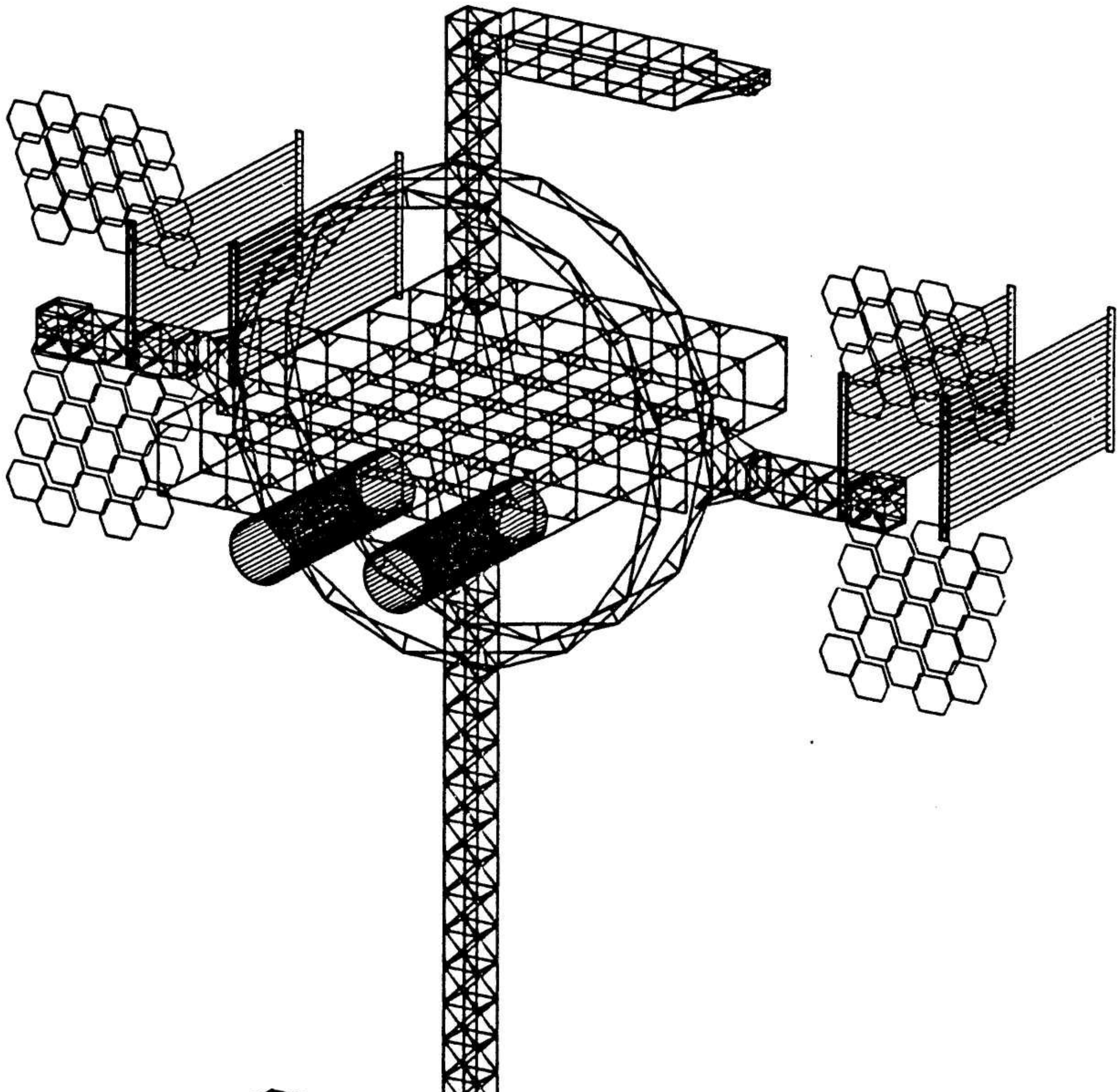
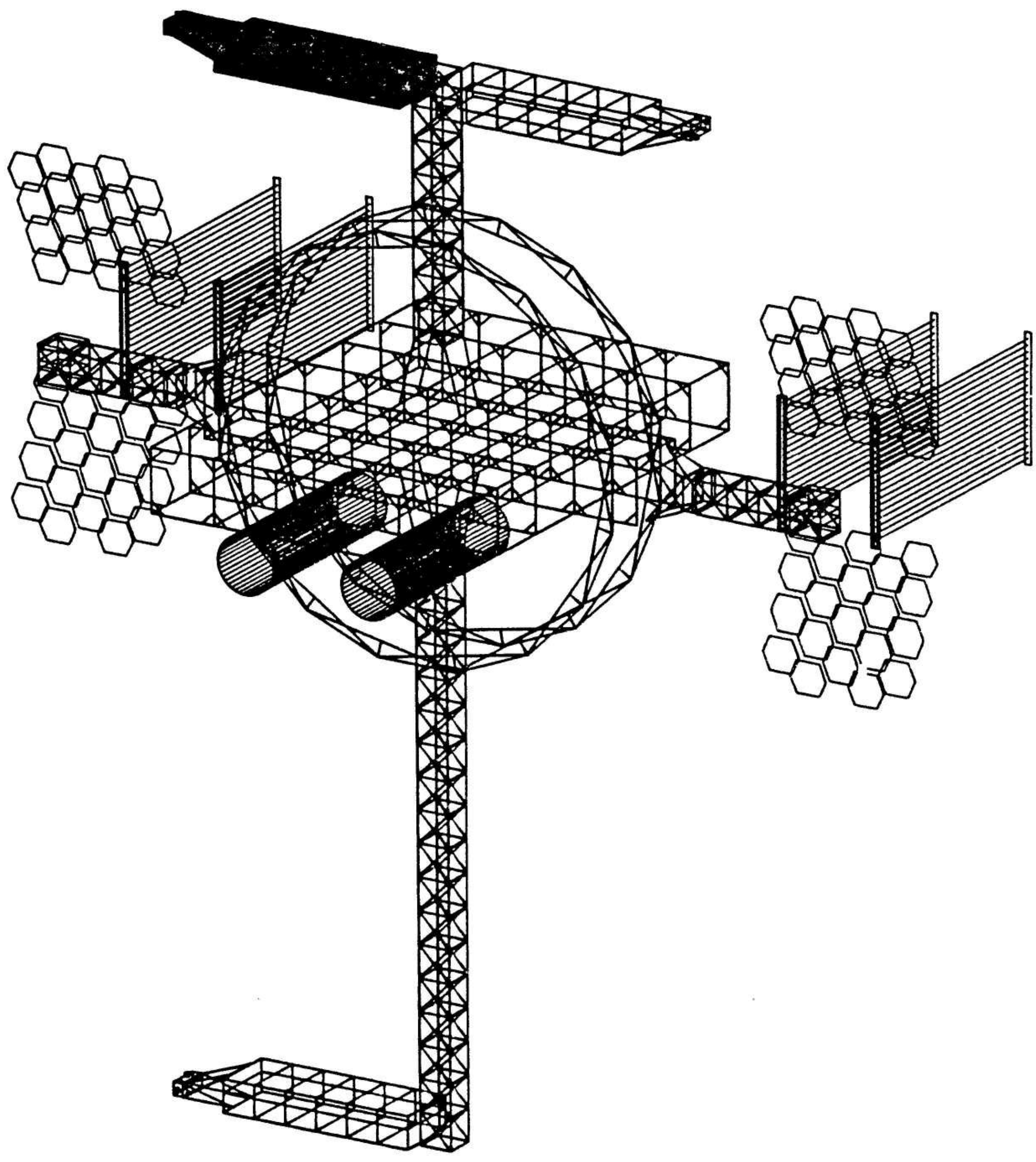


Figure 4 - 6.1



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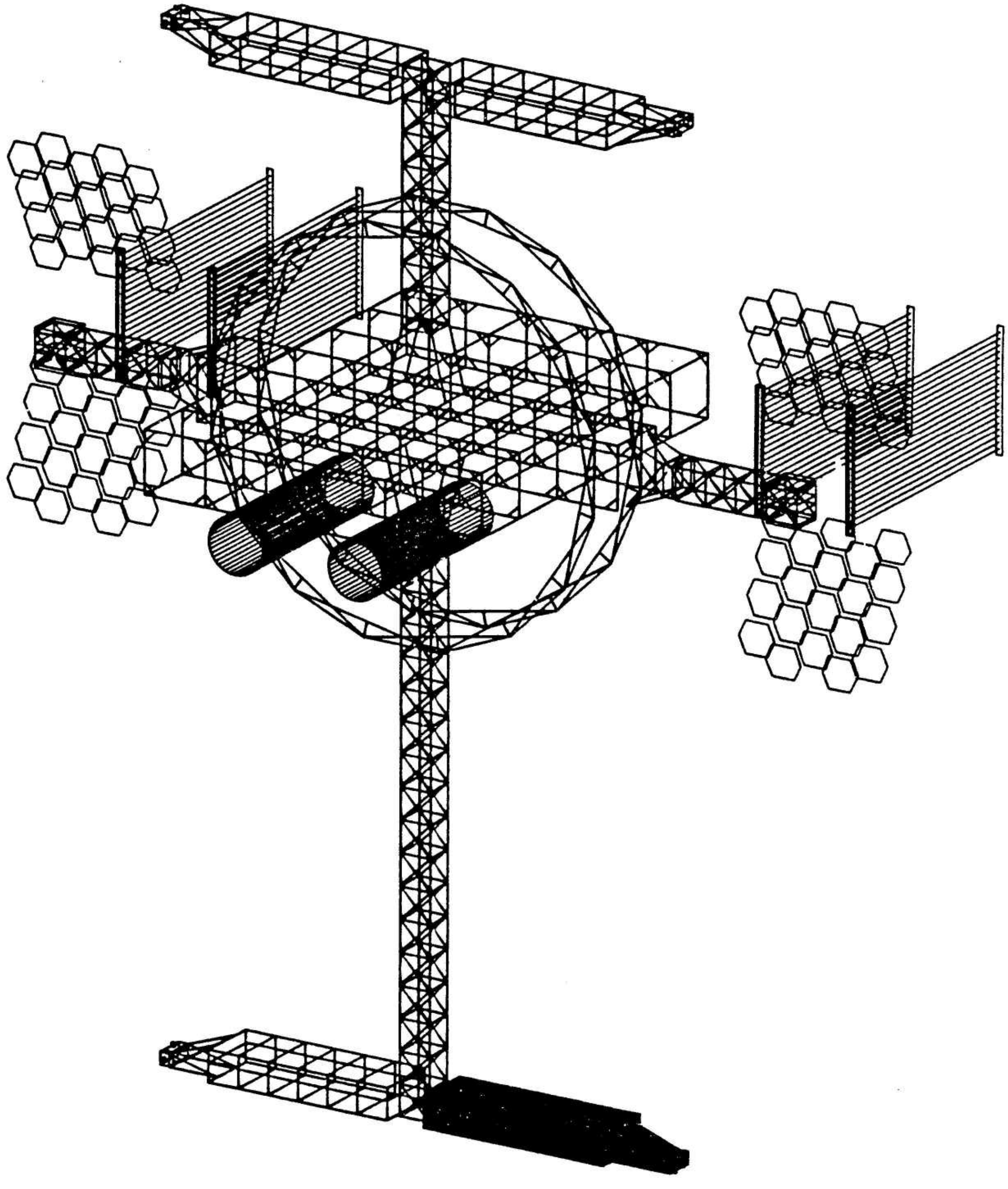


Figure 4 - 8.1

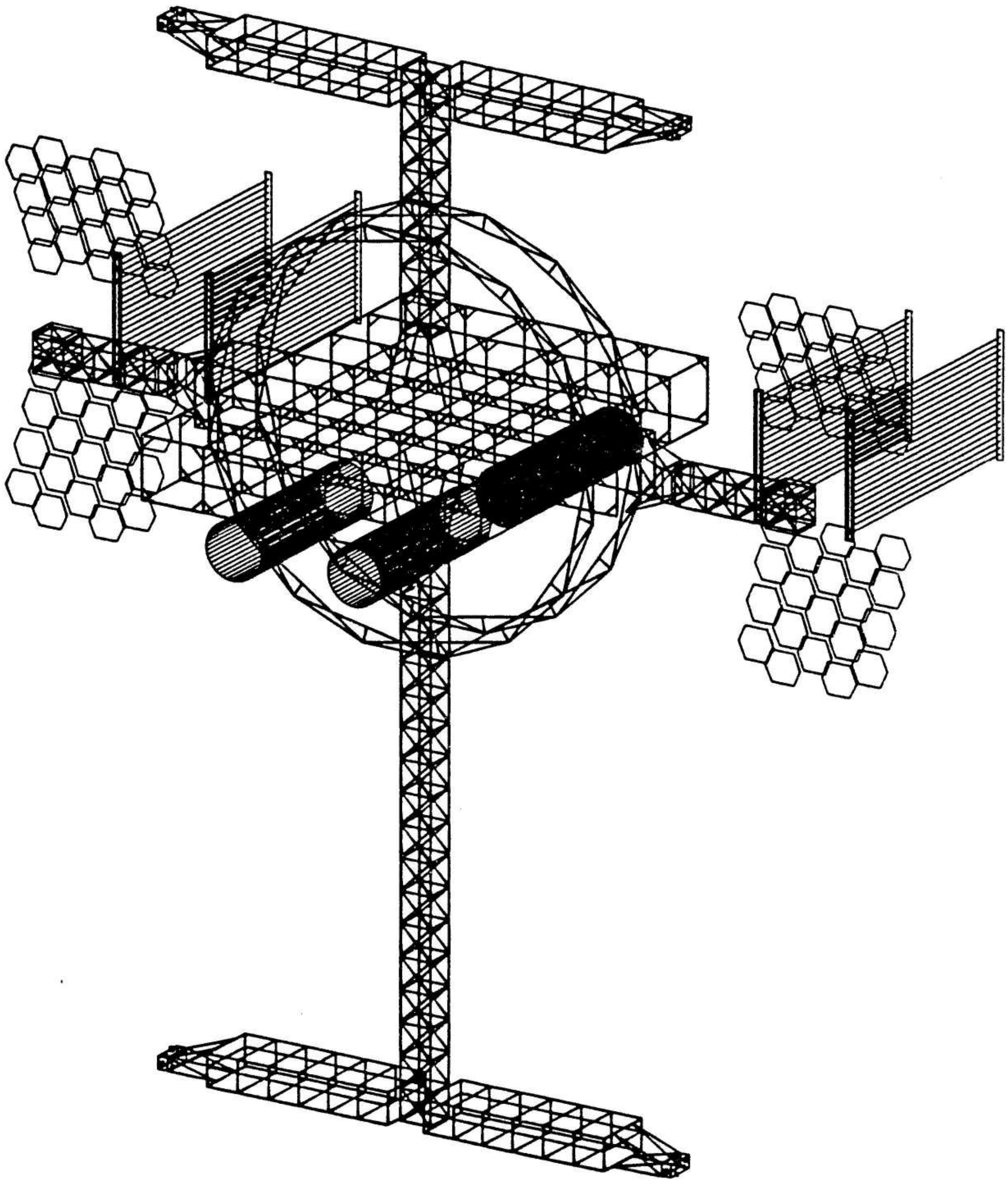


Figure 4 - 9.1

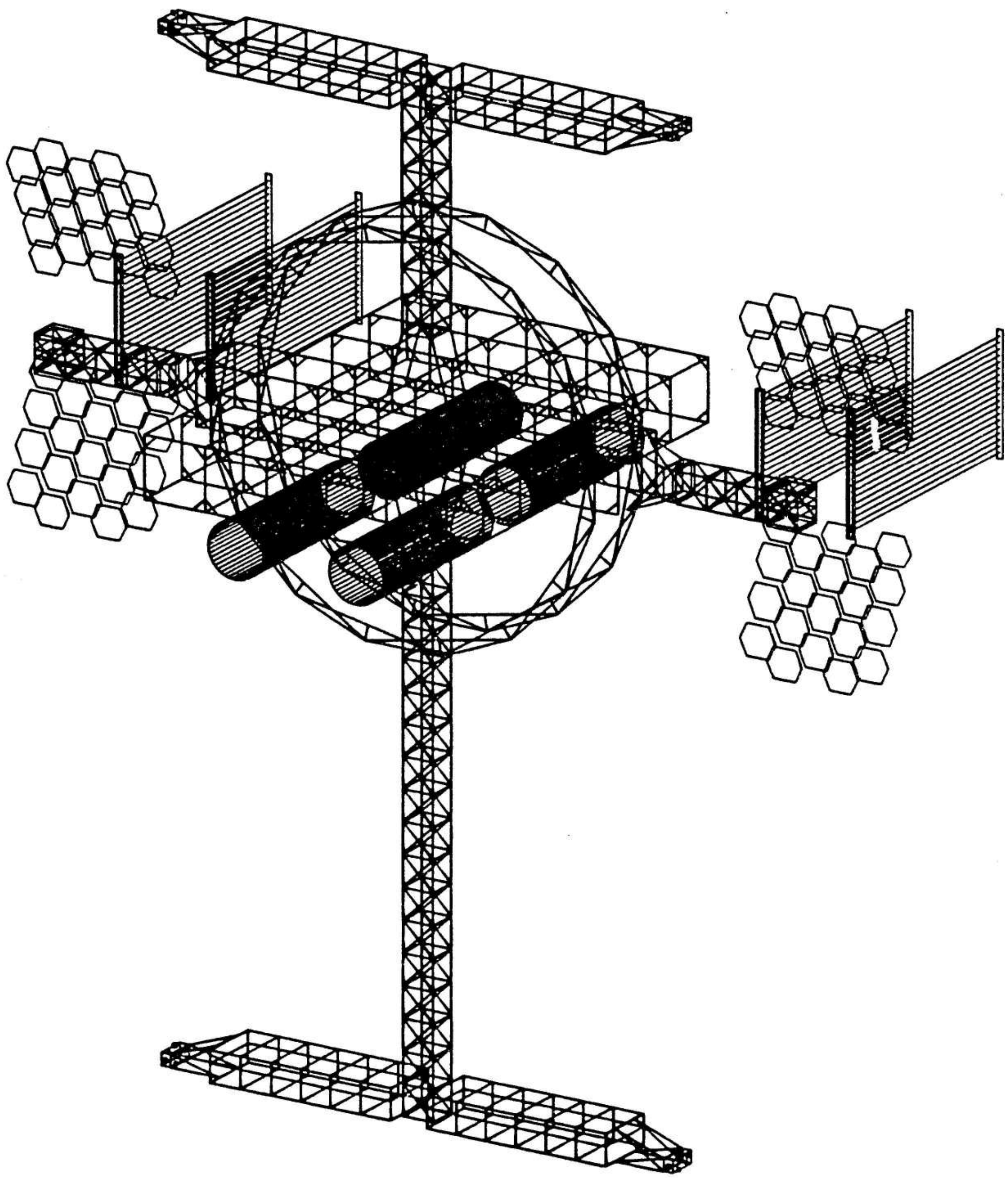
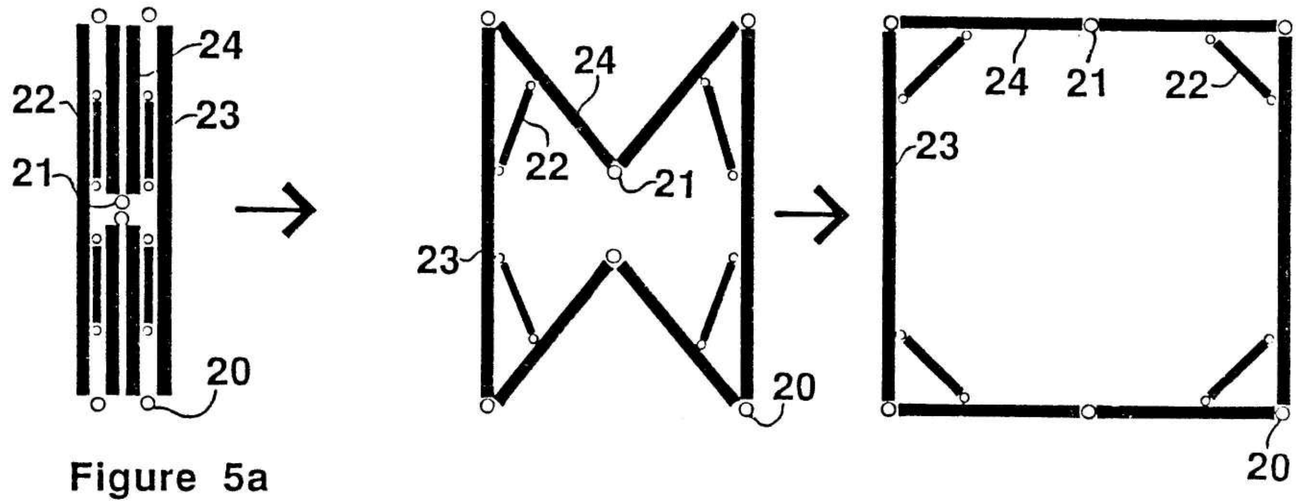


Figure 4 - 10.1



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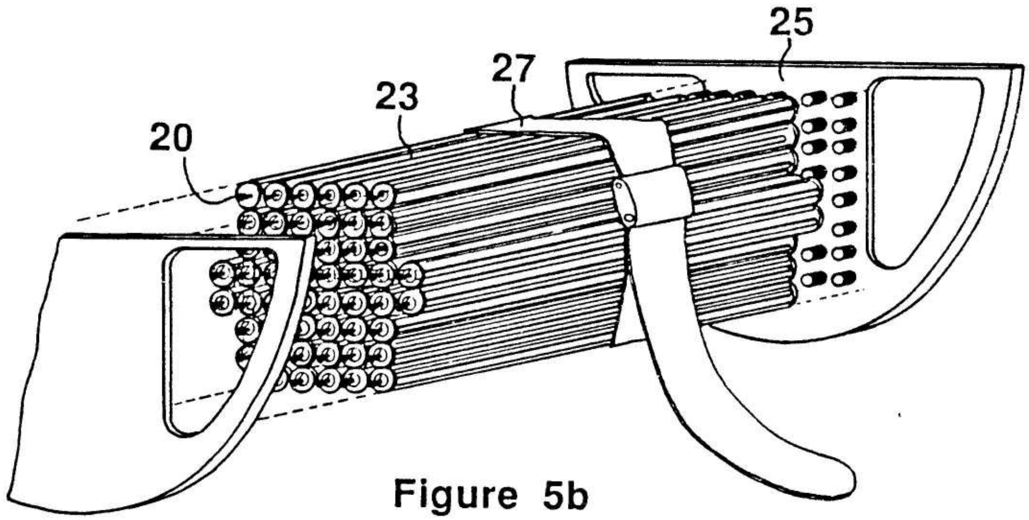

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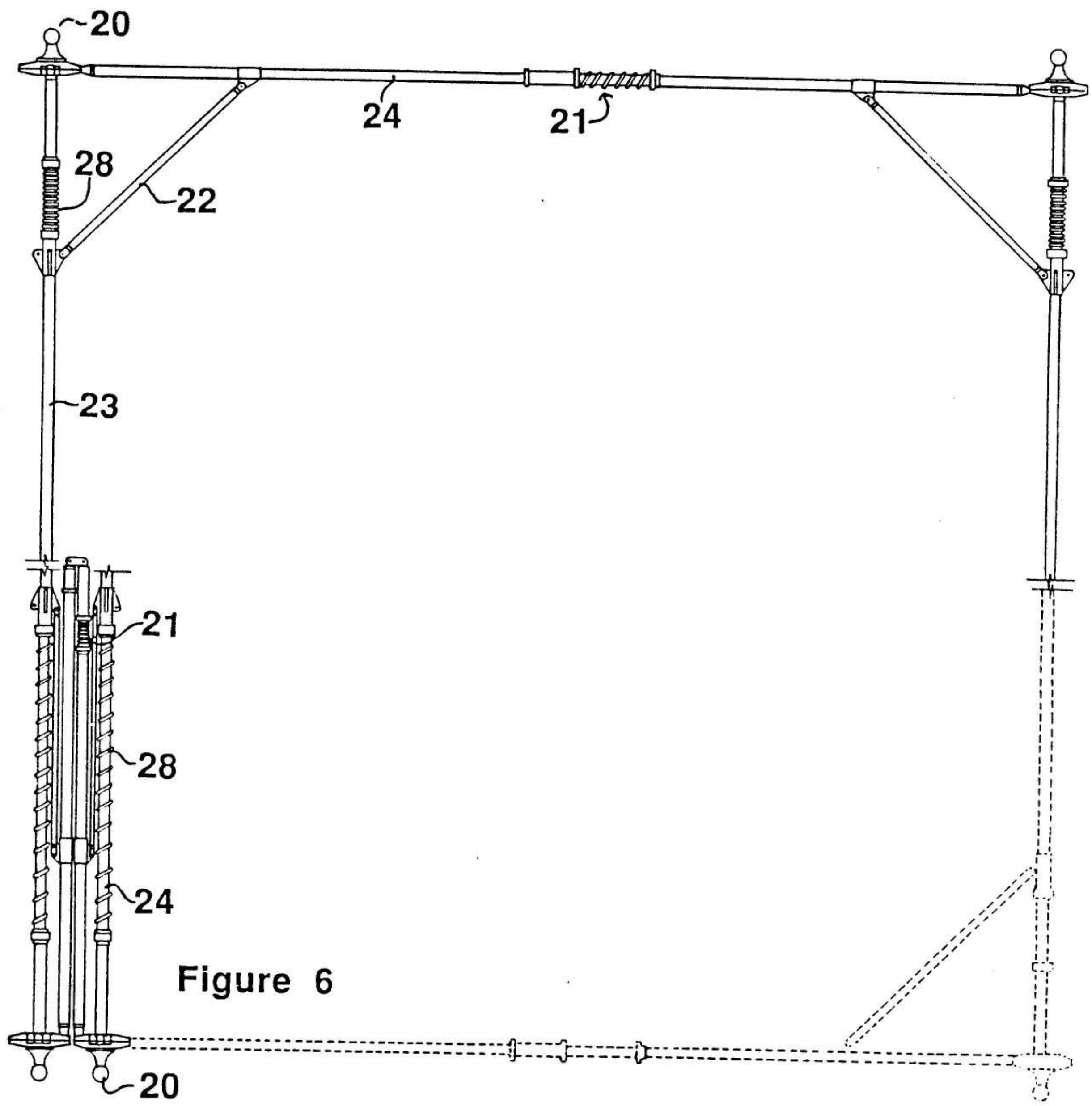

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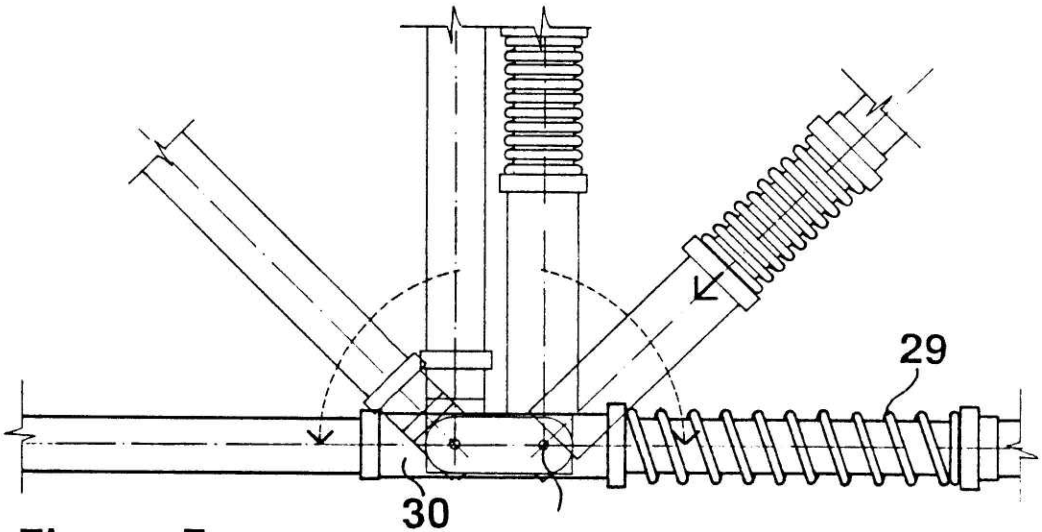

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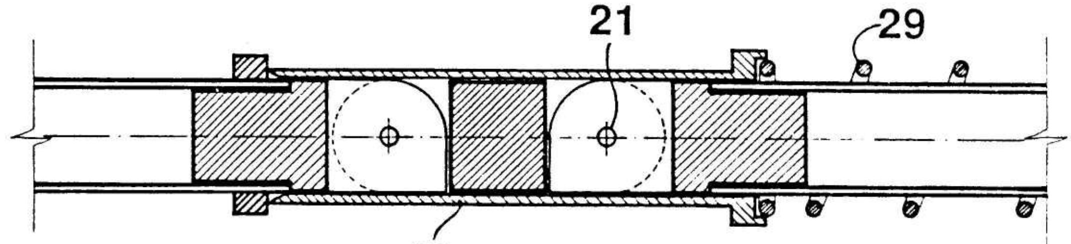

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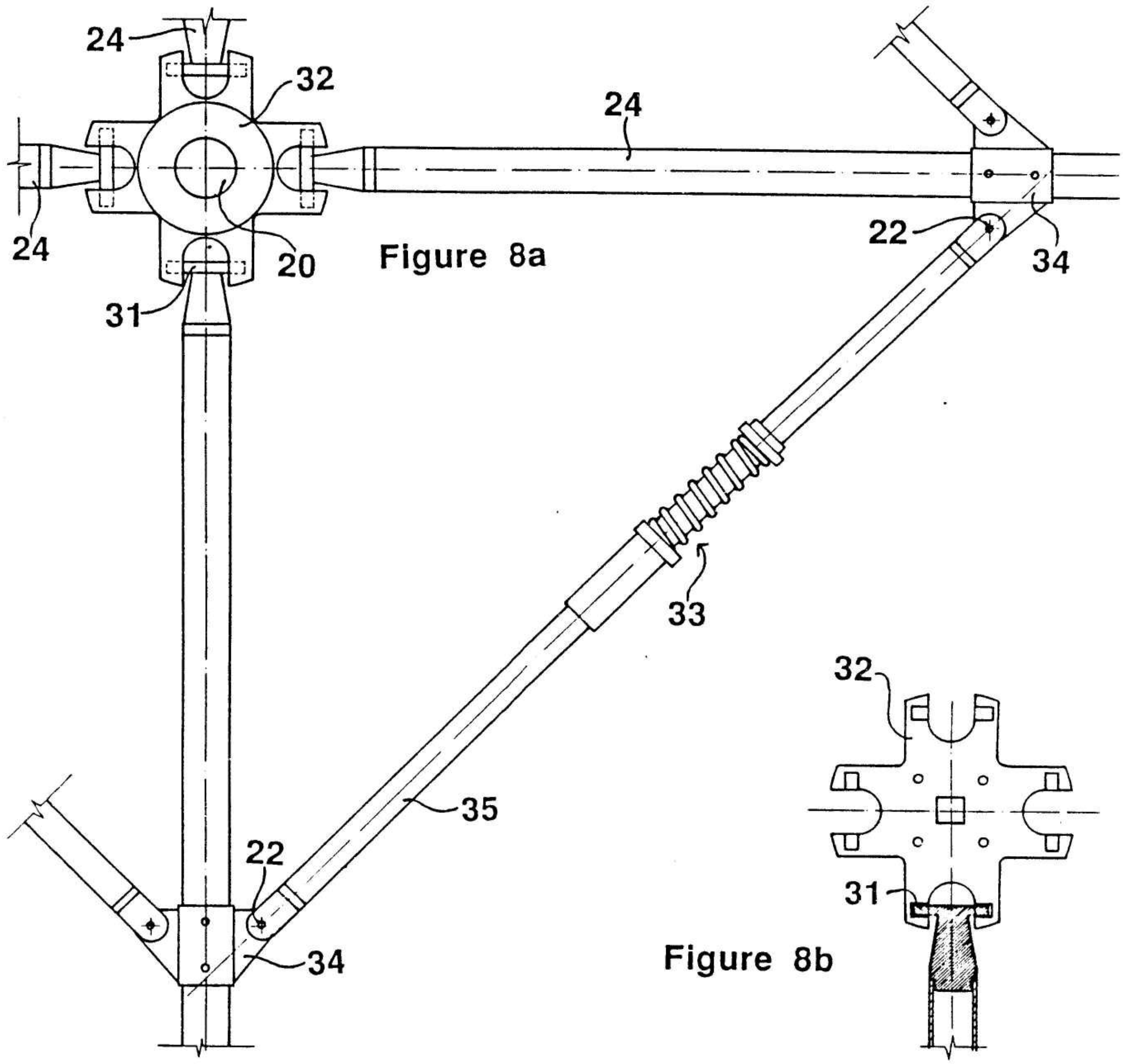


Figure 8a

Figure 8b

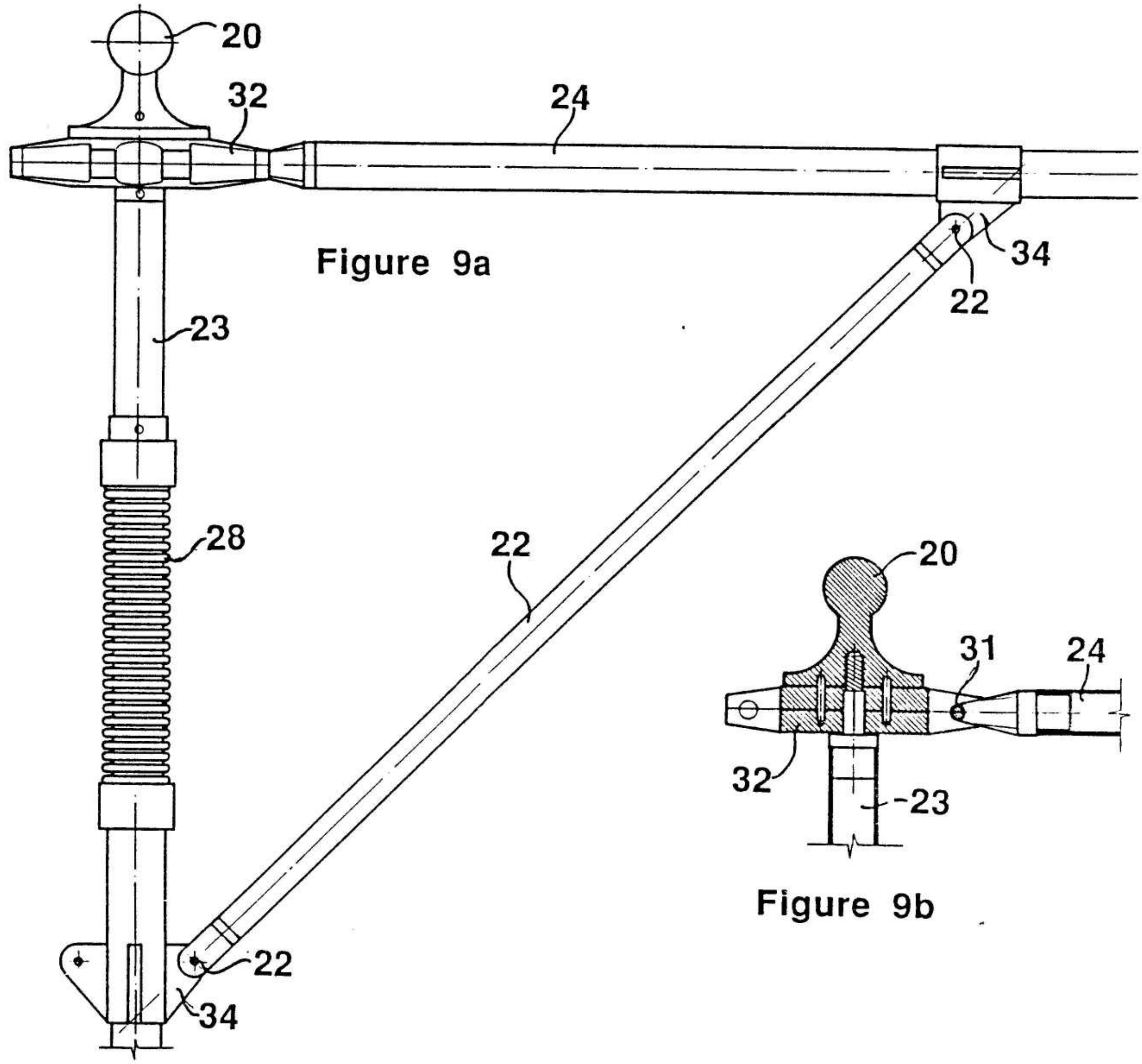
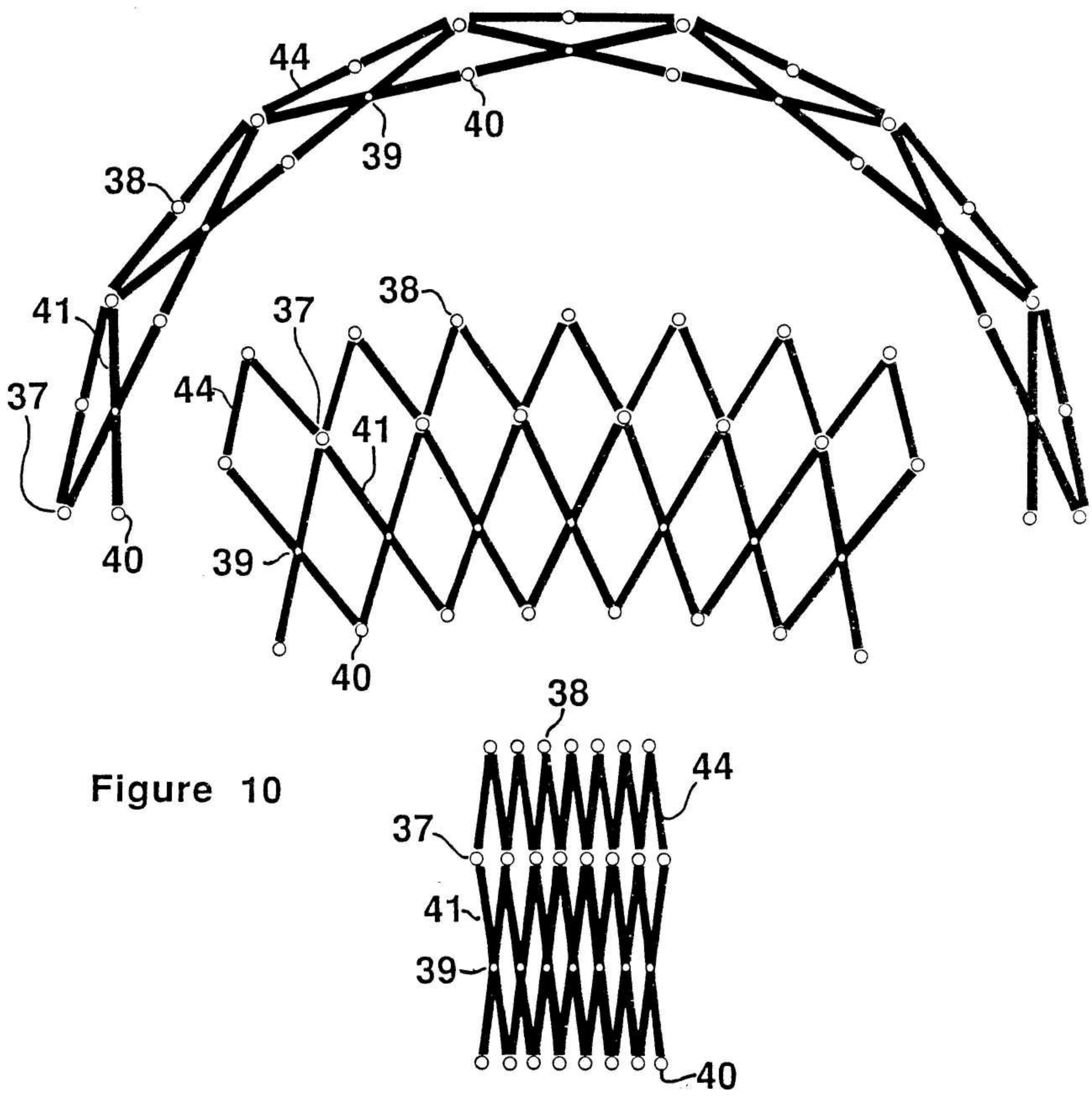


Figure 9a

Figure 9b



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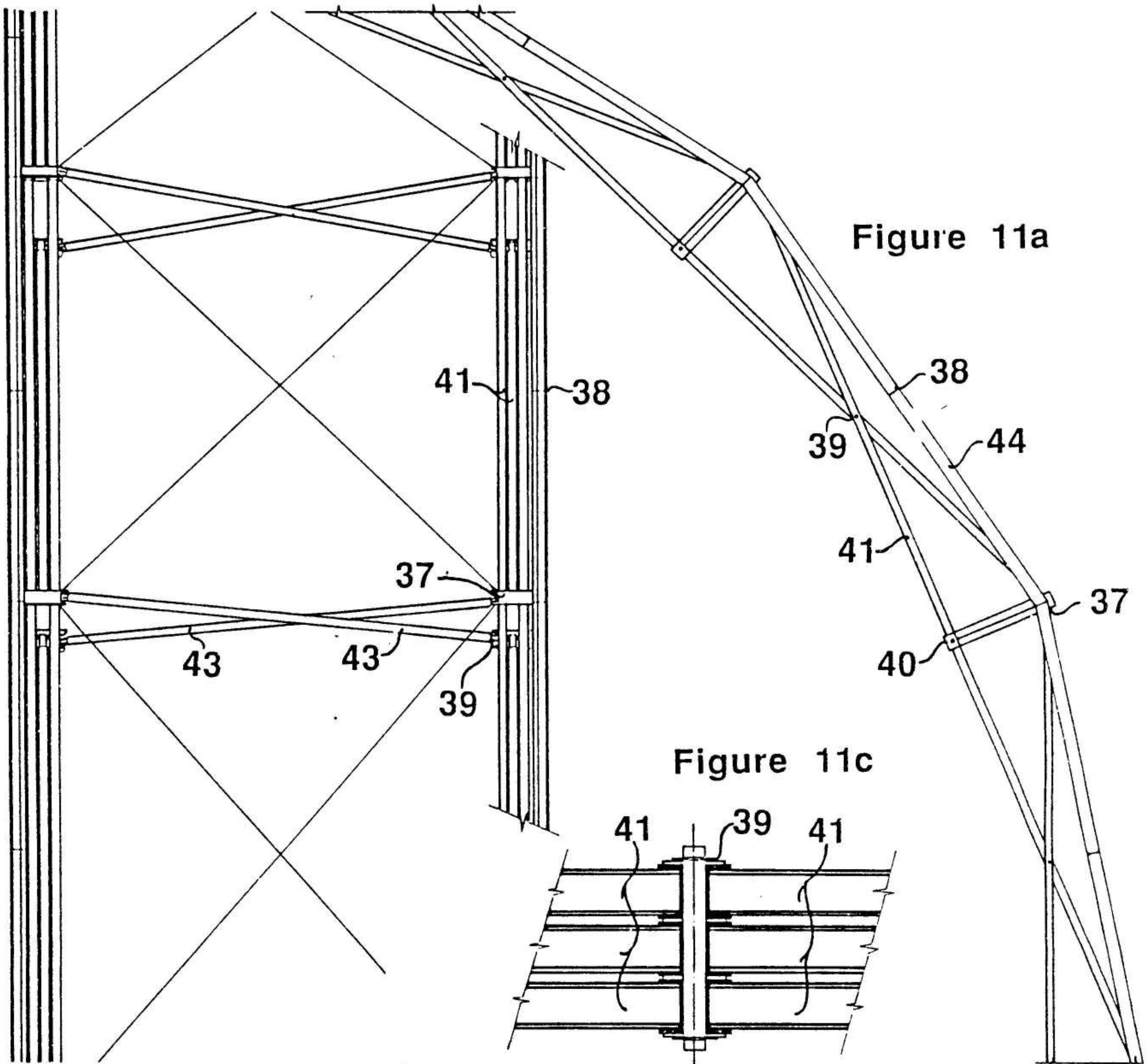
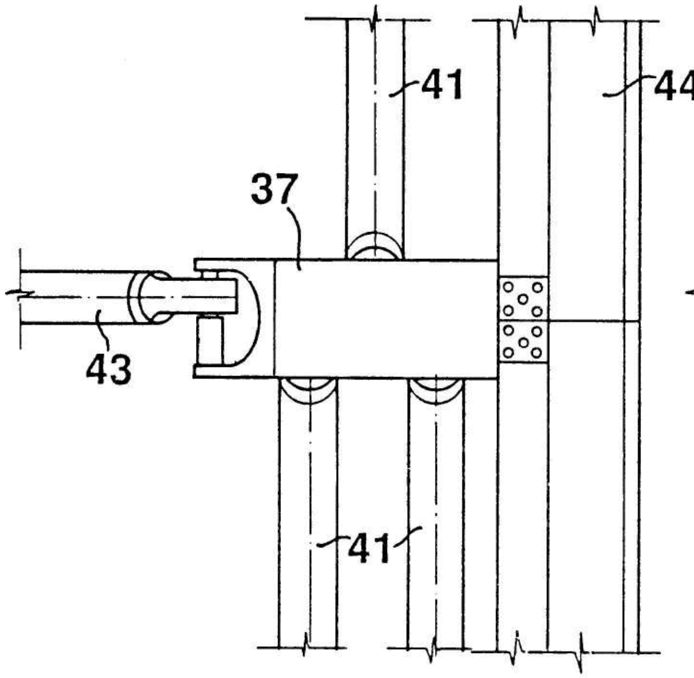


Figure 11a

Figure 11b

Figure 11c



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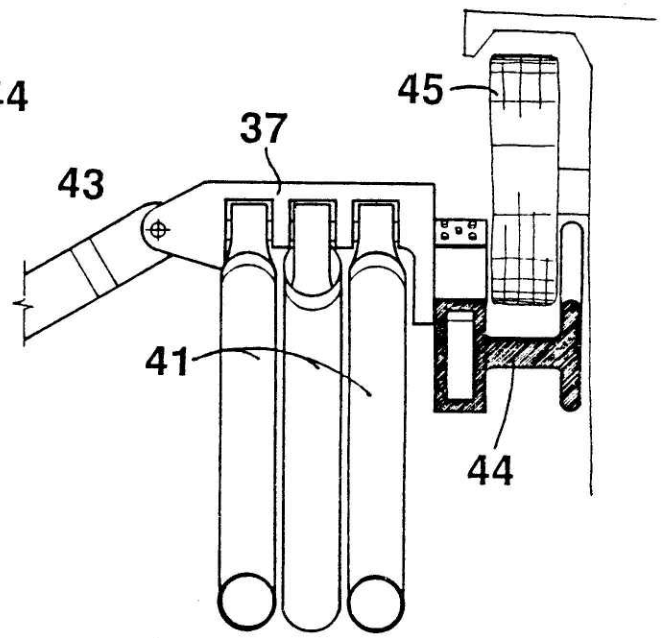

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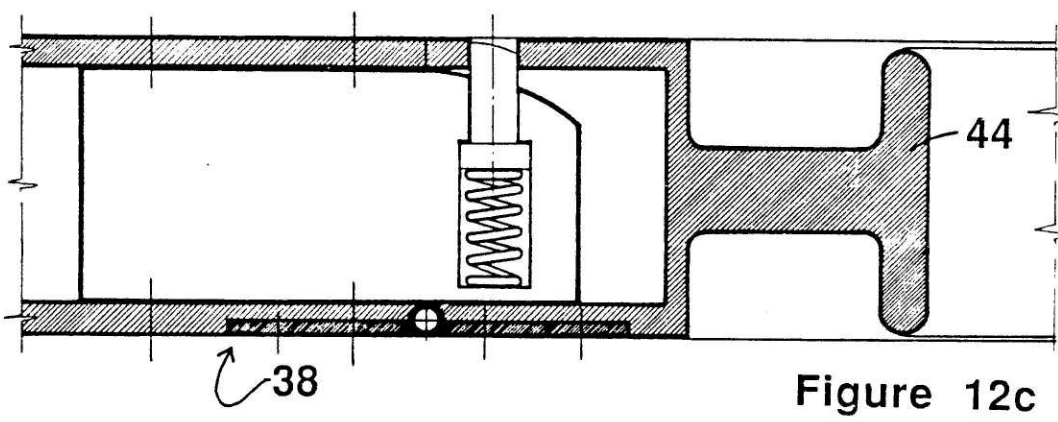

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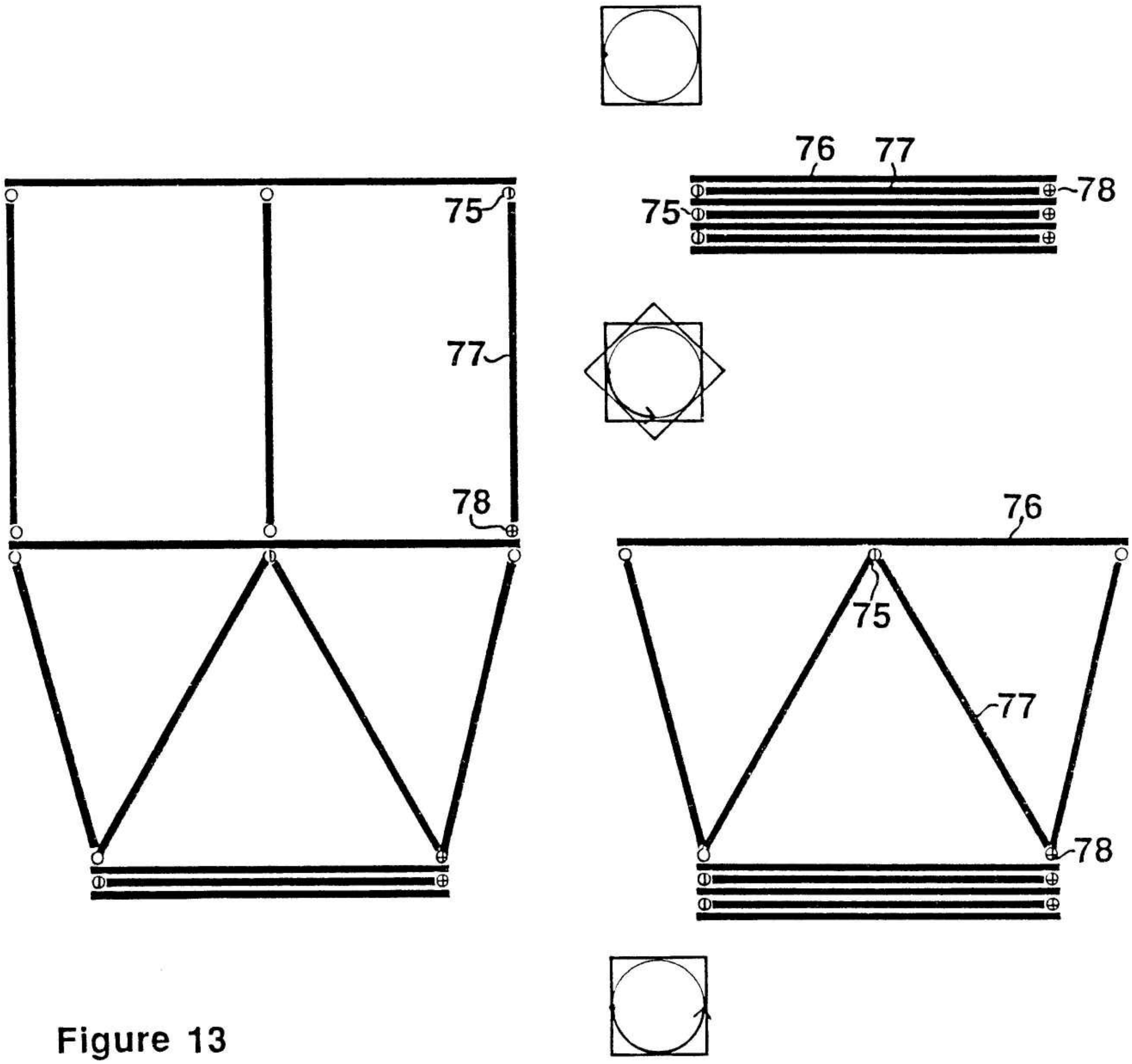

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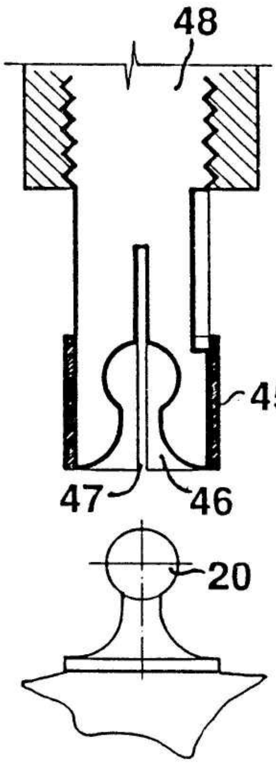

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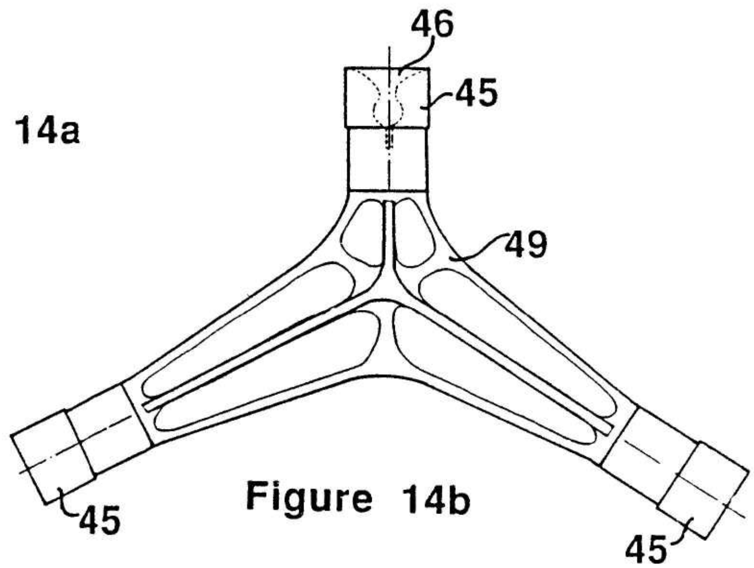

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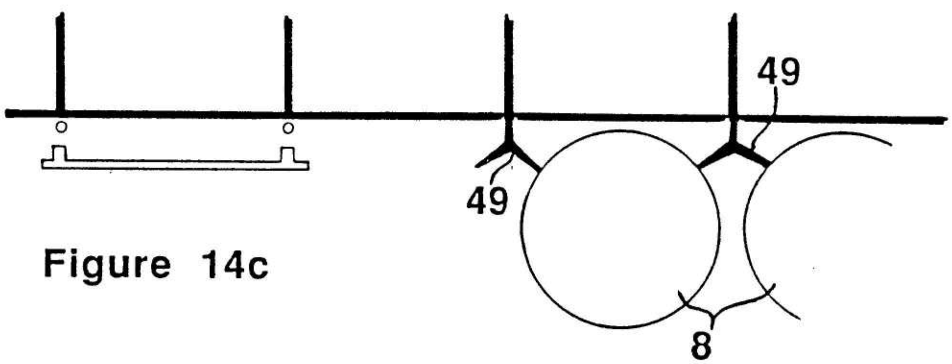

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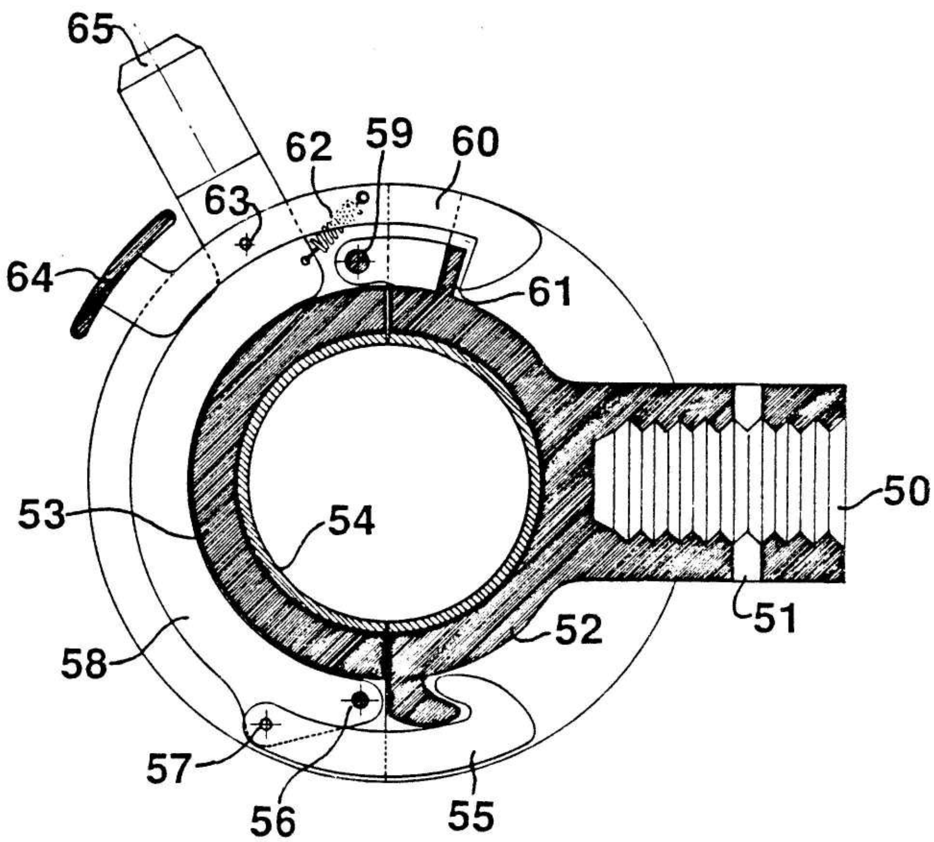

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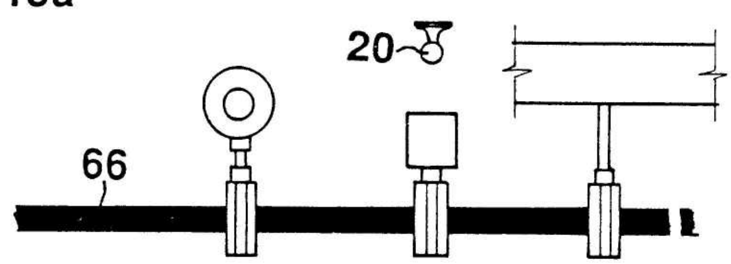

Figure 15b

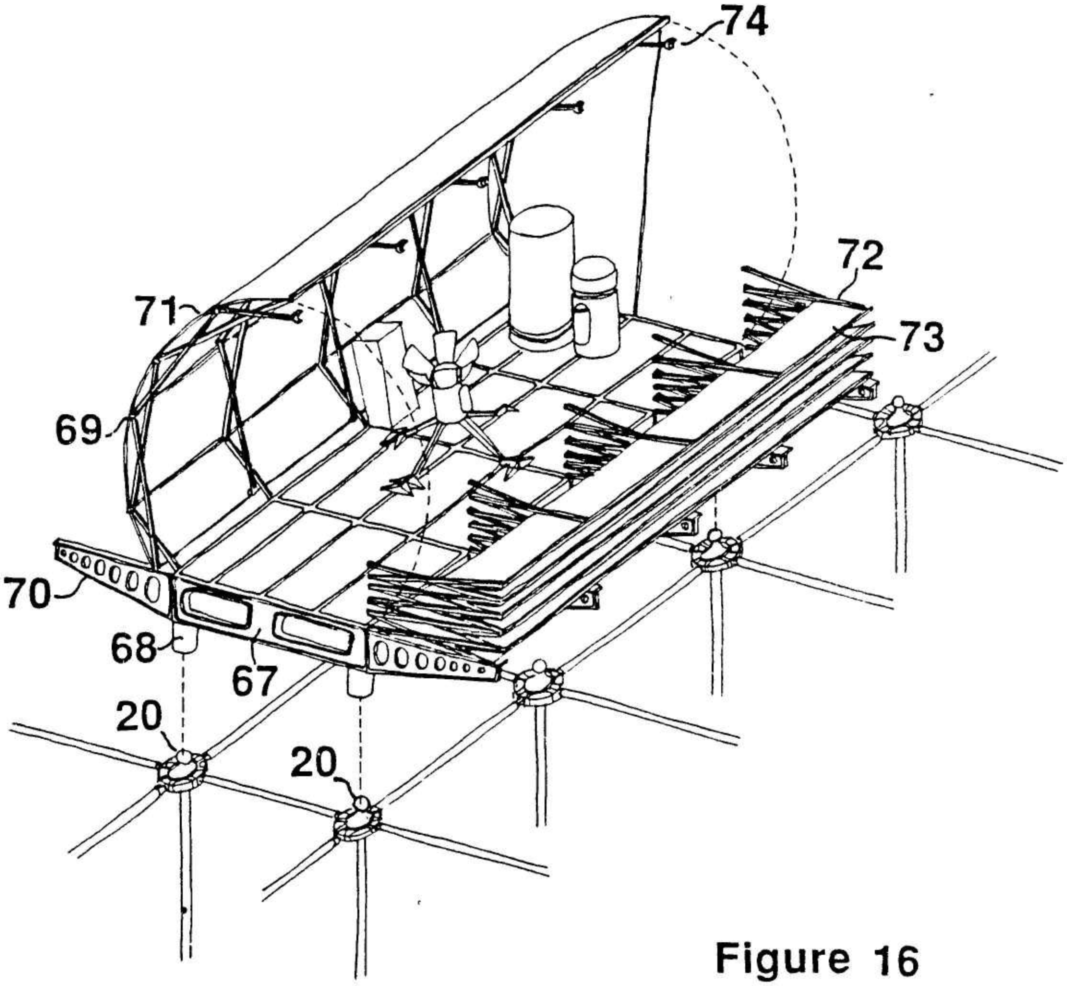

Figure 16