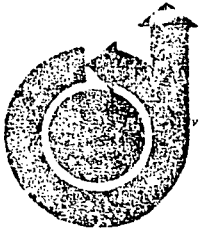


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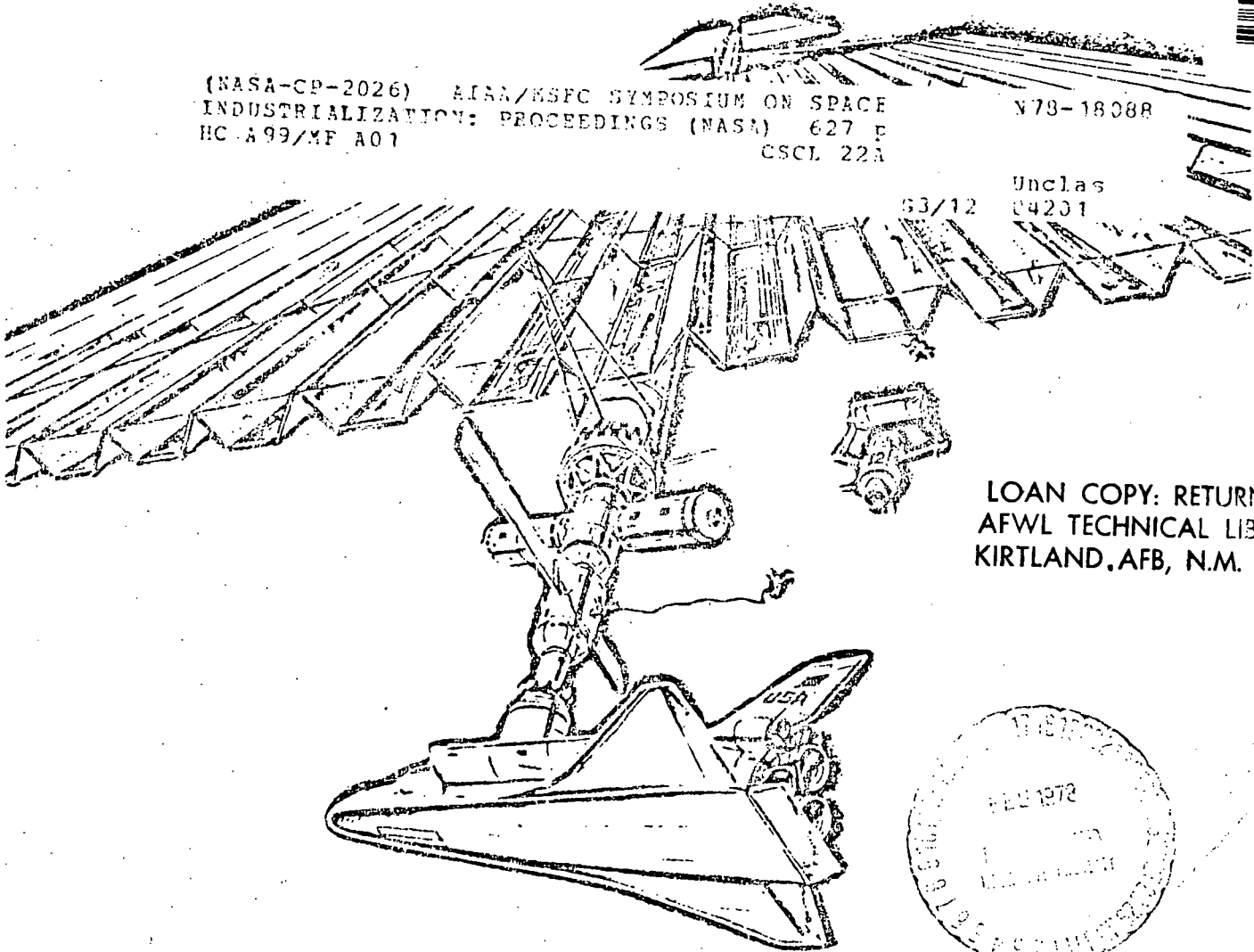
AIAA/MSFC SYMPOSIUM ON SPACE INDUSTRIALIZATION PROCEEDINGS



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NASA

National Aeronautics and
Space Administration

MAY 26 & 27, 1976
MORRIS AUDITORIUM
MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812



FOREWORD

To further the dissemination of new knowledge is one of the objectives of the Alabama Section of the American Institute of Aeronautics and Astronautics; the Space Industrialization Symposium attained this objective in the finest sense. This forum offered the opportunity to view some approaches of specific actions that mankind may pursue to utilize his ability to industrialize space. The advent of the Space Shuttle Transportation system opens the way to "easy" access to space, and the industrial use of this ability is the logical sequence.

The achieved magnitude of this symposium could not have been attained without the support of the Marshall Space Flight Center. The Alabama Section of AIAA is grateful for the cosponsorship of this Center. To all of those who participated in the planning, conduct, and presentations of this symposium, a sincere appreciation is offered. The outstanding quality and success of this event were the direct results of the willingness and personal efforts of these participants.

The proceedings included herein reflect the thoughts and ideas of many of those interested in man's advancements in space. We all look forward to these ideas becoming a reality.

Alfred G. Orillion
Chairman, Alabama Section,
AIAA - 1975-1976

SPACE INDUSTRIALIZATION

Preface

By

General Chairman, James A. Downey (MSFC)

Space Industrialization basically involves the effective utilization of the extraterrestrial environments to produce products or to provide services of value on Earth. Inherent in such a program scope are the following objectives:

1. The development of the capability for the commercial processing in space of unique and valuable materials and pharmaceuticals.
2. The support of future public service projects in space that will provide significant social and economic returns. For example, large public platforms in space offer opportunities for a variety of low cost communications, including TV, and electronic mail services.
3. The introduction and development of new techniques and concepts to satisfy national needs, such as the conversion of solar energy to electrical energy in space and its transmission to Earth for public use.
4. The development of significant advancements in the extended space capabilities required to accommodate future new space initiatives, including the development of a space operations and construction base needed to fabricate and erect the large structures needed for accomplishing future public services missions.
5. The development of permanent occupancy of space by man, an essential ingredient in truly exploiting the potential use of space for industrial purposes.

The above objectives are based on current planning. Future studies and symposia will be needed to aid in collectively identifying and understanding the full potential and opportunities offered by Space Industrialization and in developing an imaginative long range plan that will make such an undertaking a beneficial reality to all of us here on Earth. This Symposium will serve as a springboard for providing a clearer insight into current and projected technologies as they affect our long range planning and a better agreement and understanding of what our needs, goals, priorities, and expectations should be relative to a projected Space Industrialization program for the future.

CONTENTS

	Page
AGENDA	1
WELCOME by Dr. W. R. Lucas	5
KEYNOTE ADDRESS by John H. Disher	9
INTRODUCTORY REMARKS	18
SPACE HABITATS	20
SPACE TRANSPORTATION	118
MATERIALS PROCESSING	297
SOLAR SPACE POWER	396
SPACE INDUSTRIALIZATION AS A CONCEPT	568

SYMPOSIUM AGENDA

Wednesday morning, May 26, 1976

General Chairman: James A. Downey III, Marshall Space Flight Center

Co-Chairman: Konrad K. Dannenberg, American Institute of Aeronautics and Astronautics

8:00	Registration	Lobby of Bldg 4200
8:45	Welcome	William R. Lucas, Director, Marshall Space Flight Center
9:00	Keynote Address	John Disher, NASA Headquarters
9:30	Opening of Sessions	Alfred G. Orillion, Chairman, Alabama Section AIAA

SPACE HABITATS

Session Chairman: William G. Huber, Marshall Space Flight Center

Session Co-Chairman: David C. Cramblit, Marshall Space Flight Center

9:35	Introduction	William G. Huber, Marshall Space Flight Center
9:40	Evolution of Space Station Systems	George V. Butler, McDonnell-Douglas Astronautics Company
10:10	Space Station Habitability Issues	Richard L. Kline, Grumman Aerospace Corporation
10:40	COFFEE BREAK	
11:00	Orbital Assembly	Shepard B. Brodie, Martin-Marietta Aerospace Corporation
11:30	New Space Initiatives	Ivan Bekey, Aerospace Corporation
12:00	Space Settlement Planning Methodology	C. William Hamilton, Battelle Columbus Laboratories
12:30	LUNCH - Cafeteria of Bldg 4200	

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Wednesday afternoon, May 26, 1976

SPACE TRANSPORTATION

Session Chairman: Gerald W. Driggers, Southern Research Institute
Session Co-Chairman: Peter Paul Plank, Martin-Marietta Aerospace Corporation

1:30	Overview	Les Fero, NASA Headquarters
1:45	Advanced Space Transportation System Requirements	Gordon Woodcock, Boeing Aerospace Co.
2:10	Shuttle Booster/Propulsion Growth Concepts	Luther T. Spears, Jr., Marshall Space Flight Center
2:35	Advanced Earth Orbital Transportation Systems Technology	John Decker, B. Z. Henry, and C. Eldred, Langley Research Center
3:00	Single-Stage-to-Orbit Vehicles Using Technology Projections	Rudi Haeffel, Martin-Marietta Aerospace Corporation
3:25	Liquid Propulsion System Effects on Design of Large Vehicles	Rudi Beichel, Aerojet Liquid Rocket Company
3:50	Orbital Transfer Vehicle Concepts	R. Eugene Austin, Marshall Space Flight Center
4:15	Aeromaneuvering Orbit Transfer Vehicles for the Space Transportation System	J. P. Hethcoat, Marshall Space Flight Center J. White, Lockheed Missiles and Space Co.
6:30	AIAA BANQUET - Redstone Arsenal Officers Club - Speaker: Krafft A. Ehricke, Rockwell International	

Thursday morning, May 27, 1976

MATERIALS PROCESSING IN SPACE

Session Chairman: Henry Gutsche, Monsanto Company

Session Co-Chairman: Brian O. Montgomery, Marshall Space Flight Center

8:45	Program Overview	Eugene C. McKannan, Marshall Space Flight Center
8:55	Research Resources and Priorities	Gus Witt, Massachusetts Institute of Technology
9:20	Biological Materials	Grant Barlow, Abbott Laboratories
9:45	Factories in Space	William Marx, McDonnell-Douglas Aerospace Corporation
10:10	COFFEE BREAK	
10:25	Metallurgical Materials	Richard Oriani, U.S. Steel Corporation
10:50	Investments in Space -- When and How?	Leo Steg, General Electric Co.
11:20	Uses of Ultra Vacuum in Space	Len Melfi, Langley Research Center
11:50	Extraterrestrial Mining and Industrial Processing	Philomena Grodzka, Lockheed Missiles and Space Co. Ron L. Nichols, Marshall Space Flight Center
12:20	Summary	Henry Gutsche, Monsanto Company
12:30	LUNCH -- Cafeteria of Bldg 4209	

Thursday afternoon, May 27, 1976

SOLAR SPACE POWER

Session Chairman: Ralph LaRock, NASA Headquarters

Session Co-Chairman: Charles H. Guttman, Marshall Space Flight Center

1:30	Introduction	Ralph LaRock, NASA Headquarters
1:40	Potential of Satellite Solar Power Stations	Peter E. Glaser, Arthur D. Little
2:10	Space-Based Solar Power Conversion and Delivery Systems	Rudolph Adornato, Grumman Aerospace Corporation
2:40	Thermal Engine Power Satellites	Dan L. Gregory, The Boeing Co.
3:10	Microwave Power Transmission Performance Records and Applications	Richard L. Dickinson, Jet Propulsion Laboratory
3:40	Cost, Uncertainty, and Risk Analysis	George Hazelrig, ECON
4:10	Critical Development Areas for Solar Space Power	Georg von Tiesenhausen, Marshall Space Flight Center
4:40	Adjournment of Symposium	James A. Downey III, Chairman, Marshall Space Flight Center

Dr. W. R. Lucas

Welcome
AIAA/MSFC Symposium
on Space Industrialization

It is my pleasure this morning, on behalf of the MSFC and the Alabama Section of the AIAA, to welcome you to the Marshall Center and to this jointly-sponsored Symposium on Space Industrialization. To those of you from out-of-town, I also bid you welcome to Huntsville and our North Alabama community.

Because of the present status of the space program, I think this is a most opportune time for this symposium. Perhaps there are those who would say that the thrill and adventure of the space program are passed -- that the program is only the remains of a previous era of space exploration. Obviously, such thoughts are farthest from our minds. As great as have been the thrills and heartaches, and the great achievements of the past, in most of which I have been privileged to participate along with many of you, I look forward eagerly to the prospect of greater thrills from the practical pay-off to all the pioneering that has gone before.

In Apollo and previous programs, we developed the capacity to get into and out of space safely and to explore. In Skylab we developed the

capability to spend substantial time in space, to utilize man as the space laboratory director and plant manager, to revisit a semi-permanent space station, to react with great flexibility in correcting adverse situations, to take advantage of unanticipated opportunities, and to do things not possible on Earth. In the more recent Apollo-Soyuz mission, there was a continuation of useful experimentation and the results tantalize us to move ahead. Now with the approaching availability of the Shuttle offering much more frequent and lower cost access to the unique arena of space, it behooves us to get down to serious planning for the future -- to reaccess what has been done -- to evaluate the prospects in the light of good, sound science and technology, and to begin doing those things required to prepare us to utilize the unique aspects of space for the benefit of man on Earth. It is important now, more than ever, that our planning be sound-- that we be guided by intellect rather than emotions -- that we select and emphasize those things that can be uniquely benefitted by the space environment and those things that have the promise of becoming economically attractive. Although there is time to plan, I believe there is no time to waste.

In the light of what I've said and my more extensive thoughts on the prospects, I am greatly pleased to know that there are gathered

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here today some of the best brains in the country -- that are motivated by a dream of great achievement for the benefit of mankind. I wish you well in your deliberations. My hope is that this will truly be a forum for the exchange of ideas, that you will be frank and open in your discussions, both formal and informal, and that all of us will consider the time to have been well spent. I expect great things from this symposium. My regret is that a trip to Washington shortly will prevent my participation in all the symposium and the banquet tonight.

We are honored, this morning, to have with us as keynote speaker a man who is already an established space pioneer and who now is also a forward-looking analyst of our space future.

Mr. John H. Disher first joined NACA, predecessor of NASA, in 1943 as an aeronautical research scientist in the Flight Research Division of the Lewis Flight Propulsion Laboratory, Cleveland, Ohio.

He has served in NASA Headquarters as Assistant Director for Apollo Spacecraft Development, Director of Apollo Test Programs, and as Deputy Director of the Skylab Program.

For the past two years, Mr. Disher has been Director, Advanced Programs, in NASA's Office of Space Flight. In this capacity, he analyzes and evaluates concepts for future manned space activities.

defining their benefits, and determining costs and technical feasibility as they relate to changing national needs and priorities. He provides NASA with guidance in formulating the orderly transition from present to future manned space flight systems and programs.

In looking at the purposes of this symposium and the background and present assignment of Mr. Disher, it is readily evident that he is a most fitting person to keynote this meeting.

I present Mr. John H. Disher.

#####

KEYNOTE ADDRESS

SPACE INDUSTRIALIZATION

By: John H. Disher, Director
Advanced Programs
Office of Space Flight
NASA Headquarters
Washington, D. C.

What do we mean by Space Industrialization? I believe a simple straight-forward definition will suffice. Space Industrialization is the use of space to produce a salable/profitable product or service which companies, as a business expense, or citizens, through their taxes, are willing to pay for. Other basic uses of space of course include Scientific Research and Exploration, typified by the Voyager and Apollo programs and National Security. But we're here today to talk about Space Industrialization and I believe the prospects are bright enough to say that they may form the nucleus for a 3rd industrial revolution - some of which were already seen.

Where do we stand today in the Industrialization of Space? Certainly communications satellites are the outstanding examples to date. Necessary R&D on COMSATs was carried out in the early 1960's, and by the mid-60's commercial firms had made substantial commitments to their development. Today the commercial investment in COMSATs totals well over a billion dollars, and substantial returns on investment are being realized. Sporting events and important news happenings are routinely relayed from continent to continent on a commercial paying basis. Inter-

estingly, this revolution in communications has come on so smoothly and effectively that the general public has taken it for granted as a routine activity that just somehow evolved in the normal course of events. Actually, of course, it happened because the necessary R&D expenditures and investigations were carried out in the early 1960's to show the way, validate the feasibility and thereby encourage the commercial investments necessary to make it all happen.

On what I believe to be a fairly conservative basis, annual world-wide business rates of several billion dollars a year are projected for this business by the mid-1980's. Further, I believe the projections to date for the most part include only growth of the type of uses experienced to date -- conventional telephone and TV relay, etc., and don't adequately reflect the potential for new uses such as electronic mail, video teleconferencing, facsimile relay, personal point to point communications, etc. Communications by itself constitutes a multi-billion dollar Space Industry. To meet future needs we'll likely need quite large, sophisticated systems in space -- systems large enough and expensive enough to require or benefit strongly from man's direct participation in space in their assembly, checkout, periodic maintenance and repair and updating -- extension of the conventional ground role for construction workers, electronic technicians and trouble shooting engineering into space. Happily, the shuttle with its routine access to space capability will pave the way and in due time make such operations routinely feasible.

Weather satellites are a good example of the service aspect of Space Industrialization. Their use has become indispensable in world-wide weather monitoring and long range forecasting. Their value to those elements of world-wide economy dependent on weather is incalculable. If it could be reduced to monetary terms, it would I'm sure, be staggering. In any event, use of space for meteorological purposes now constitutes an over 50 million dollar a year service for which using agencies, on behalf of tax paying businesses and citizens are willing to pay. The loss of that service to farmers, shippers and all the myriads to whom weather is a \$ or ¢ matter would be intolerable.

As to the future uses of space for meteorological purposes, advanced operational systems, with their sophisticated surface and atmospheric sensors are bound to greatly enhance their usefulness and service oriented market value. Over the longer term there exists the potential for weather modification through use of large solar reflectors in space or by other means.

Other examples of the service oriented use of space include navigation, mapping and Earth resource survey. The use of satellite provided data has quietly revolutionized each of these areas and continued expansion of their operational uses is inevitable. Just to give one small example, the observation of sea and lake ice fields and icebergs has extended shipping seasons and reduced shipping hazards to an extent where financial savings each year to shippers far exceed the total R&D expenditure to date for such services.

Now, as to the future in other almost completely untapped areas:

First, let's consider in the general sense, what are the unique attributes of space, that make it amenable to industrial use.

First, there is the overview of Earth from the vantage point of space. We can have this overview continuously of a selected area as large as a hemisphere from GEO, or we can have a repetitive overflight of the entire surface of the Earth from low altitude. Each of these orbits and variations in between have valuable uses. Generally, it is the hemisphere overview for GEO that has given us the COMSATS and the repetitive overflights at low altitude that provide us the weather, navigation, mapping and Earth resource data. In many cases, data for low and GEO orbit can be used to complement each other and provide a greatly enhanced capability. Overview is the dominant attribute we've used in our Space Industrialization to date.

Another vital characteristic of space is the "zero gravity" effect. The absence of gravitational effects makes possible processes that are unfeasible on the surface of the Earth -- or on the surface of the moon, for that matter. Although gravity has many beneficial effects on Earth, such as keeping things in place, it prevents or makes very difficult many industrially valuable processes. In the absence of gravitational forces, it is possible to make some products in space that are completely unfeasible to make on Earth -- such as alloys of materials that are immiscible in the presence of gravity -- or products that cannot be separated out of a mixture in the presence of gravity, such as some

vaccines and pharmaceuticals. It is also possible to make some things in space very much better than they can be made on Earth -- giving greatly increased performance and greatly decreased cost of production. Examples here include crystals for solid state electronic devices and certain medications. In addition, the absence of large gravitational forces makes feasible the fabrication and assembly of very large, extremely lightweight structures which on Earth would collapse of their own weight. This characteristic fits extremely well with the need for very large antennas in space (hundreds of feet in extent) for future space communications systems and for very large assemblies of reflectors or collectors of solar energy for use in space or on Earth -- which we'll address further a little later on. The absence of gravity also provides unprecedented mobility for work crews and construction equipment in space. In addition, the absence of gravity with the associated absence of natural convective forces, enables research into physical and biological processes they may have extremely important impact on future industrial uses of space. For example, space hospitals are certainly not out of the question over the longer term.

Another important attribute of space is the essentially perfect vacuum it offers. This can be important to certain industrial processes and indeed makes feasible increased efficiency of certain large electronic devices which are impeded on Earth by the necessity of surrounding them with an evacuated shell. Associated with the perfect vacuum is the acoustic isolation possible in space. The acoustic isolation, combined with seismic iso-

lation afforded by a freely flying body can also be of critical importance to certain research investigations and potentially to industrial processes.

Another attribute of space is the unlimited reservoir it provides for disposal of waste heat or storage or disposal of waste products. Over the long term the ability to locate selected heat and waste-producing industries in space rather than polluting the Earth and its atmosphere may become critically important. For instance, if all countries on Earth were to attain the level of Earth-bound industrialization of today's developed nations, thermal pollution could become a problem of major consequence. With industrial processing in space waste heat can be radiated harmlessly to deep space, while waste products can either be stored indefinitely in long term stable orbits or placed in Earth escape trajectories. Waste products generated on Earth can of course similarly be stored or disposed of to this space reservoir.

Perhaps the most important characteristic of all of space is the essentially uninterrupted solar energy available there. This energy can be collected and used in space as we've done in a limited way in surveying many of our satellites to date. Future in-space use of solar power will grow expansively with the growing communications power requirements and the large power usage of materials processing facilities. However, the really large potential for space generated solar power is its relay to Earth by microwave for use on Earth. This subject will of course be discussed in papers to be presented later in this conference. Suffice it here to say that electric power between now and the end of the century is a trillion dollar

business. Even a small percentage of that market would dwarf total expenditures on space R&D since 1958. The potential there requires that as a nation we make the relatively modest R&D expenditures over the next several years that will be necessary to verify technical and economic feasibility of and subsequent commercial development of this potential for Space Industrialization.

A final major attribute of space is the capability it offers for mechanics and the absence of atmosphere or other retarding forces, the operating lifetime of a space system need be limited only by our ingenuity in making its systems reliable for operation over long periods. Once the investment has been made to place our spacecraft in orbit, energy costs thereafter are nil. As an example, the Lageos spacecraft recently orbited has an expected lifetime of 8,000,000 years -- although operations plans provide only for monitoring during the next 50.

So, with that catalog of space attributes, let's review how we've used them to date and how can we anticipate their further use in the future. To date, we've primarily confined our industrial use to the overview and "perpetual motion" attributes of space. The overview is of course essential to the communications, weather, navigation mapping and Earth resource uses while orbital mechanics and solar energy have allowed these satellites to operate for long periods without further expenditure of energy after the initial launch. As we proceed into the future, larger more sophisticated systems will evolve to utilize the overview function and will

also utilize zero gravity to allow use of large lightweight structures.

These uses can be expected in both LEO and GEO to exploit the full overview capabilities of future more sophisticated systems.

To date, use of weightlessness for materials processing has been only of a research nature, with limited experiments on Apollo, Skylab and ASTP. With the onset of the shuttle and Spacelab we can expect operational verification and limited pilot plant operations. Full-scale pilot plant commercial operations can be expected by the mid-1980's. Industrial opportunities appear almost unlimited and will be discussed in subsequent papers at this symposium. Certainly, commercial operations at levels of hundreds of millions of dollars per year can be anticipated over the next two decades. From what we know today, first commercial operations can be expected in selected electronics products and pharmaceuticals. However, realistically, the potential is probably greater in areas we have not even anticipated today.

The unlimited supply of energy from the sun will be an essential ingredient of large scale industrial operations in space. Potentially of greater importance for the near term is collection and relay of solar energy for use on Earth. This development will likely require a large scale model development/verification test in orbit before any commitment to full scale development. Such a test would be part of the substantial R&D investment necessary to bring this major facet of Space Industrialization into being.

The unlimited reservoir of space could find first large-scale application in safe long-term storage or disposition of nuclear waste material gen-

erated on the surface of the Earth. Such use will depend on a continuing consideration of all the alternatives and tradeoffs involved. Over the long term, this attribute plus the unlimited supply of pollution free solar energy could be the most important to large-scale industrial use of space.

A further opportunity for industrialization of space relates to tourism. Surely the time is not far distant when tourists will have the opportunity to experience the wonders of space through 6-day all expense excursions to orbit. Today, people willingly pay \$2,000 to fly supersonically round trip from France to South American and pay \$10,000 all expense cruise around the world. Within the next two decades it should be possible to take a commercial excursion to space for comparable rates and a whole new dimension to tourism will be born - no longer tied to the two dimension of the Earth's surface.

Taken collectively, the prospects for industrialization are almost staggering in the breadth and depth. I believe that most of the things we've talked about in a summary sense here today are inevitable - these things will happen. The questions are only when and whom will take the lead. I believe it is essential that we in the United States take the lead and insure that our country continues as the industrial leader of the world.

INTRODUCTORY REMARKS

The objective of this Symposium on "Space Industrialization" was to focus attention on such an endeavor which promises to become a reality beginning with the era of the Space Shuttle. Presented papers and visual aids have amply demonstrated the advanced state in which many of the potential measures are at this time. It was clearly shown that "Space Industrialization" can become a reality in the not-too-distant future.

Participation by the scientific and engineering community was excellent, as expected. A particularly pleasant surprise was rather strong participation from a sizeable number of persons without an aerospace background or occupation. National and international interest in space activities appears to be on the upgrade again.

Since one of the purposes of the Symposium was to disseminate to the scientific and technical community the latest information on the planning of expanded space operation, all presenters were asked to supply a brief summary of their presentation as well as a set of prints of their visual aids. Session chairmen provided, in a similar fashion, overviews or summaries.

All this material has been compiled and is being published in the form of these proceedings, which also contain the Welcome to the Symposium by the Director of the Marshall Space Flight Center, Dr. W. R. Lucas, and the Keynote Address by Mr. John Disher of NASA

Headquarters. In the interest of rapidly disseminating this data, no editing of material submitted by the speakers has been undertaken. Accordingly, it is suggested that any questions concerning the published material be directed to the speakers.

All those chairing and supporting the Symposium wish to express utmost gratification for the outstanding assistance that was provided by all those who were called upon to contribute to the preparations of the Symposium, its actual conduct, and this publication of the proceedings.

A limited number of copies are available over and beyond those distributed to the participants on a first-come, first-served basis from:

Hugh Dudley, PS03
Marshall Space Flight Center, AL 35812

Konrad K. Dannenberg
AIAA Co-Chairman

James A. Downey, III
General Chairman

A I A A / M S F C S Y M P O S I U M

o n

" S P A C E I N D U S T R I A L I Z A T I O N "

S e s s i o n o n

S P A C E H A B I T A T S

Session Chairman : William G. Huber, Marshall Space Flight Center

Co-Chairman : David C. Cramblit, Marshall Space Flight Center

Presenters and Papers :

William G. Huber	Introduction
George V. Butler	Evolution of Space Station Systems
Richard L. Kline	Space Station Habitability Issues
Shepard B. Brodie	Orbital Assembly
Ivan Bekey	New Space Initiatives
C. William Hamilton	Space Settlement Planning Methodology

Wednesday morning, May 26, 1976

SPACE HABITATS

Introductory Remarks

W. Huber - Chairman

D. C. Cramblit - Co-Chairman

As Dr. Lucas and Mr. Disher have indicated, the opportunities for industrializing space appear substantial at this point in time. As we define it, space industrialization is "the utilization of the extra-terrestrial environments to produce products or to provide services of value on Earth or for Earth." The products or services are relatable to a wide variety of national needs and mission opportunities, including such applications areas as conservation of energy and the development of new energy sources, improved Earth resources management, improved weather forecasting techniques, increased food production, advanced ocean navigation and national service/security systems, improved and lower cost materials, medicines, and vaccines, and advanced communications systems. To support our planning efforts in these areas, we will be releasing an RFP to industry on May 27 to address mission opportunities, needs, and concepts for a long range industrialization program.

Inherent in an overall Space Industrialization program must be (1) a mission or reasons for going, (2) a way to get there, (3) provisions for the on-orbit facilities and capabilities needed to support the mission, and (4) a plan to cost effectively define and accomplish the program. Transportation will be discussed as a separate topic this afternoon; tomorrow will be devoted to discussions of two specific reasons for going; energy and space processing. Our session this morning will address all aspects of the program with emphasis on the space habitats, facilities, and operations associated with man's ability to live and effectively work in space for long periods of time. Our first paper by Mr. Butler will review the conceptual design evolution of space stations or habitats that has occurred with time; Mr. Kline will address some of the unique environmental problems associated with long duration manned space habitats. Mr. Brodie will address large structures assembly, an essential operational support capability required of future space habitats, followed by Dr. Bekey who will describe a few of the more promising mission opportunities, and the resultant technological implications on future space systems and transportation needs. Finally, Mr. Hamilton will discuss an approach for methodically planning and organizing a long range space industrialization program.

We hope you will find these topics stimulating to your future assessments of space industrialization mission opportunities. Any suggestions or comments you may have for guiding our future planning efforts in this area will be welcomed. Let's now proceed with our first paper.

EVOLUTION OF SPACE STATION SYSTEMS

G.V. BUTLER

**PROGRAM MANAGER, SPACE STATION SYSTEMS
MCDONNELL DOUGLAS ASTRONAUTICS CO.**

PRESENTED TO

AIAA/MSFC SYMPOSIUM

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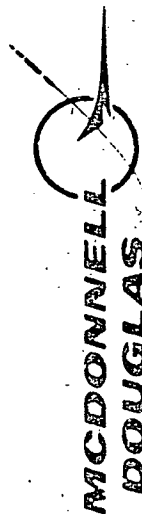
SPACE INDUSTRIALIZATION

MAY 26, 1976

MORRIS AUDITORIUM

GEORGE C. MARSHALL SPACE FLIGHT CENTER

ALABAMA



SPACE INDUSTRIALIZATION SYMPOSIUM

May 26 -- 27

Huntsville, Alabama

"Evolution of Space Station Systems"

• George V. Butler
Program Manager, Space Station Systems
McDonnell Douglas Astronautics Company

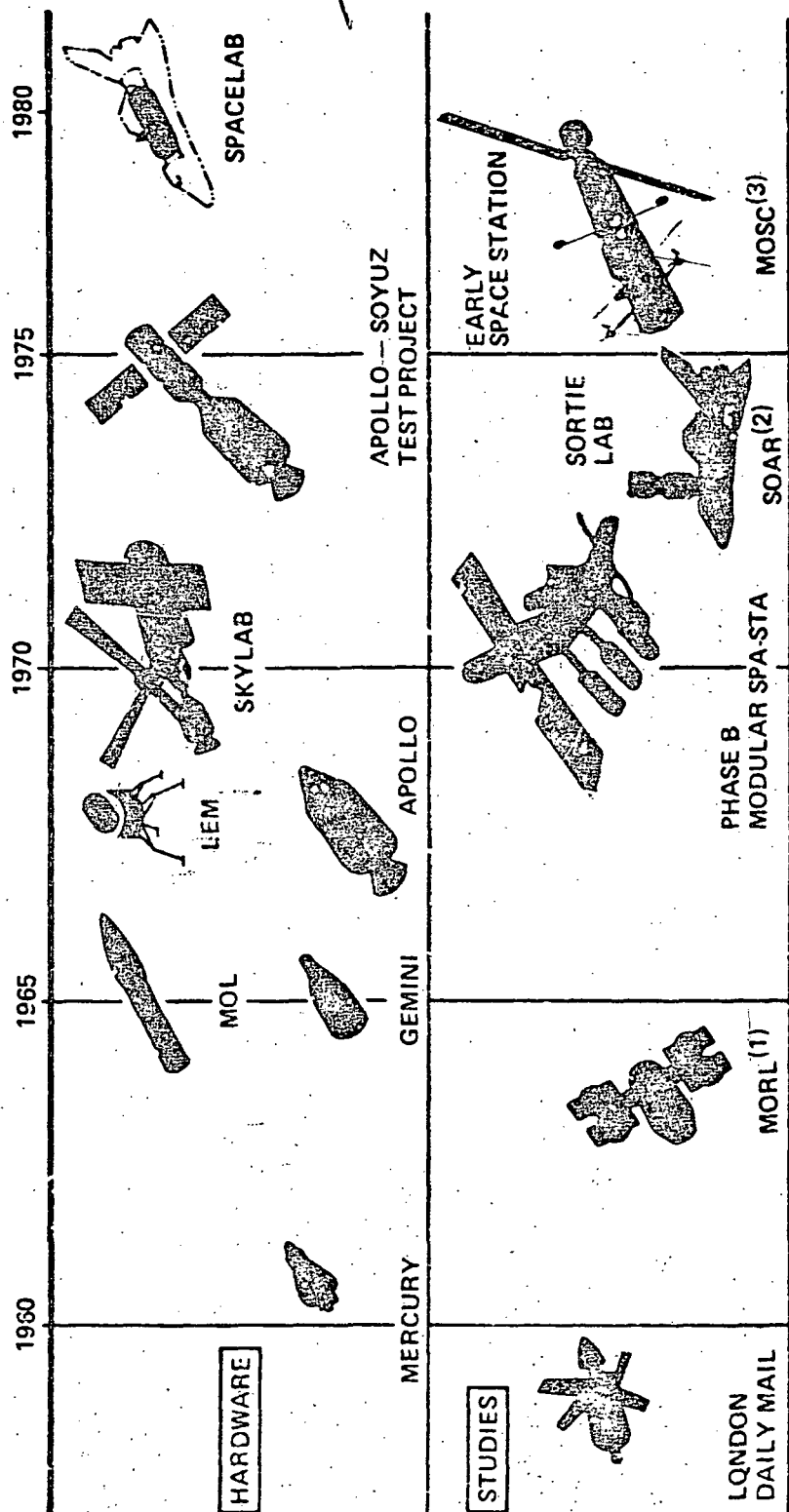
Abstract:

Our nation's rich legacy in manned space vehicle activities provides the technological base for programming mankind's next major space venture, the industrialization of space. The Space Station will be the principal support facility for industrialization activities. Space Station concepts have been studied since 1959, in support of a variety of mission objectives. In addition, design and development programs undertaken have resulted in a first generation space station, Skylab, and the genesis of a second generation in the Spacelab program.

This paper reviews briefly the evolution of space station concepts as reflected in previous studies and hardware programs and discusses how early space stations will support the development of operational bases necessary in the eventual industrialization of space.

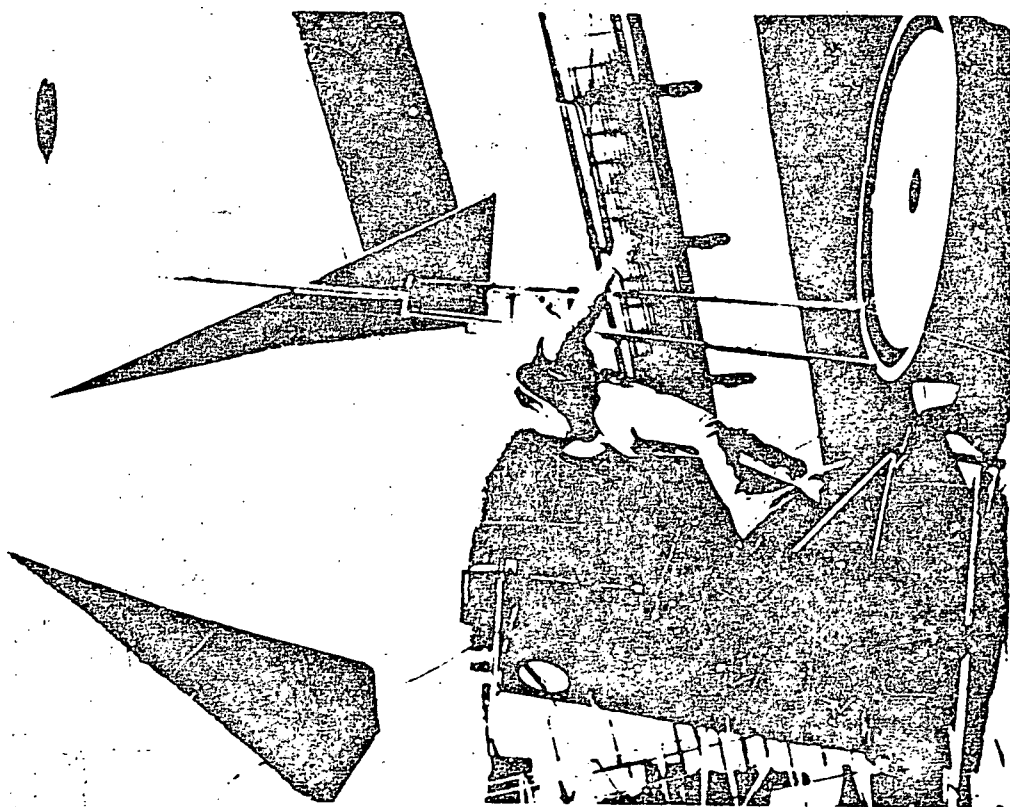
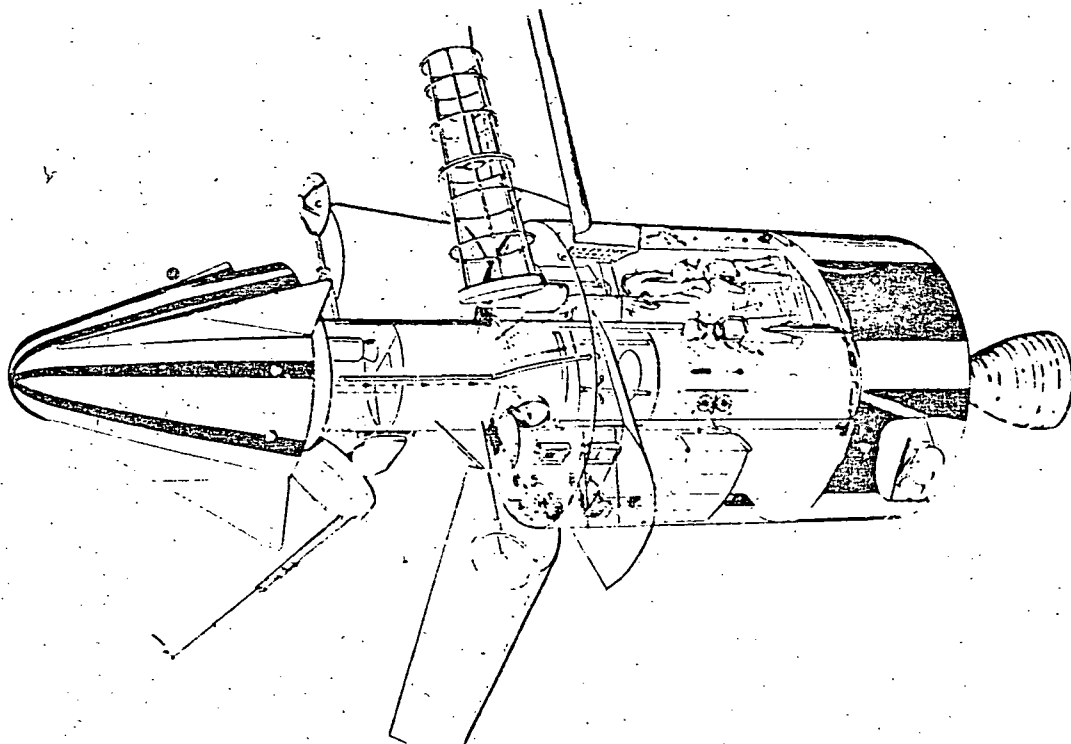
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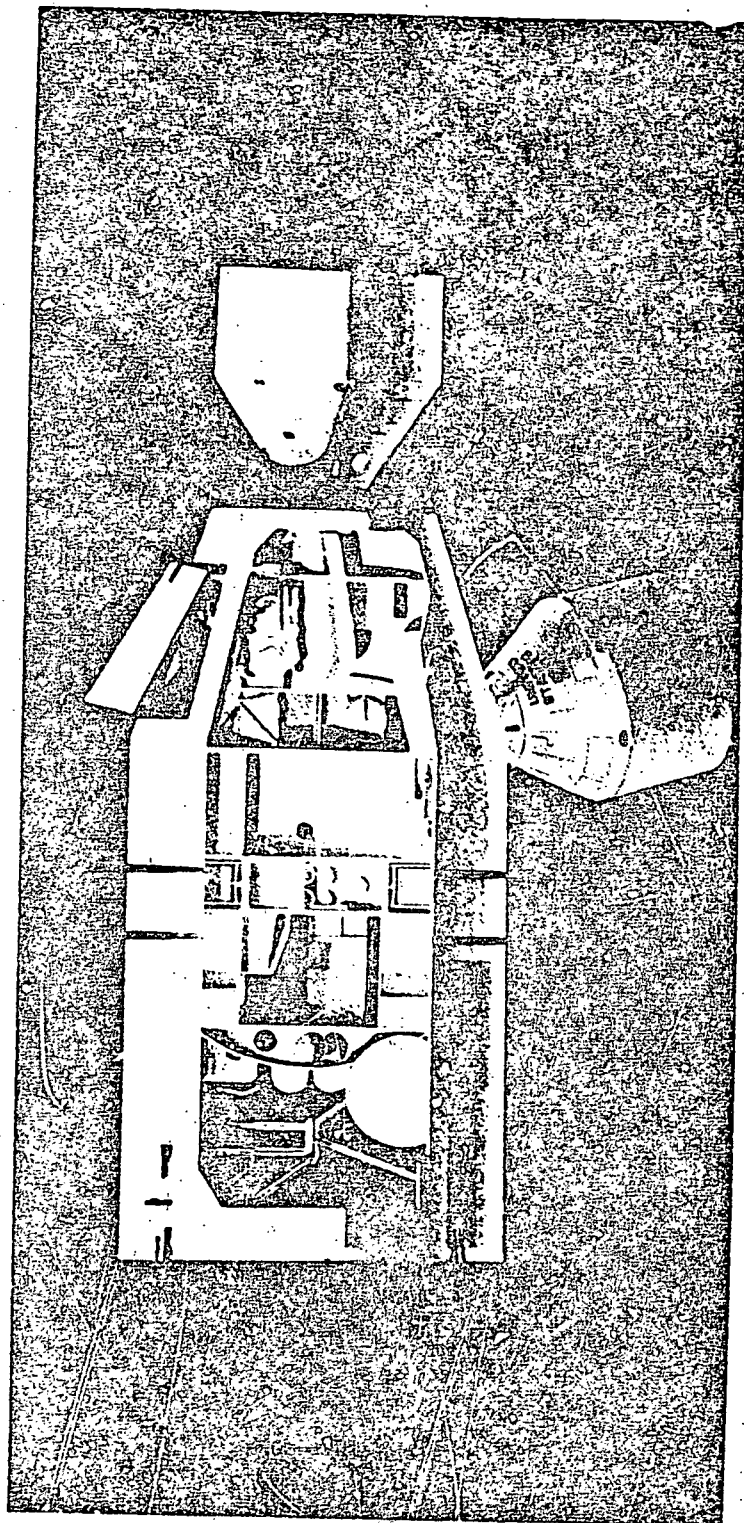
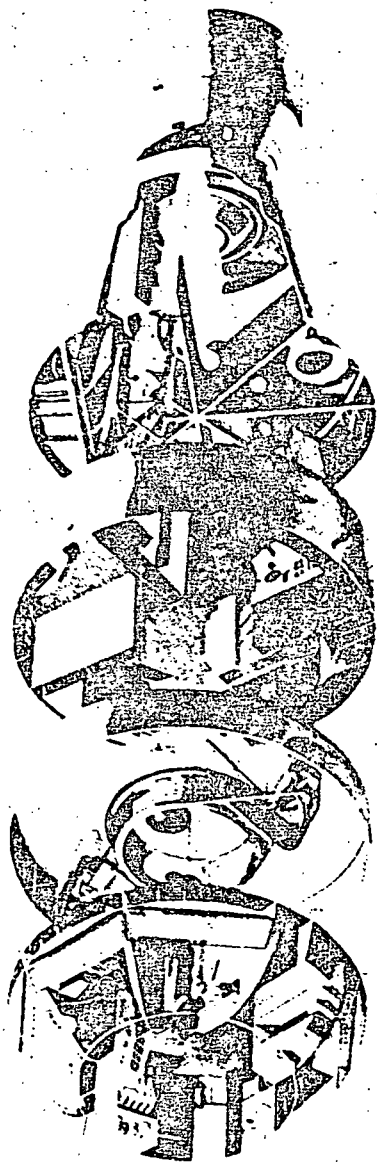
SPACE STATION SYSTEM EVOLUTION*



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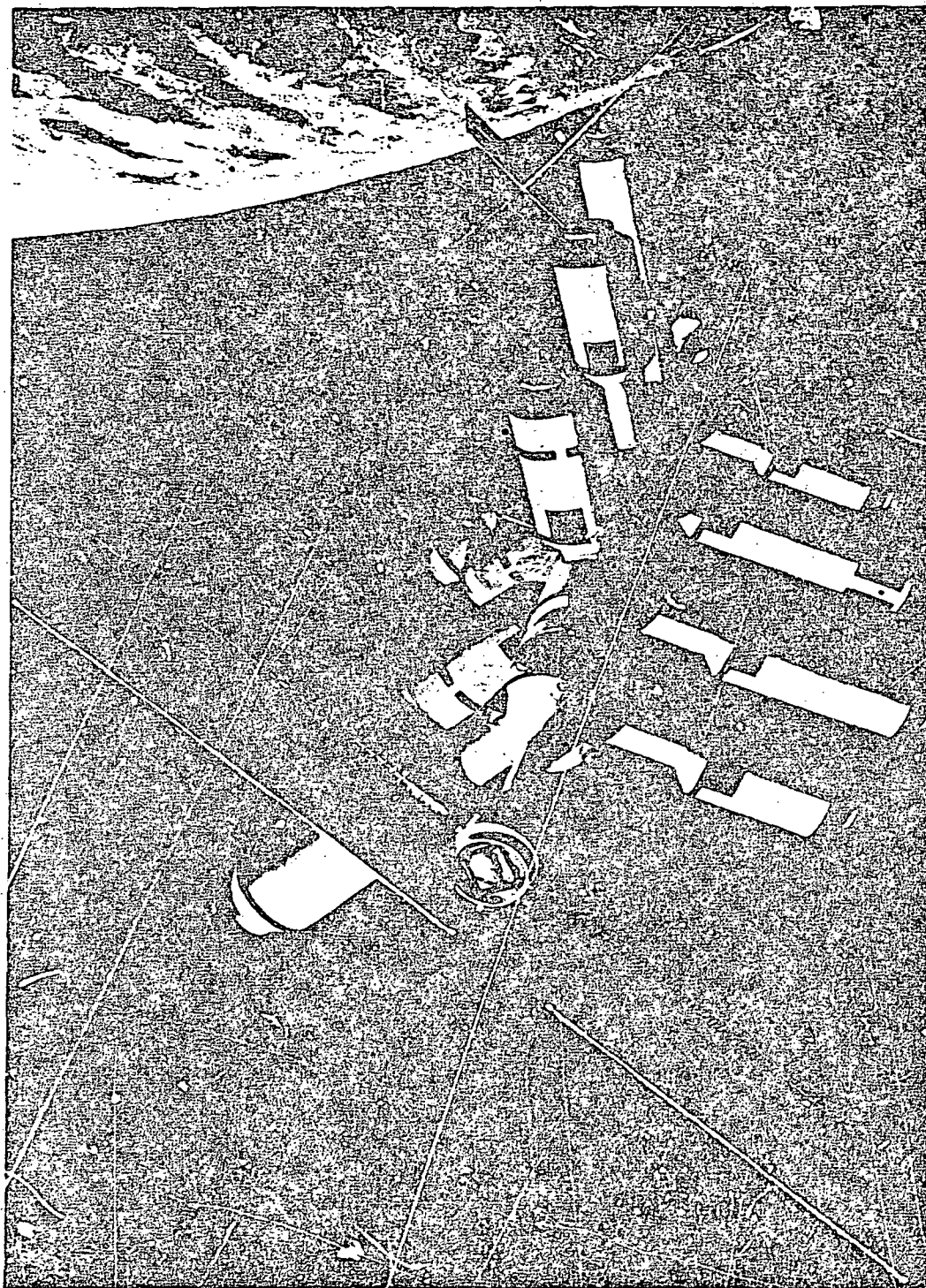
LONDON DAILY MAIL
ASTRONOMICAL SPACE OBSERVATORY





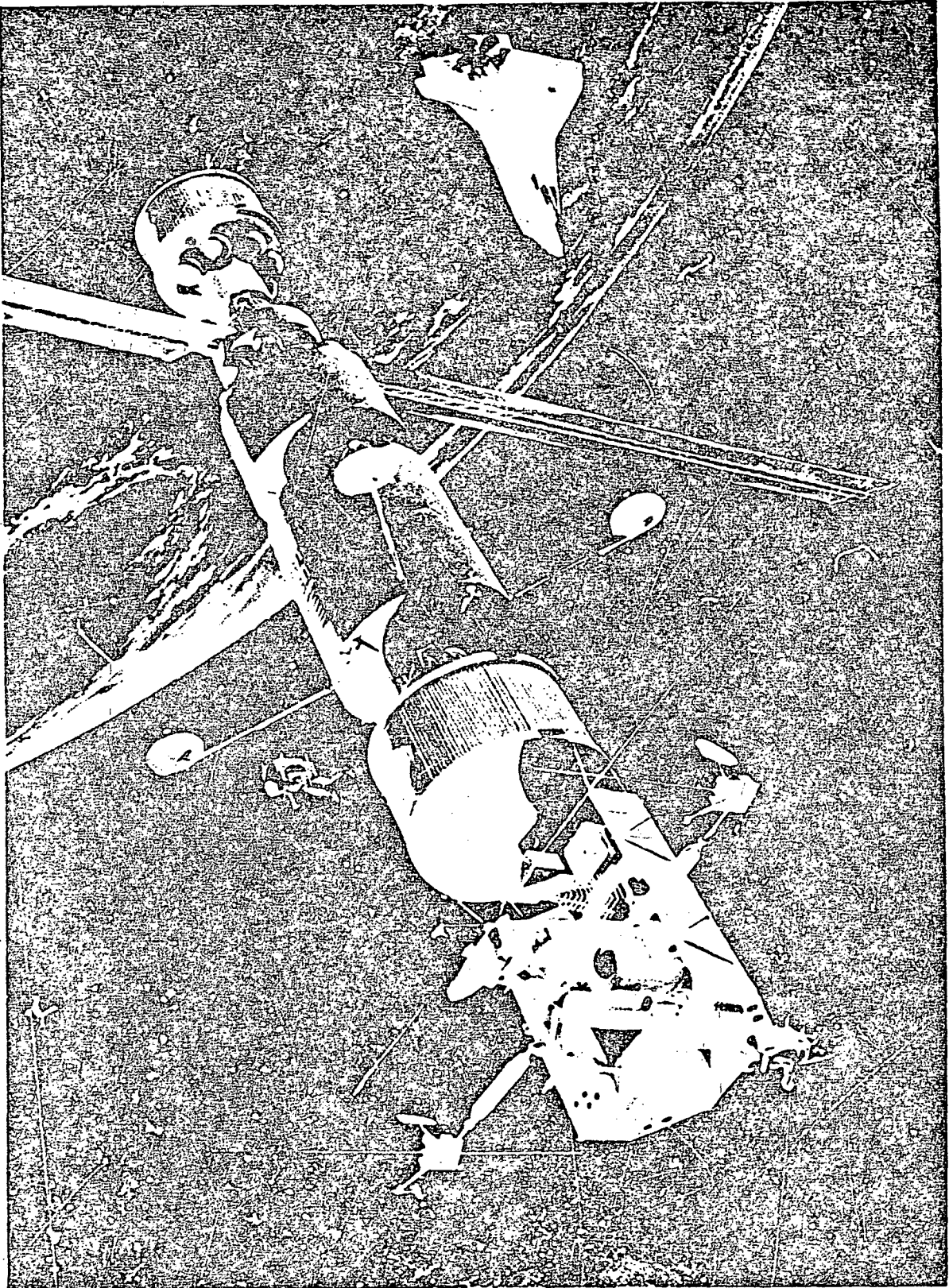
19747

PHASE B MODULAR SPACE STATION



19742

MANNED ORBITAL SYSTEMS CONCEPT



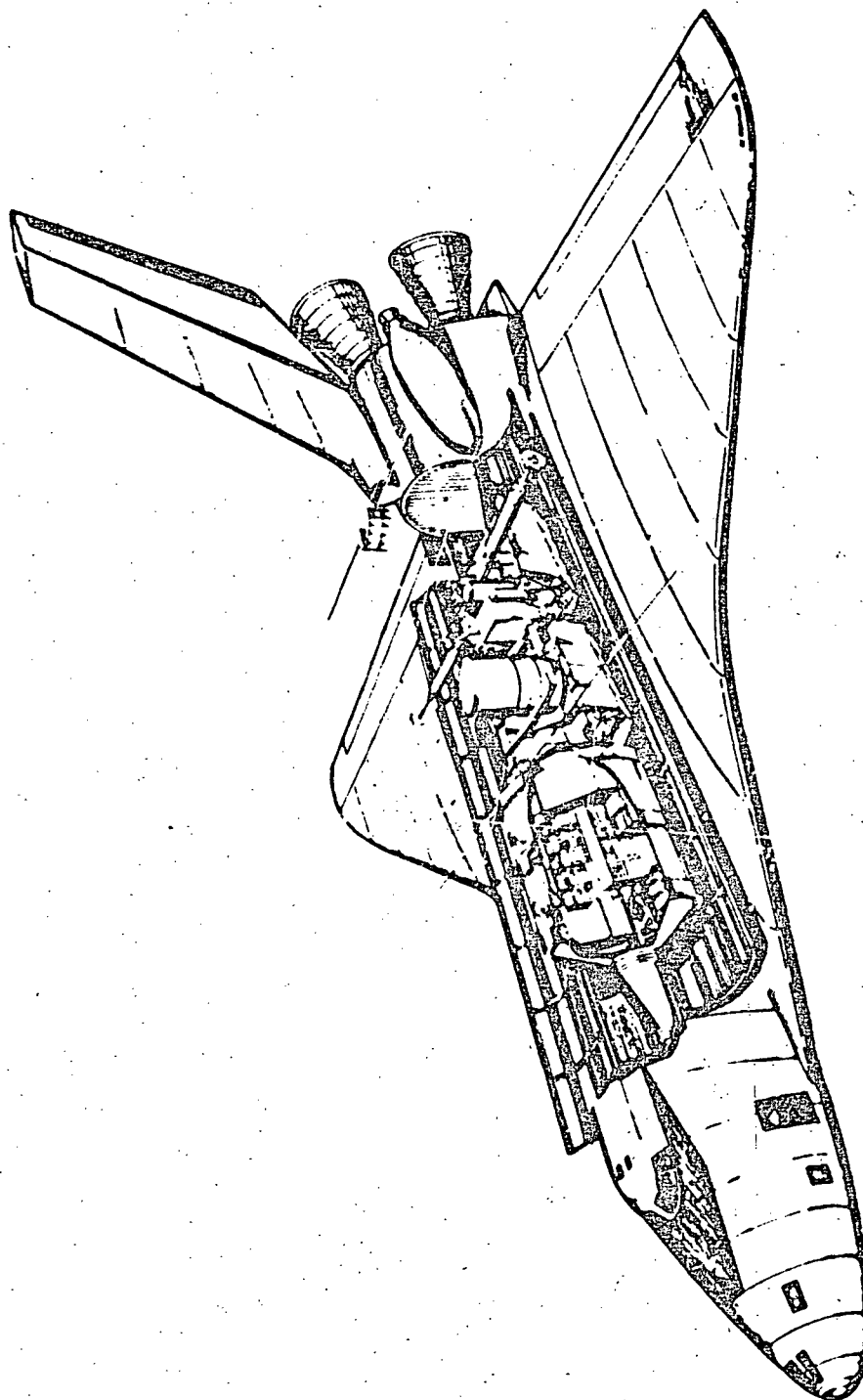
19748

SKYLAB



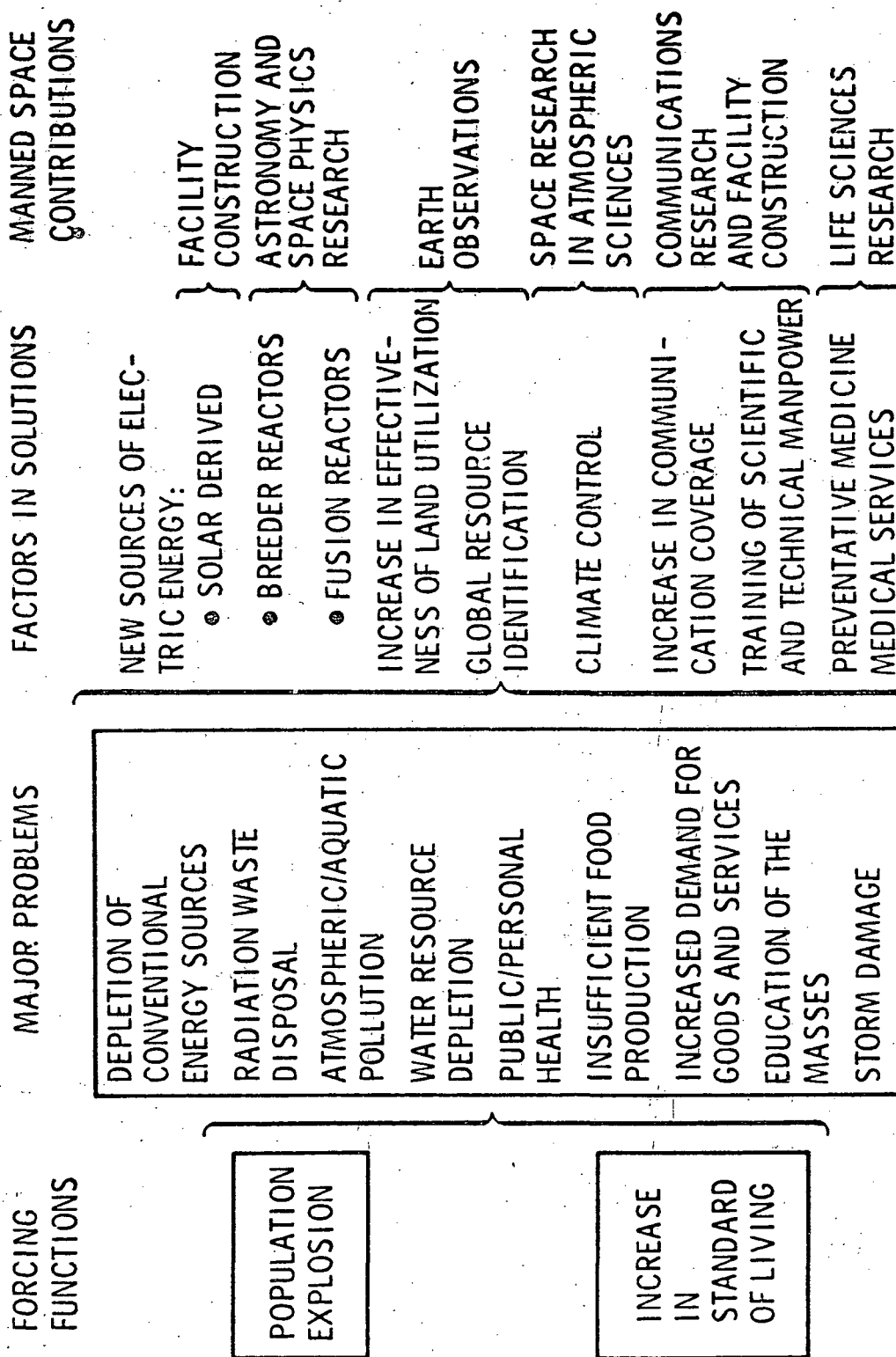
19749

SPACELAB



FUTURE NEEDS AND MANNED SPACE RESEARCH

19614



"OUTLOOK FOR SPACE-SP-386"

FUTURE SPACE OBJECTIVES - 1980 TO 2000

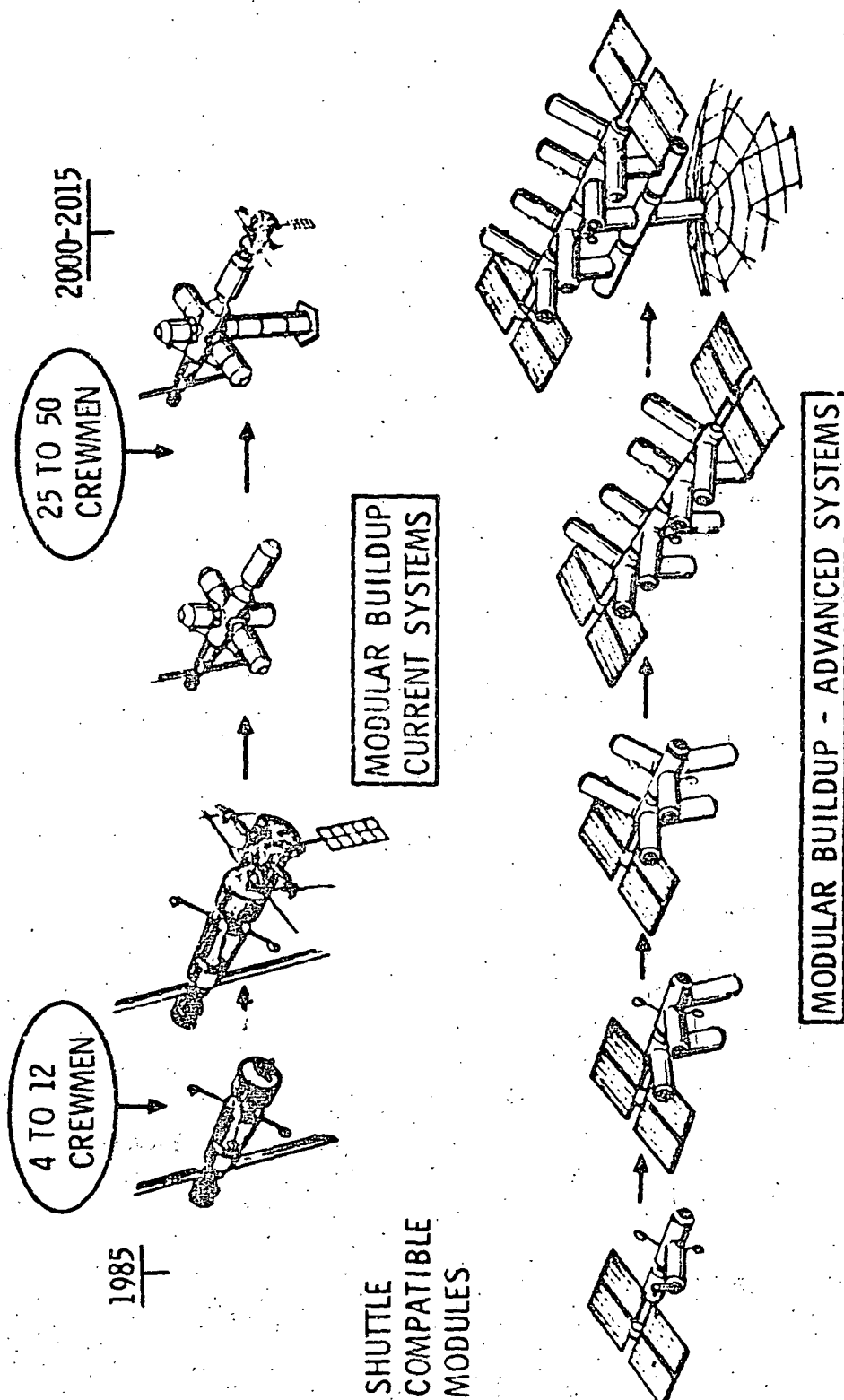
EARTH-ORIENTED ACTIVITIES RESPONSIVE TO BASIC HUMAN NEEDS

- PRODUCTION AND MANAGEMENT OF FOOD AND FORESTRY RESOURCES
- PREDICTION AND PROTECTION OF THE ENVIRONMENT
- PROTECTION OF LIFE AND PROPERTY
- ENERGY AND MINERAL EXPLORATION
- TRANSFER OF INFORMATION
- USE OF ENVIRONMENT OF SPACE FOR SCIENTIFIC AND COMMERCIAL PURPOSES
- EARTH SCIENCE

EXTRATERRESTRIAL ACTIVITIES RESPONSIVE TO INTELLECTUAL HUMAN NEEDS

- THE NATURE OF THE UNIVERSE
- THE ORIGINS AND FATE OF MATTER
- THE LIFE CYCLE OF THE SUN AND STARS
- EVOLUTION OF THE SOLAR SYSTEM
- ORIGINS AND FUTURE OF LIFE

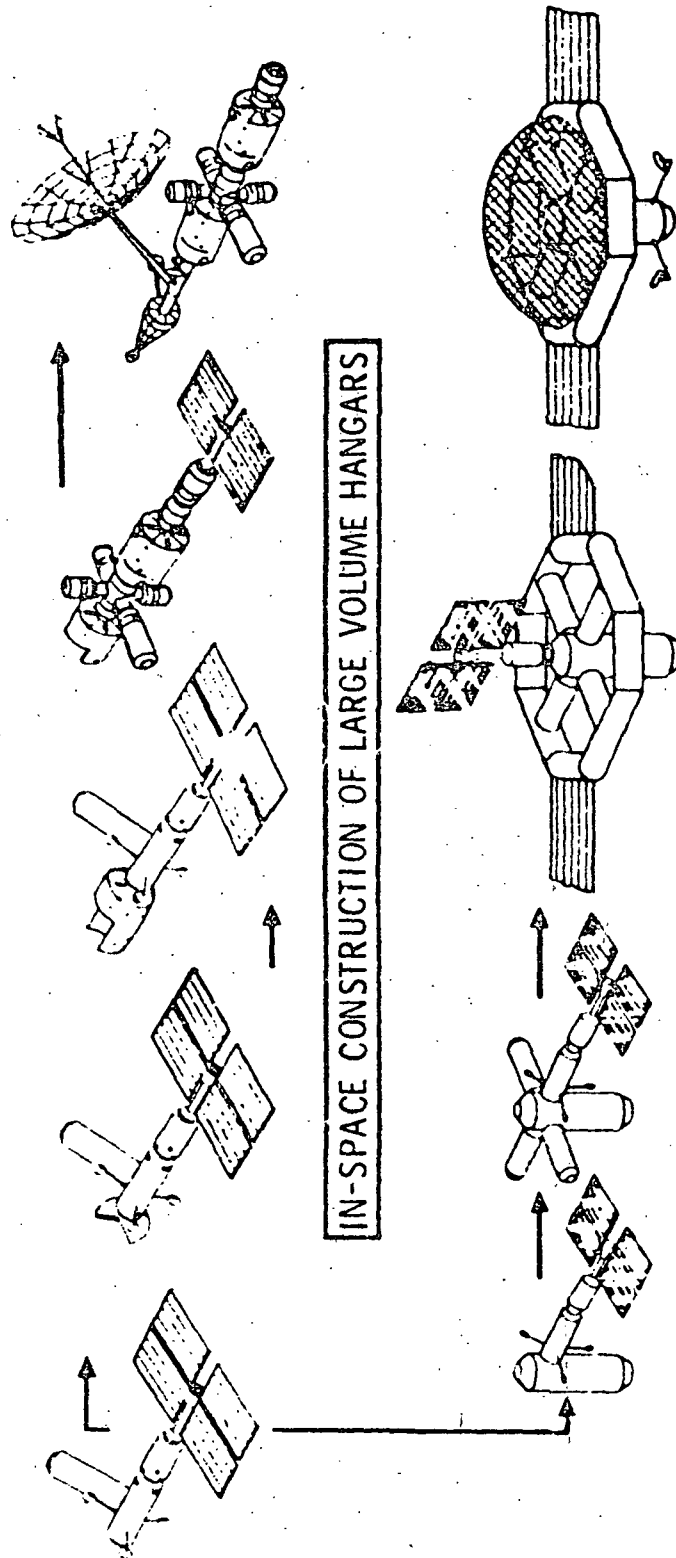
GROWTH ALTERNATIVES - I



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GROWTH ALTERNATIVES - II

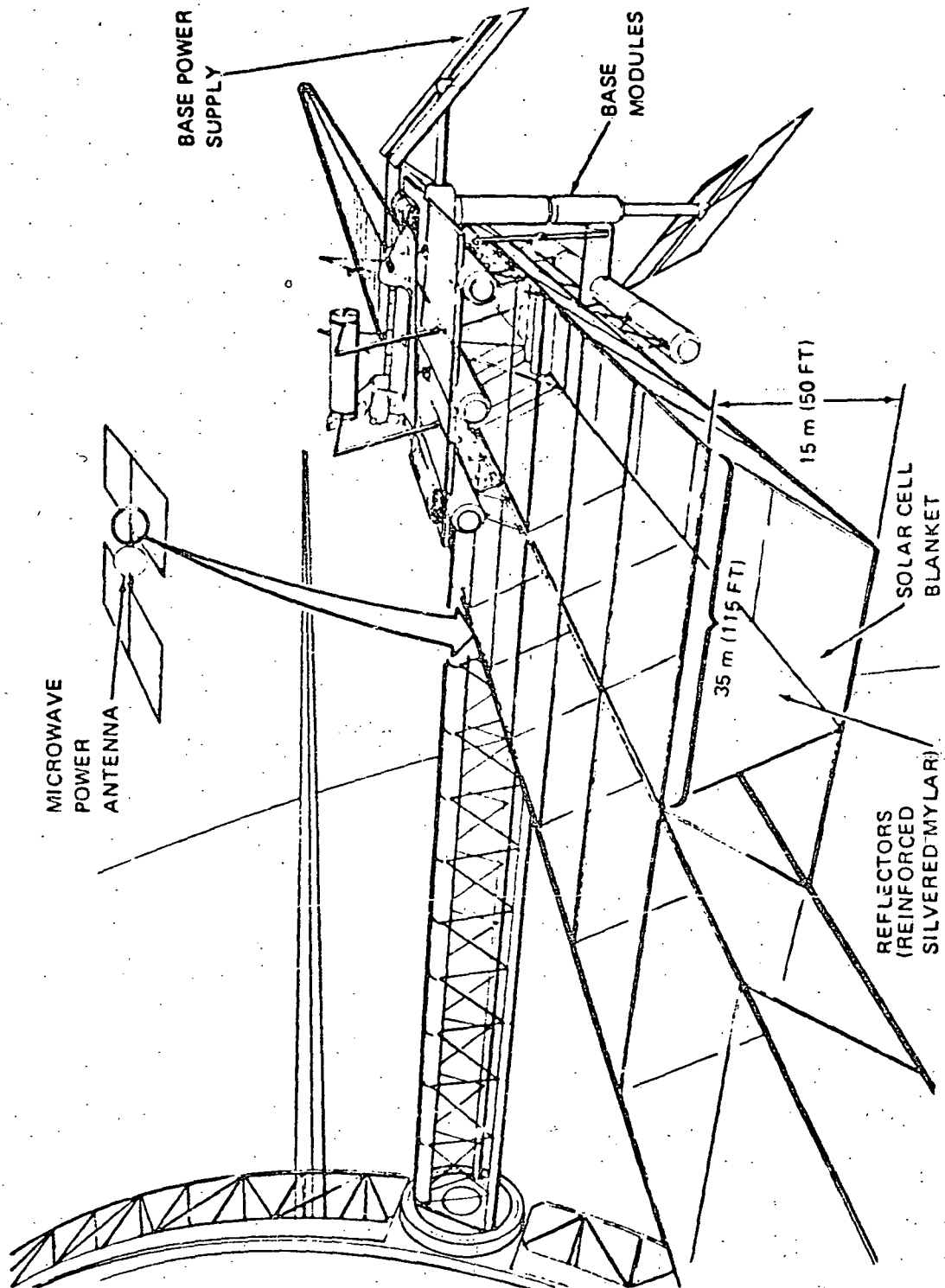
LARGE DIAMETER
ADVANCED ASSEMBLY CONCEPTS
SHUTTLE COMPATIBLE



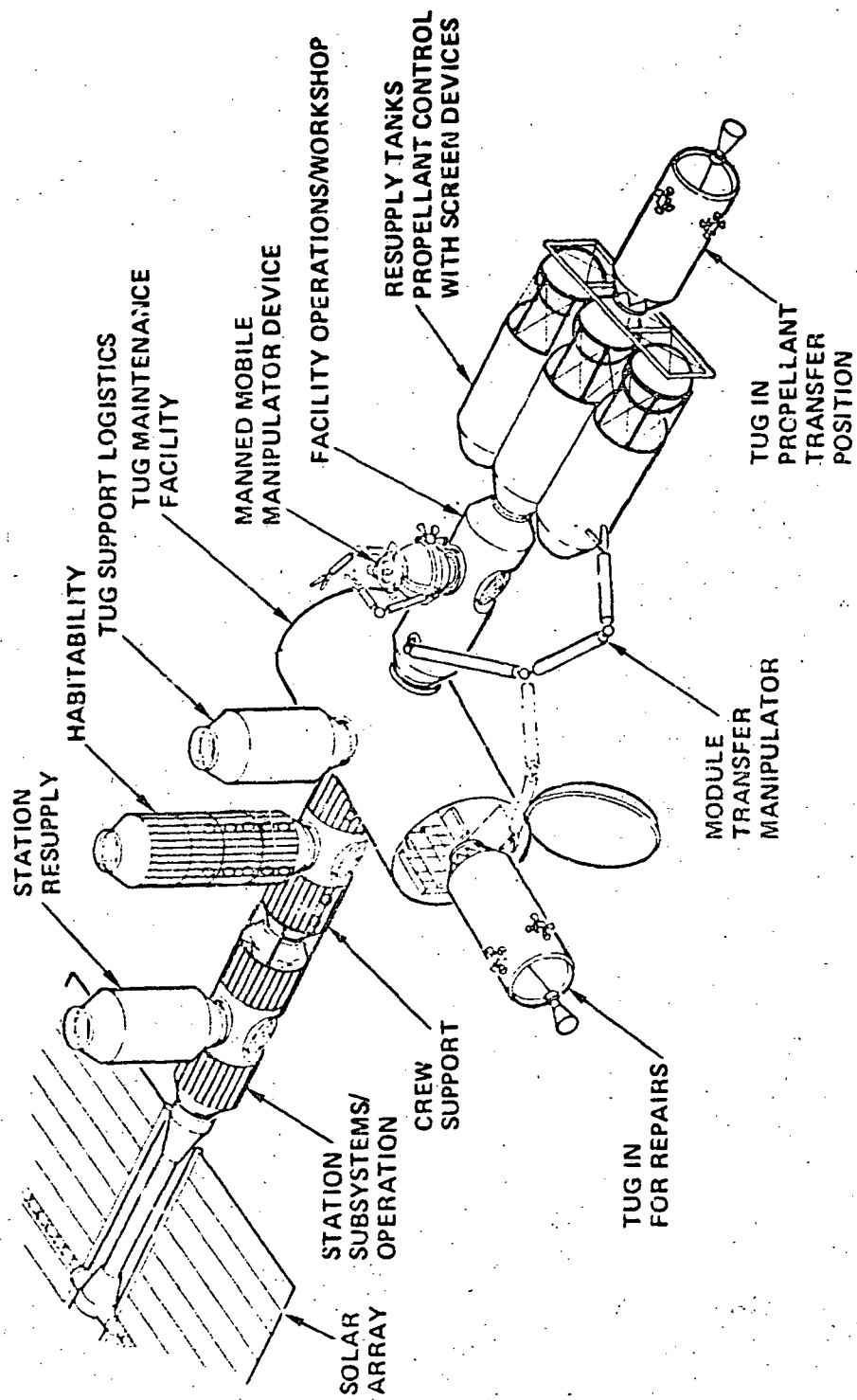
IN-SPACE CONSTRUCTION OF LARGE VOLUME HANGARS

ASSEMBLY OF INITIAL BASE FOR SPACE COLONY

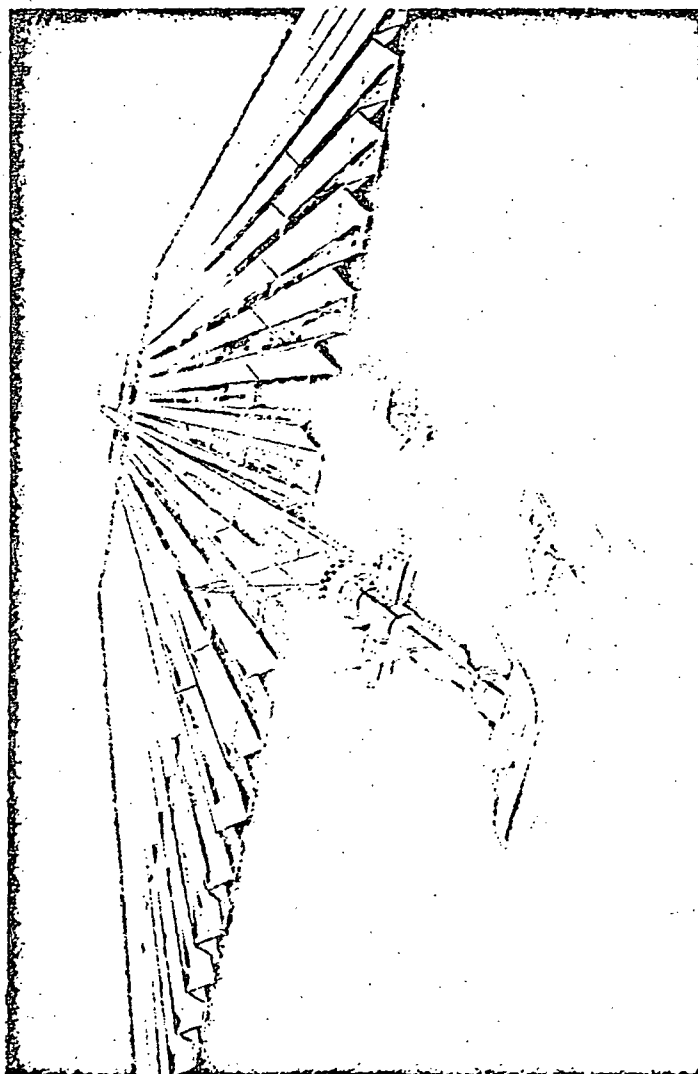
SPS CONSTRUCTION BASE CONCEPT USING AUTOMATED ASSEMBLY TECHNIQUES



ORBITAL DEPOT



AIAA/MSFC SYMPOSIUM ON SPACE INDUSTRIALIZATION



SPACE STATION HABITABILITY ISSUES

Richard L. Kline

26 & 27 MAY 1976

GRUMMAN

AIAA/MSFC SYMPOSIUM ON SPACE INDUSTRIALIZATION

May 26 & 27, 1976

Space Station Habitability Issues

By

Richard L. Kline, Grumman Aerospace Corporation

Space Station will capitalize upon the on-orbit opportunities for Space Industrialization. The advantages of limitless vacuum, near zero gravity environment and commanding location for earth observation and communications offer a wide potential for new manned initiatives.

To make this practicable we must consider the radiation environment in both low earth orbit and geosynchronous orbit to prepare and plan for manned participation in an efficient and routine fashion.

While Skylab has provided considerable experience regarding habitability of low-earth orbits, no comparable experience exists on prolonged residency in geosynchronous orbit such as is planned for the Space Station. This paper outlines the habitational and operational requirements and restrictions imposed by the geosynchronous radiation environment. The primary components of this environment comprise trapped radiation, galactic cosmic rays, and solar radiation. The average daily doses from these components behind 4 lb/ft² of aluminum shielding are compared in

Figure 1 with corresponding values encountered in low earth orbit (at 200 nm). The much higher dose rates in geosynchronous orbit are due to the higher intensity electron and associated bremsstrahlung environment and the effective absence of geomagnetic shielding against solar flare particles and cosmic rays. On the other hand the geosynchronous altitudes are essentially free of trapped protons with energies above 5.0 MeV.

Assumptions about maximum permissible exposure levels for man can be guided by the operational planning limits used for the 56-day Skylab mission: 250 rem skin dose and 25 rem to bloodforming organs. However, in extrapolating these limits to mission dose limits for geosynchronous orbit operations, Figure 2, allowance should be made for the qualitatively different composition of the synchronous radiation environment.

The assessment of total mission dose for geosynchronous orbit operations must include the contribution from passage through the intense radiation belts at intermediate altitudes as shown in Figure 2. For a high-thrust, 5.3-hr, Hohman transfer to synchronous altitude the total transit dose (from trapped protons, deuterons, and bremsstrahlung) is modest, provided that shielding equivalent to at least 1.5 g/cm^2 aluminum is provided. On the other hand a 170-day transfer using ion engine

thrusters, as envisioned for ferrying large structures assembled in low earth orbit, is clearly unacceptable for carrying personnel.

As earlier implied, an important aspect of Space Station design relates to provisions for solar flare protection. Unless adequate advance warning techniques can be developed (with acceptable false alarm rates) to permit deorbiting of personnel to geomagnetically shielded altitudes, the concept of a "storm shelter" must be used. The tissue dose from the proton component of an anomalously large solar flare, approximating the intensity of the August 1972 flare, received behind a range of aluminum shield thicknesses is calculated, Figure 4. The dose calculation includes the contribution from secondary nucleons. The dose component due to the alpha particle flux in the solar flare is not included; its contribution for shield thicknesses exceeding 30 g/cm^2 is less than 20 percent of the total proton rem dose. About 40 g/cm^2 of aluminum shielding is required, Figure 4, to reduce the proton dose from such a large event to 25 rems. (At such shielding depths the ratio of skin dose to blood-forming organ dose from solar flares declines to nearly unity, Figure 6. The shielding requirement, therefore, is dominated by the dose limit for the blood-forming organs.) This shield thickness is used to assess the total shield mass for a solar flare shelter, as a function of the number of occupants, Figure 7. Twenty seven thousand pounds of shielding is required for a crew of 10 at $50 \text{ ft}^3/\text{occupant}$. Some of this shielding mass can be

supplied by structure, fuel, and appropriately positioned components of the life support system.

For extravehicular activities in geosynchronous orbit the radiation components of concern are the trapped electrons and associated bremsstrahlung. The average daily rem dose from these radiations is shown as a function of aluminum shield thickness, Figure 8. Since for shield thicknesses greater than typically 250 mils the dose is primarily from bremsstrahlung, a dramatic dose reduction can be achieved by filtering the bremsstrahlung through a small thickness of tantalum or other high atomic number material. Also, as shown in Figure 7 the trapped electron intensity varies cyclically with local time; during 10 out of 24 hours the dose is less than 70 percent of the daily average value. By comparison, restrictions on EVA's in low earth orbits derive mainly from the energetic trapped proton environment in the South Atlantic Anomaly, Figure 10. With a 30-degree inclination orbit the anomaly is traversed in only 30 percent of the orbits, so that there are daily periods of about 16 hours during which EVA's can be routine.

I would particularly like to acknowledge and thank Michael Stauder for his contribution to the preparation of this paper.

RADIATION ENVIRONMENT FOR SPACE STATION -- DOSE RATES (REM/DAY) BEHIND 300 MILS OF ALUM

ALT, N MI	LEO				GEO °
	200		235		
ORB INCL, DEG	30	90	50 (SKYLAB)	0	
TRAPPED E ⁻	3.5 x 10 ⁻³	0.01	} 0.3	-	
BREMSSTRAHLUNG	10 ⁻⁴	2.5 x 10 ⁻³		2.12	
TRAPPED PROTONS	0.25	0.17		-	
SOLAR FLARE P	0	0.15	0.01	0.60	
GALACTIC COSMIC RAYS	4 x 10 ⁻⁴	0.006	0.001	0.05	
TOTALS (REM/DAY)	0.25	0.34	0.31	2.77	

NASA PLANNING DOSE FOR 56-DAY SKYLAB MISSION:

- 250 REM TO SKIN
- 25 REM TO BLOOD FORMING ORGANS

Figure 1



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AVERAGE BIOLOGICAL RAD DOSES IN GEOSYNCH ORBITS (TRAPPED ELECTRONS AND BREMSSTRAHLUNG)

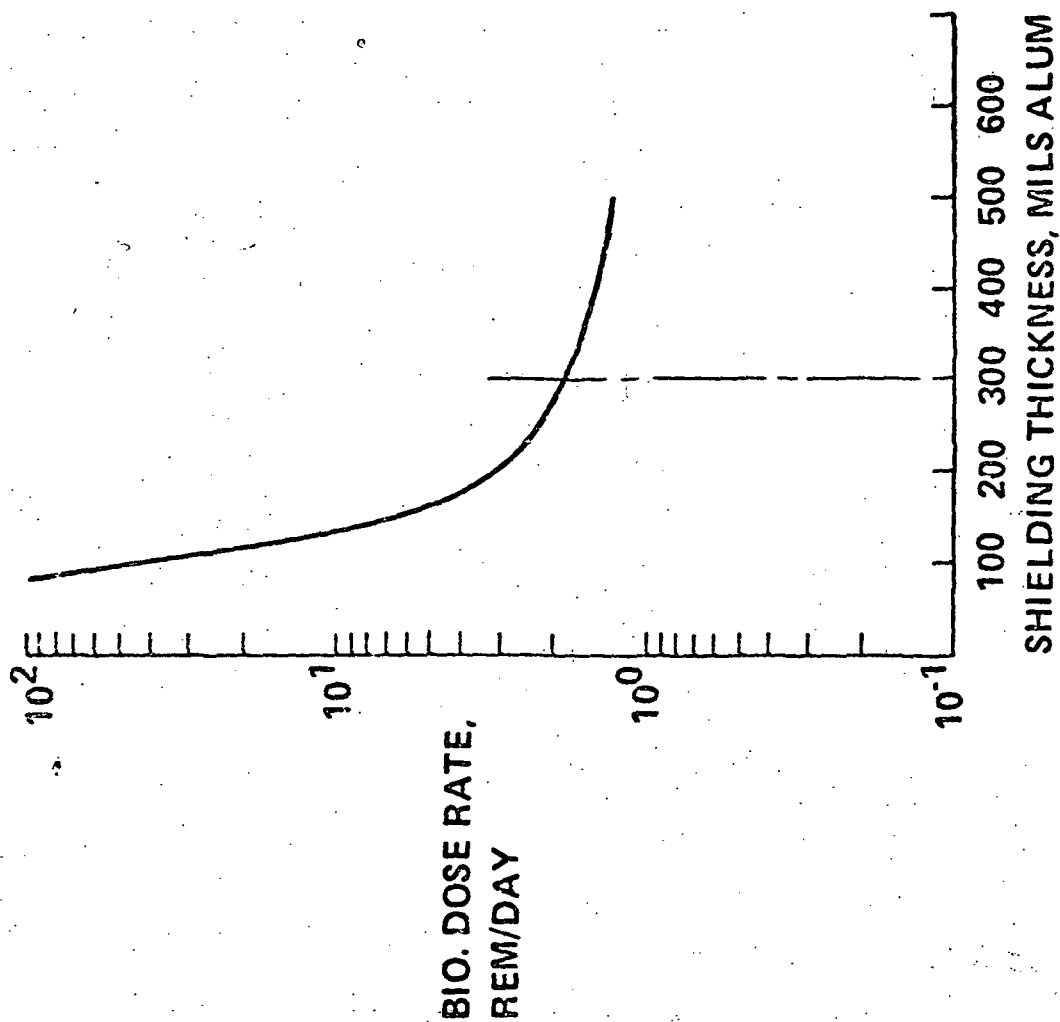


Figure 2

TRANSIT REM DOSE (LEO TO GEO)

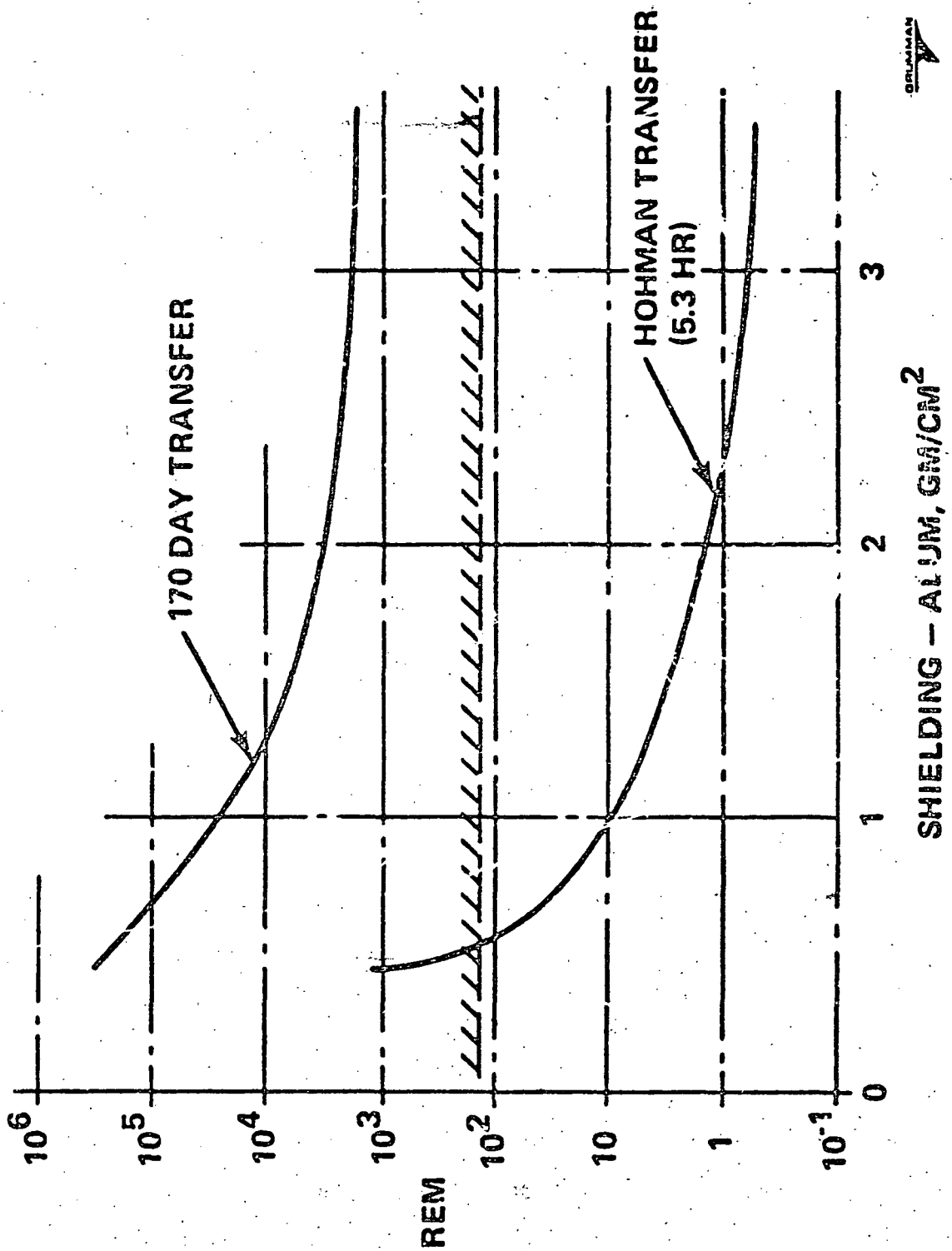


Figure 5

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EQUIVALENT FLARE (AUG. '72)

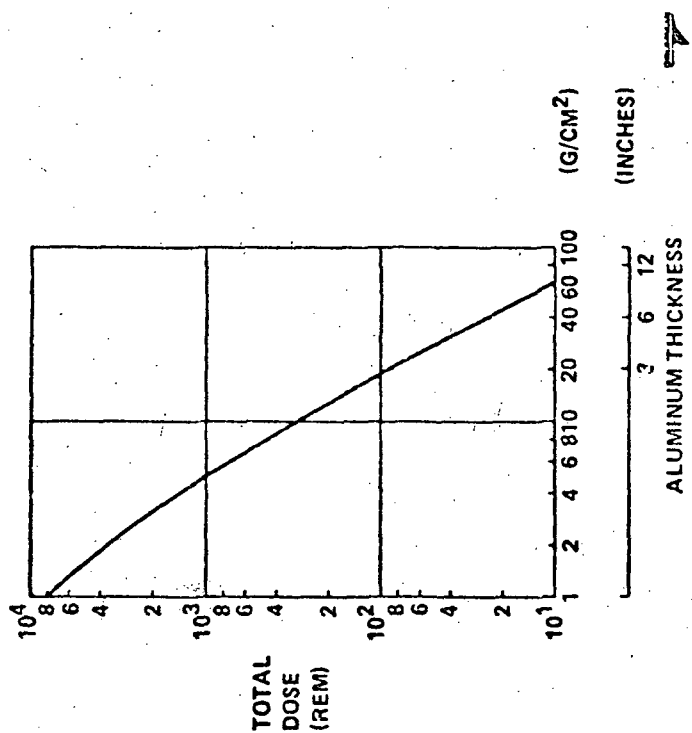


Figure 4

EQUIVALENT FLARE (AUG. '72)

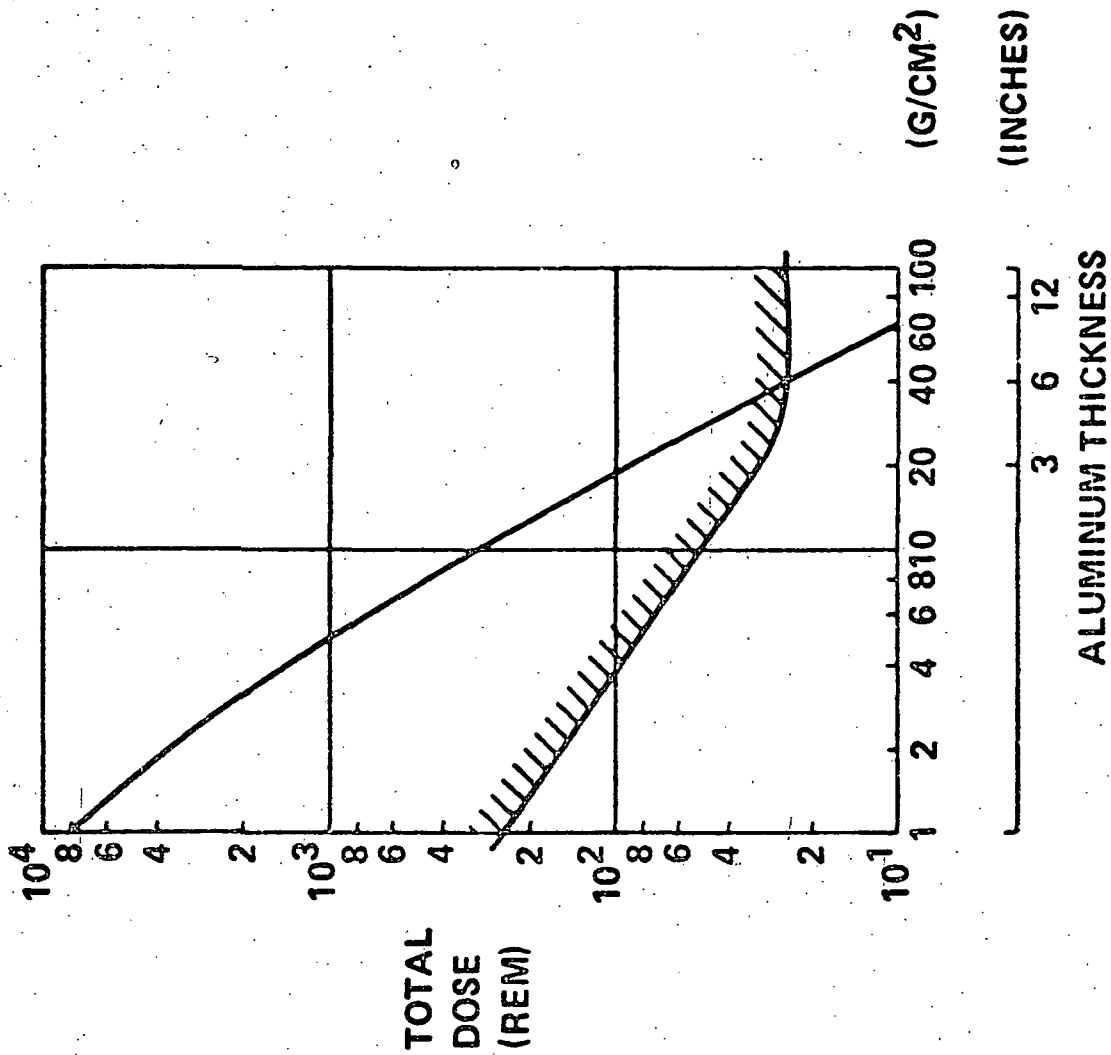
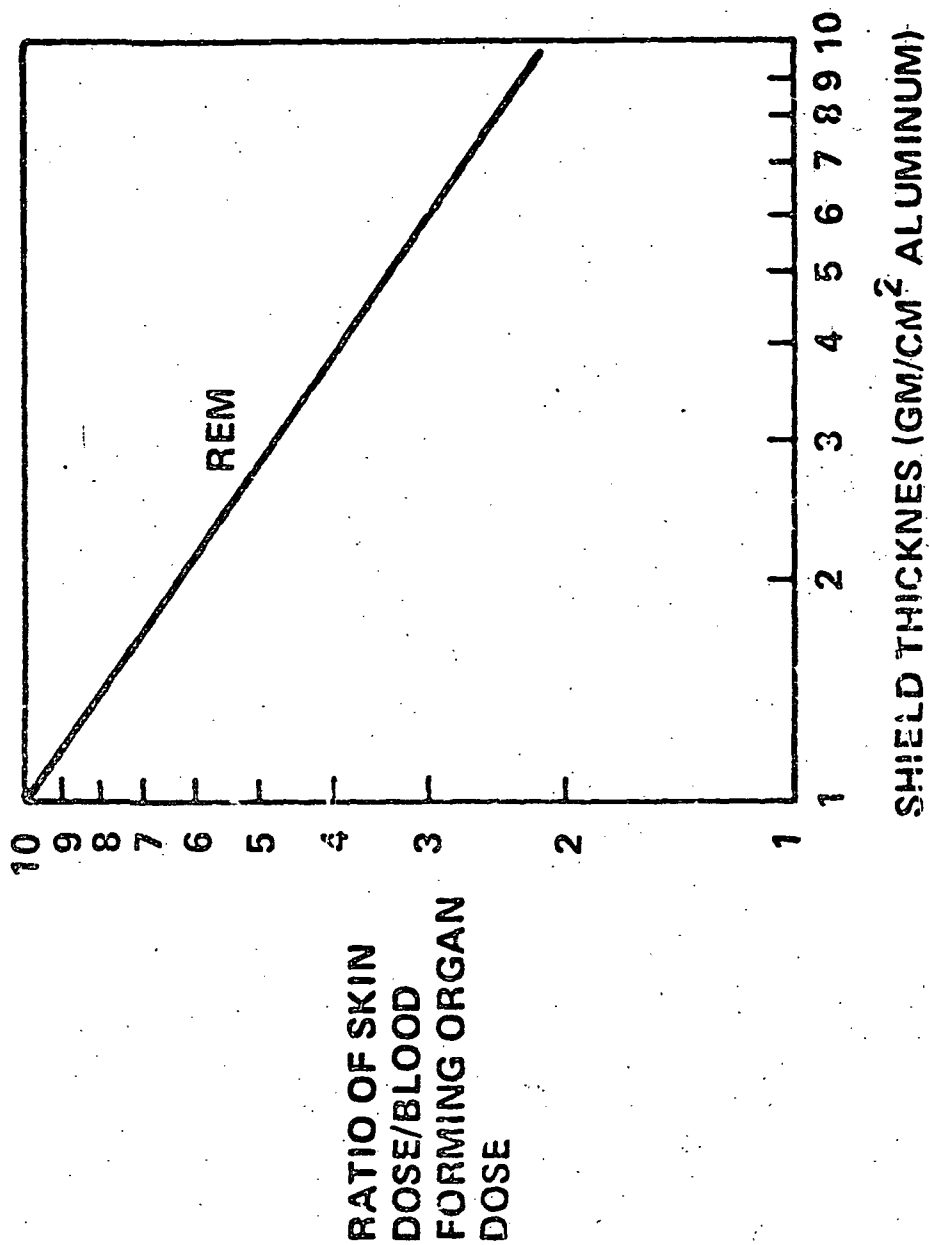


Figure 5



RATIO OF SKIN-TO-BLOOD-FORMING-ORGAN DOSE SOLAR FLARE PROTONS



From J.W. Haffner, *Radiation and Shielding in Space*,
Academic Press, N.Y. 1967

Figure 6



SOLAR FLARE STORM SHELTER - ALUM SHIELD MASS VS OCCUPANCY

- SHIELD THICKNESS = 80 LB/FT²
- PROTECTS AGAINST ANOMALOUSLY LARGE EVENTS

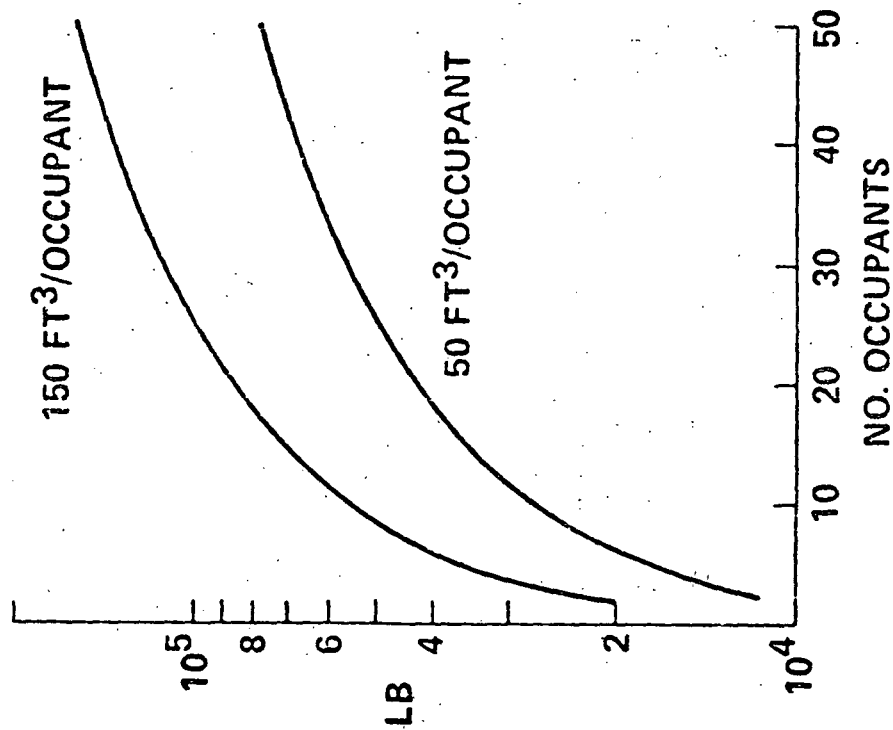


Figure 7

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AVERAGE BIOLOGICAL RAD DOSES IN GEOSYNCH ORBITS (TRAPPED ELECTRONS AND BREMSSTRAHLUNG)

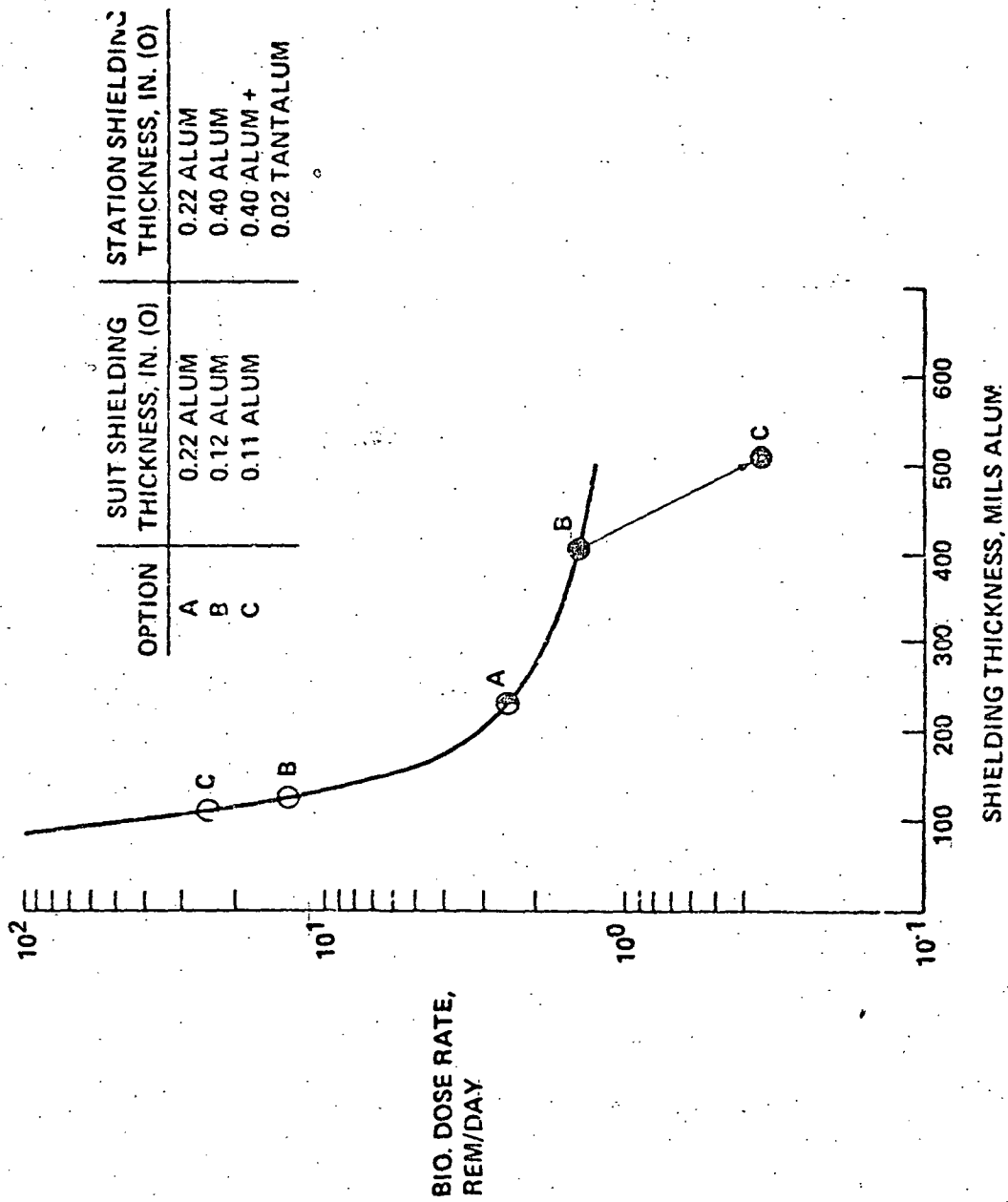


Figure 8

TIME VARIATION OF TRAPPED ELECTRON & BREMSSTRAHLUNG DOSE RATE IN GEOSYNCH ORBIT

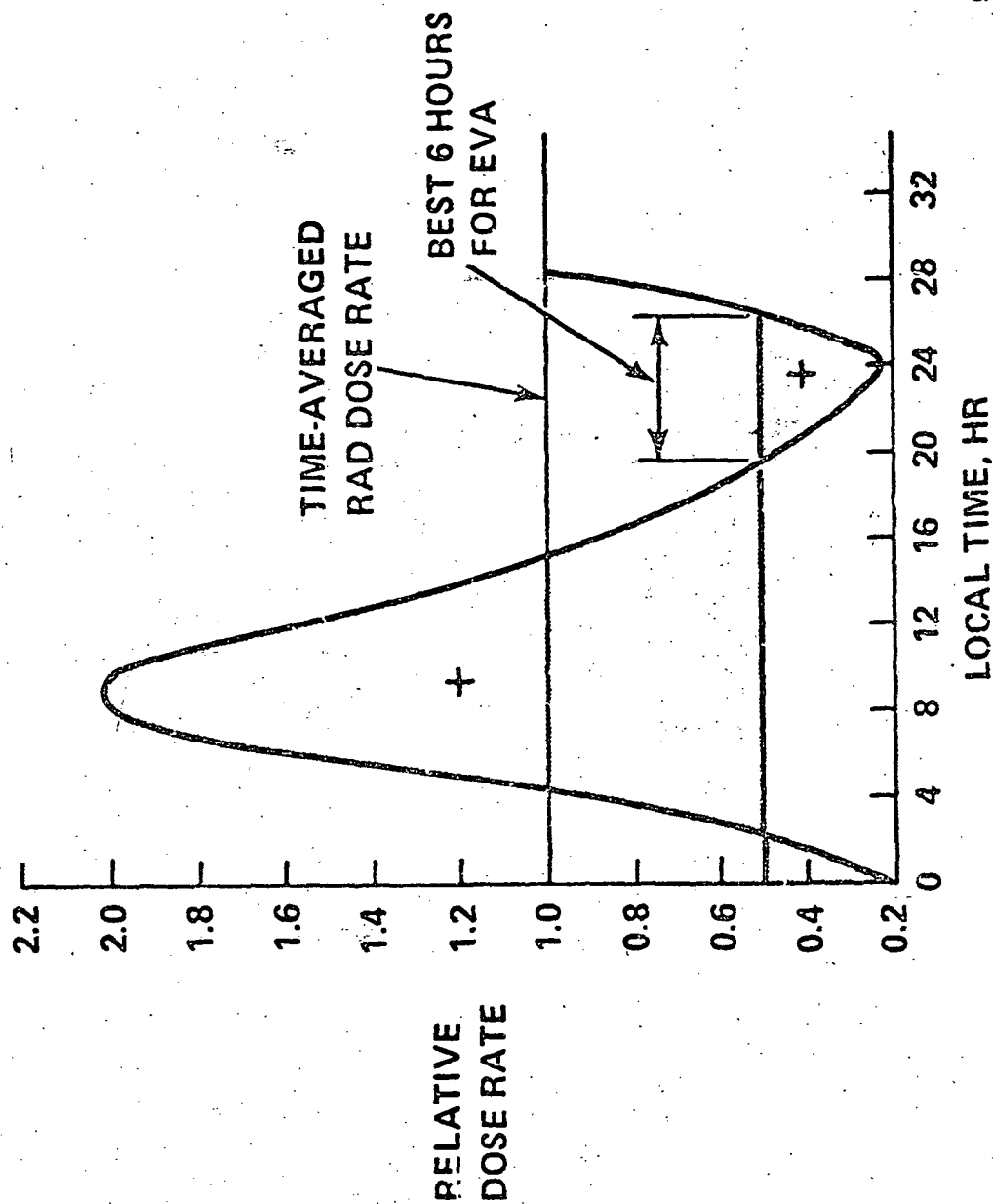


Figure 9

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SOUTH ATLANTIC ANOMALY

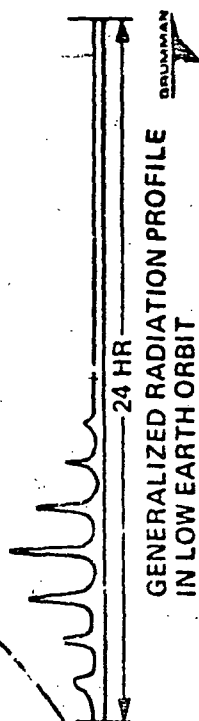
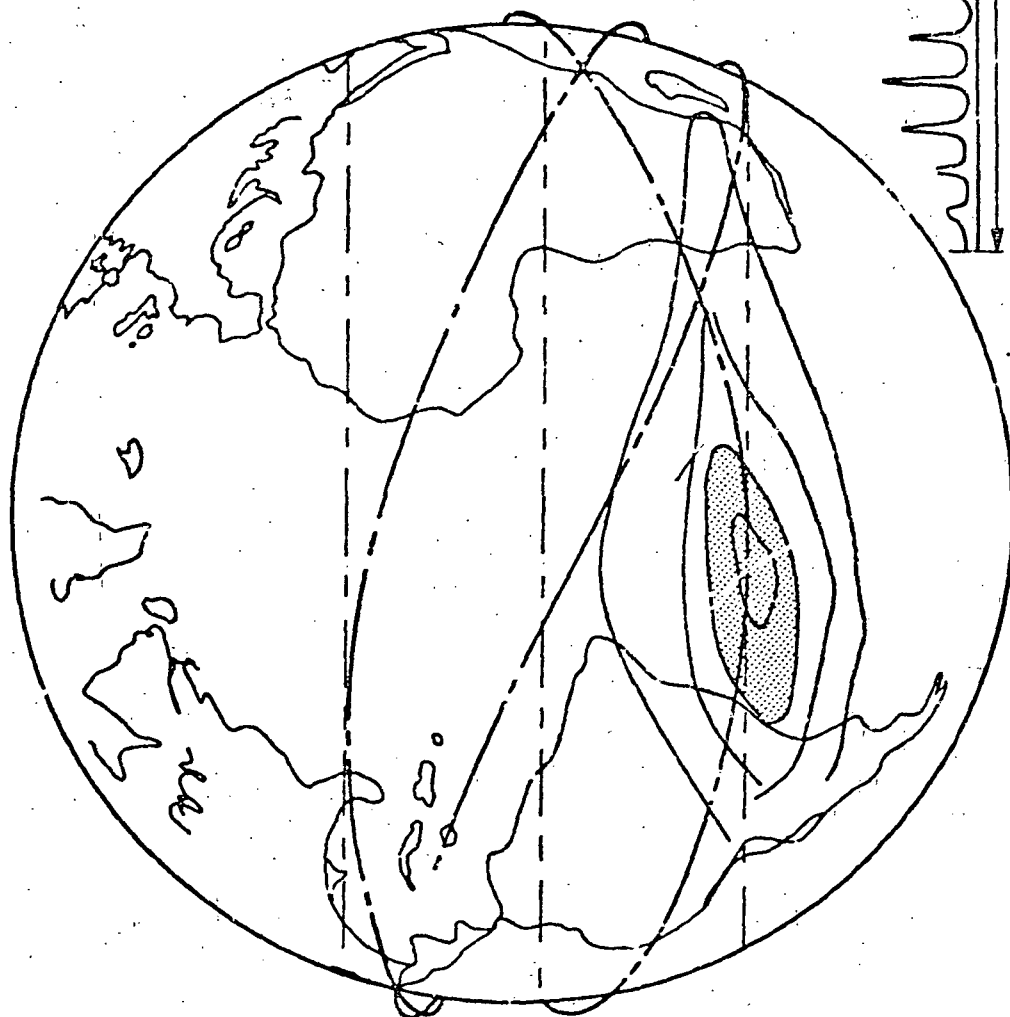


Figure 10

CONCLUSIONS & RECOMMENDATIONS

- LEO
 - LOW LEVEL RADIATION
 - CONSIDERABLE EVA PRACTICABLE
 - SOUTH ATLANTIC ANOMALY-NUISANCE FACTOR
- ORBIT TRANSFER
 - MAKE IT FAST IN SHIELDED ENVIRONMENT
 - AVOID MANNED CONSTRUCTION ACTIVITY ON LONG-TIME DURATION CARGO TRIPS
- GEO
 - RE-EXAMINE BIOLOGICAL DOSE LIMITATIONS
 - RADIATION LEVEL MANAGEABLE FOR SPACE STATION DESIGN
 - NEED STORM SHELTER, OR RETREAT TO GEOMAGNETICALLY SHIELDED ALTITUDES, TO AVOID SOLAR FLARES
 - EVA OPERATIONS
 - MAKE NON-ROUTINE
 - EMPHASIZE CAPSULE MOBILITY AIDS

GRUMMAN AEROSPACE CORPORATION

BETHPAGE, NEW YORK 11714



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ORBITAL ASSEMBLY

Shepard B. Brodie
Martin Marietta Corporation
Denver Division
Denver, Colorado 80201

This abstract describes work* done at Martin Marietta Corporation on the methods and techniques for orbital assembly of large structures. An example used in the study was a 1000-meter diameter microwave power transmission system (MPTS) antenna. The MPTS is a part of a solar power station satellite that will be used to convert orbital solar energy into ground electrical energy. The techniques developed for assembling the support structure for this microwave antenna will be discussed here.

The MPTS is a flat antenna that is to be operated in geosynchronous orbit. A baseline design was developed by Raytheon and Grumman for NASA**. We have modified the baseline design to make the structure more readily transportable by the Shuttle and more feasible to assemble in space.

Our design is made up of 2,520 60-ft cubes. Figure 1 shows the support structure. A standard 60-ft cube is shown in Figure 2. This cube is composed of triangular horizontal beams and square vertical beams. This structure is self-supporting and there is no limit to the number of cubes that can be added to it in either direction. Adjustment points are built into each joint to allow continuous alignment as the structure is built.

We have investigated several techniques for attaching the structural mating joints. We have concluded that a permanent bond is required. Our present concept utilizes welding for joining the beam member pads. Small, electrically activated charges are imbedded in each attachment pad. After final alignment, these are activated and metal is fused between the pads at predetermined spots. Pyrotechnic devices are used to drive locking pins into the sliding tubes which serve as tension members.

The antenna is assembled in two phases. Phase 1 is done in low earth orbit with the use of the Shuttle Remote Manipulator System (RMS). Phase 2 is done in geosynchronous orbit using a mobile assembler.

During Phase 1 a core assembly is constructed. Two Shuttle flights are required to bring a telescoping central section, sufficient beams to construct a core section and several attaching cubes, and two mobile assemblers. Figure 3 shows the Shuttle RMS completing the assembly of the core section. After this core section is completed, the mobile assemblers begin building adjoining cubes. Figure 4 shows the core section and one completed adjoining cube. Two mobile assemblers are shown in the figure.

* Orbital Assembly and Maintenance Study, NAS9-14319.

** Contract NAS3-17835.

These assemblers work in conjunction with beam pallets which store collapsed beams. Both the assembler and the beam pallets have similar mobile bases, which are supported at each end by four legs. These legs have end-effectors which grasp the intersection of the vertical and horizontal beams for maximum strength. To maneuver the base, the support legs on one end are retracted and the base is pivoted about the opposite end. A 90 degree pivot brings the end of the base over the opposite corner of the structure. Its legs are then re-attached to the structure. The assembler has a six-degree-of-freedom manipulator with a 60-ft reach and 30-lb tip force. Electrical power is furnished from solar cells located on the manipulator or base. The manipulator extracts beams from the beam pallet and places them on the structure. The beam pallets are on mobile bases which are used to follow the assembler around during assembly. Figure 5 shows the mobile assembler and beam pallet. Figures 6 and 7 show two steps in the assembly procedure.

Phase 2 takes place in geosynchronous orbit after the central core and several adjoining cubes are boosted to the high earth orbit. There the remainder of the assembly takes place with the mobile assemblers being operated remotely from the ground using TV.

A method has been developed for folding the triangle beams and the square beams in such a way that one Shuttle cargo bay can hold 92 square beams, 192 triangular beams, and 288 (telescoped) tension tubes. Total weight of a Shuttle load with beam pallet is 37,870 lbs.

- 2520 60 -ft Cubes
- Weight - 2,033,420 Lbs

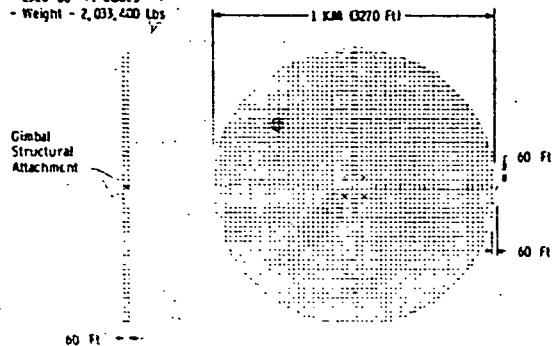


Fig. 1 Total Microwave Antenna Support Structure

Install Beam Packages on Holders
Complete 60 ft. sq. Core Assembly With Assemblers

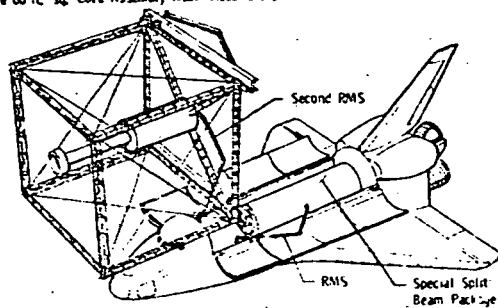


Fig. 3 Assembly of Core Section

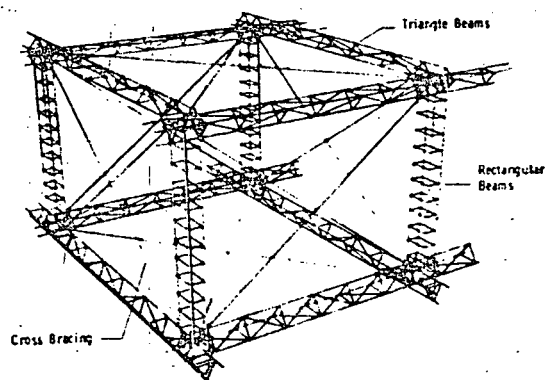


Fig. 2 Typical 60-ft Cube

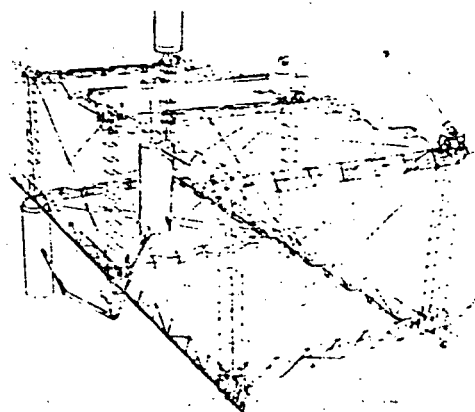


Fig. 4 Building Cube Adjoining Core Section

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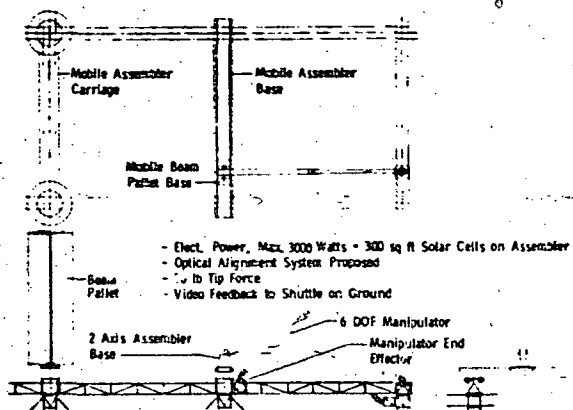


Fig. 5 Mobile Assembler and Beam Holder Concept

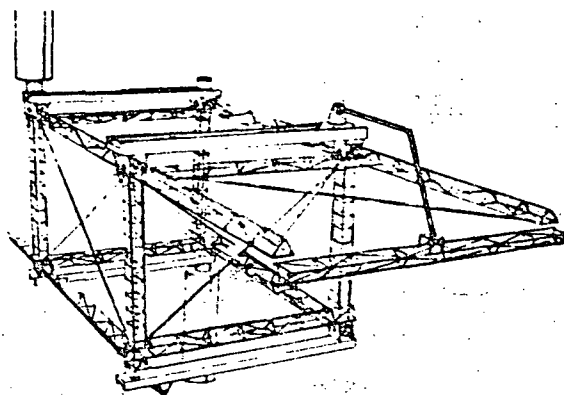


Fig. 7 Cube Assembly Sequence, Step 2

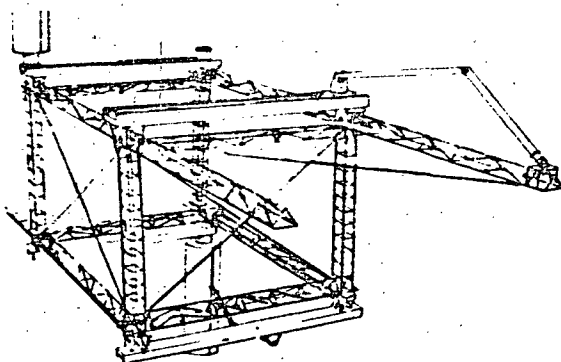
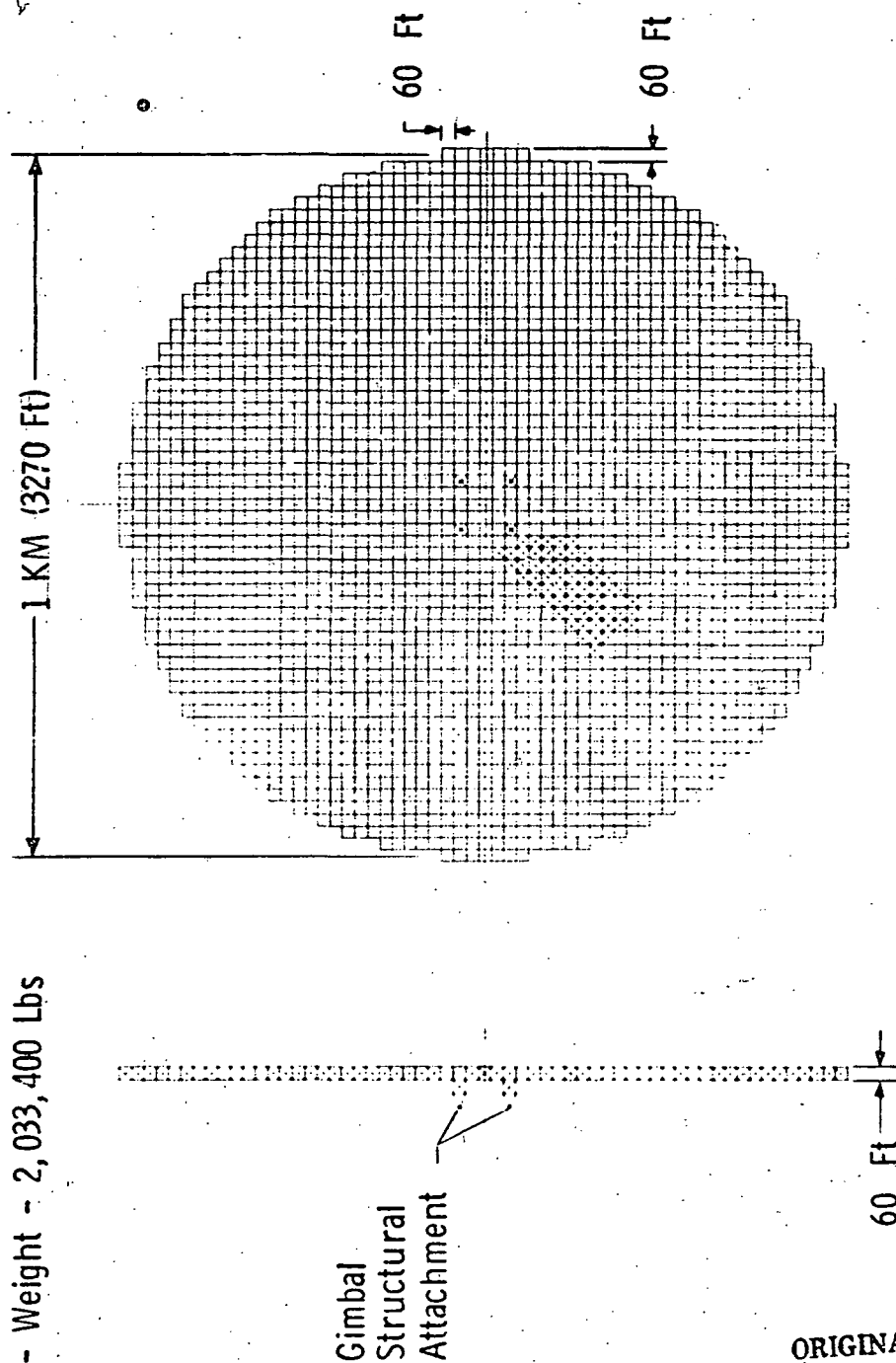


Fig. 6 Cube Assembly Sequence, Step 1

VISUAL AIDS

TOTAL MICROWAVE ANTENNA SUPPORT STRUCTURE

- 2520 60 -Ft Cubes
- Weight - 2,033,400 Lbs



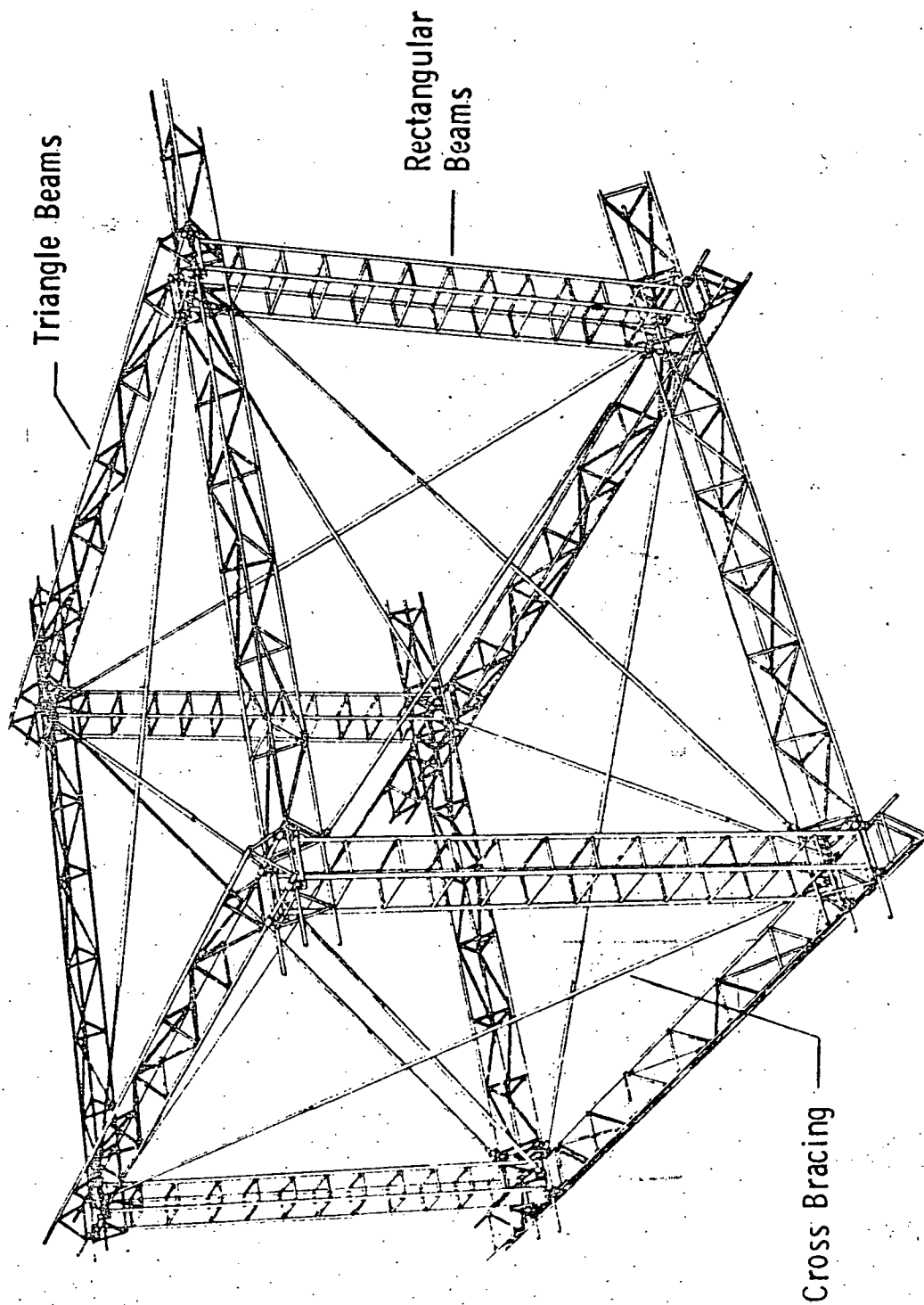
Gimbal
Structural
Attachment

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TYPICAL 60-FT CUBE

The basic element of our assembly concept is shown. This 60-ft cube is composed of triangular horizontal beams and square vertical beams. This structure is self-supporting and an infinite number of additional cubes can be added to it in either direction. Adjustment points are built into each joint to allow continuous alignment as the structure is built.

TYPICAL 60 -FT CUBE



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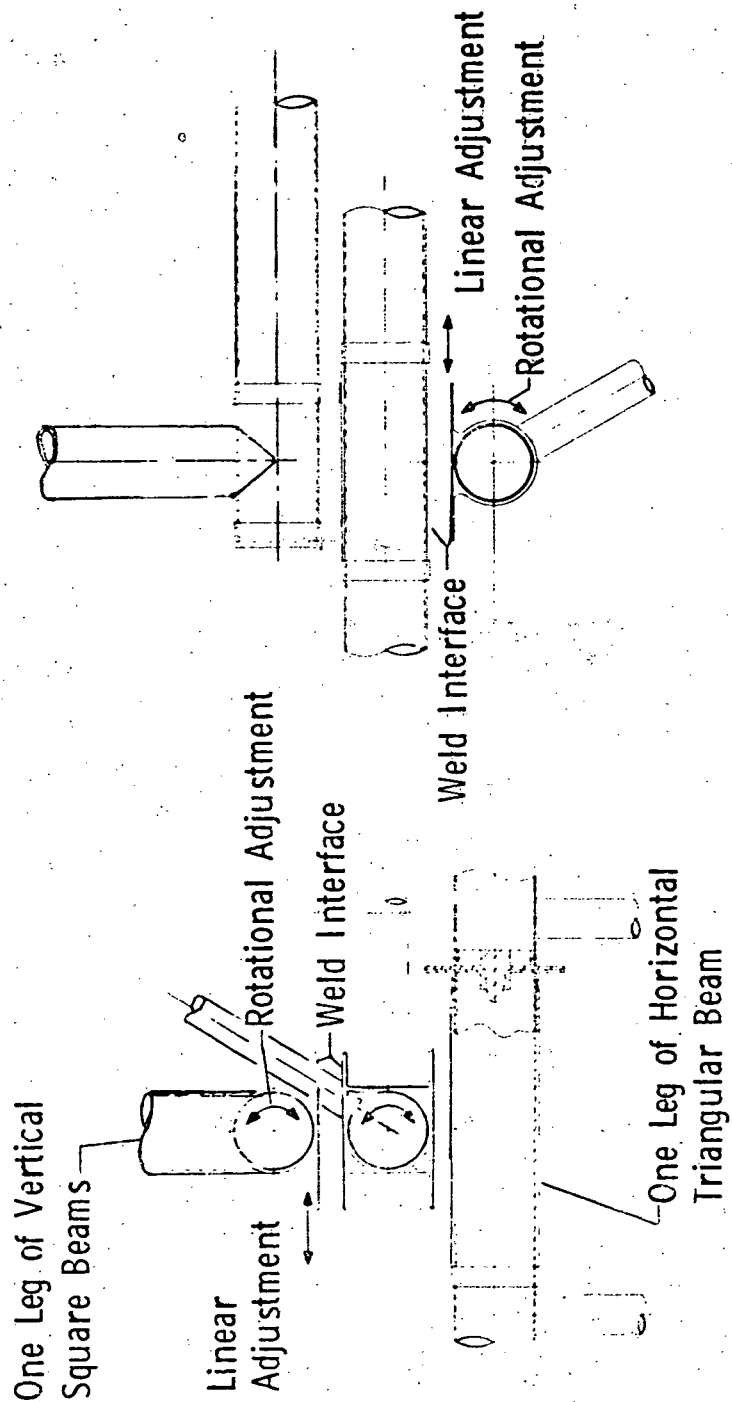
JOINT DRAWING (DETAIL)

Shown is an individual structural joint which mates one vertical and two horizontal beams together. There are a total of 43,600 of these joints to be aligned and mated in the total antenna support structure. Each beam has pre-assembled mating pads which align with the appropriate pads on the adjoining beam. These pads have a small amount of angular travel, permitting positive alignment on their flat surfaces. They may also be shifted linearly for final adjustments. The triangular, horizontal beam pads contain pins to facilitate initial alignment. - After the beam alignment is verified, the pads are welded to provide a permanent bond.

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MICROWAVE ANTENNA STRUCTURAL JOINT DETAIL

-Typical Joint, 43,600 Req'd
for Total Support Structure

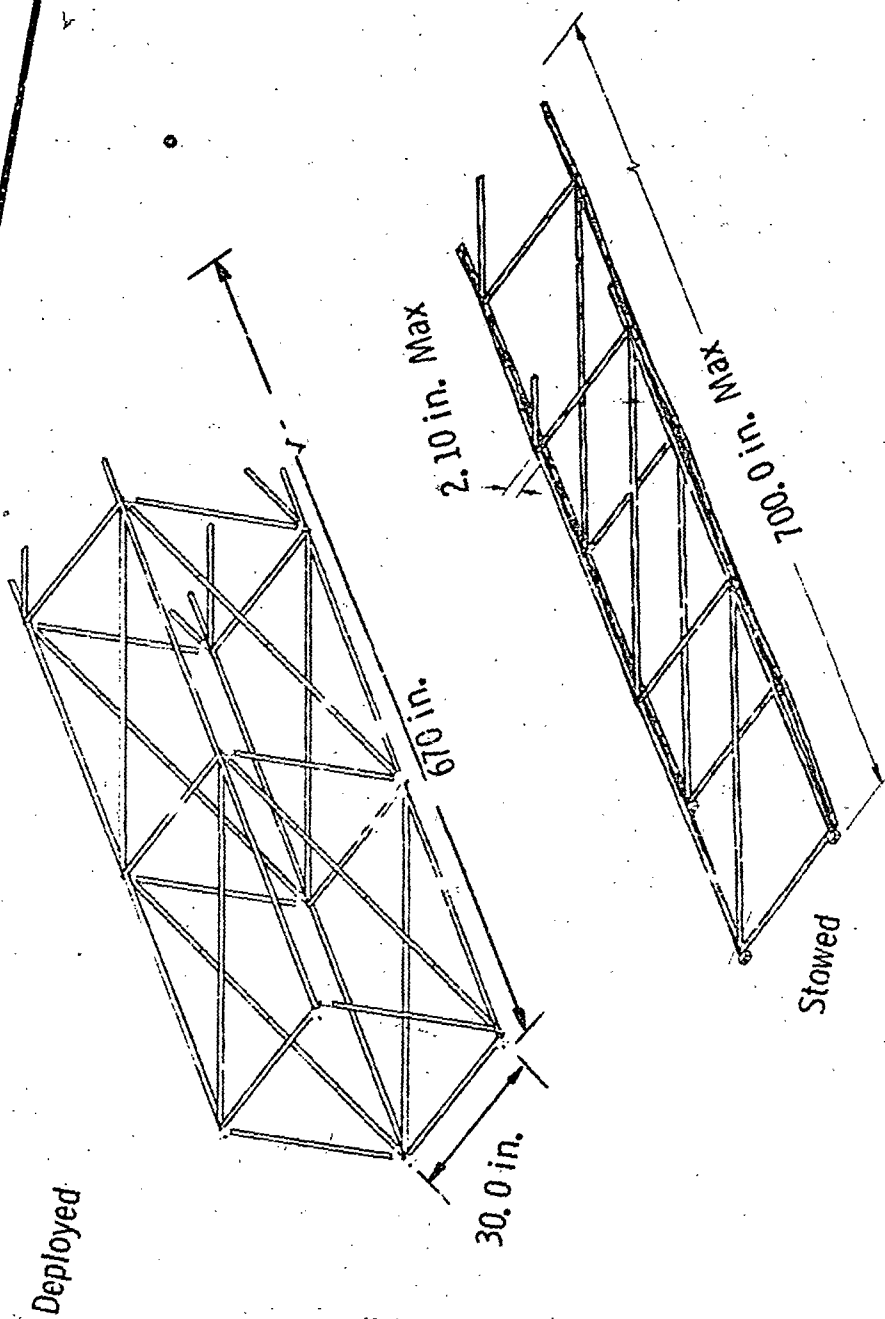


JOINT BONDING ALTERNATIVES

We have investigated numerous techniques for attaching the structural mating joints. We have concluded that a permanent bond is required, such as welding. The standard bolts, rivets and clamps require precise alignments and either manned operations or very sophisticated mechanisms. Male/female connections require precise alignments to preclude binding while insertion is made and do not provide a rigid structural attachment. Our present concept utilizes welding for joining the beam member pads. Small, electrically activated charges are imbedded in each attachment pad. After final alignment, these are activated and metal is fused between the pads at predetermined spots. Pyrotechnics are used to drive locking pins into the sliding tubes which serve as tension members.

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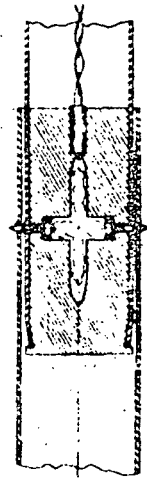
COLLAPSIBLE SQUARE BEAM



SQUARE BEAM - DETAILS

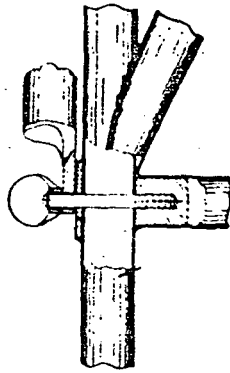
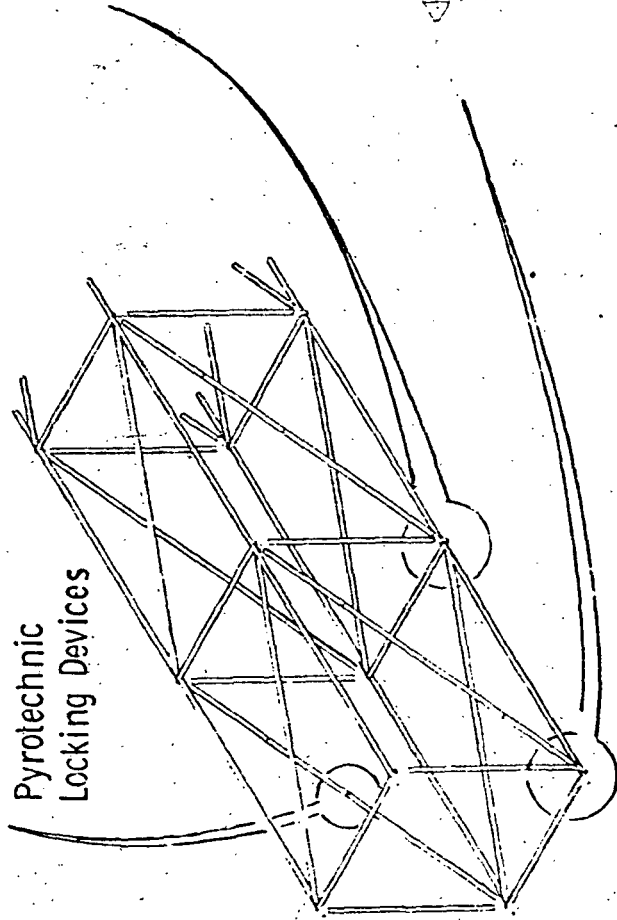


LOCKING DEVICE, PRINED

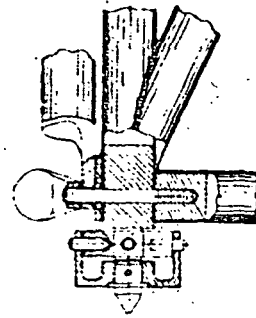


LOCKING DEVICE, ACTIVATED

Pyrotechnic
Locking Devices



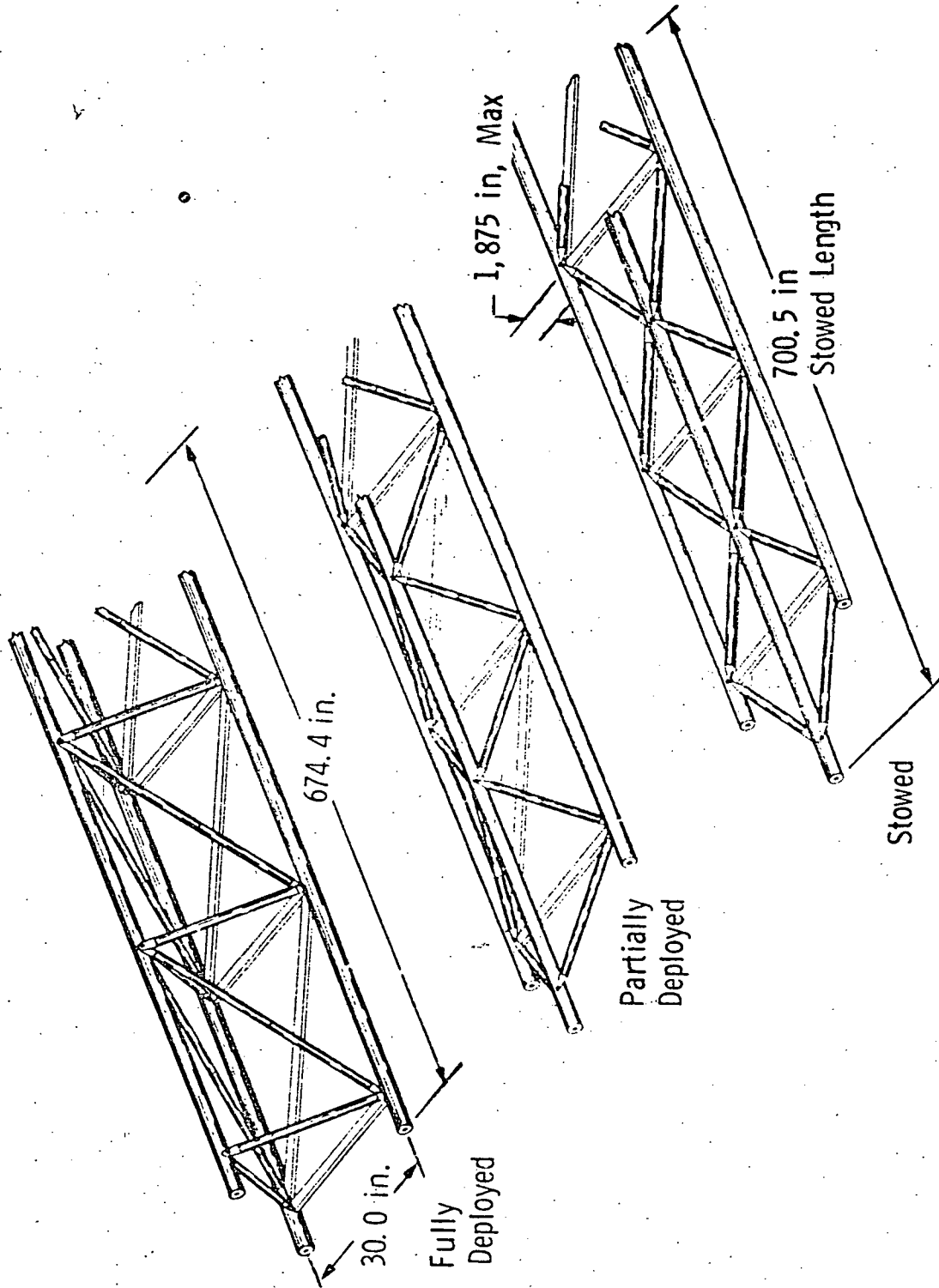
Pivot Detail



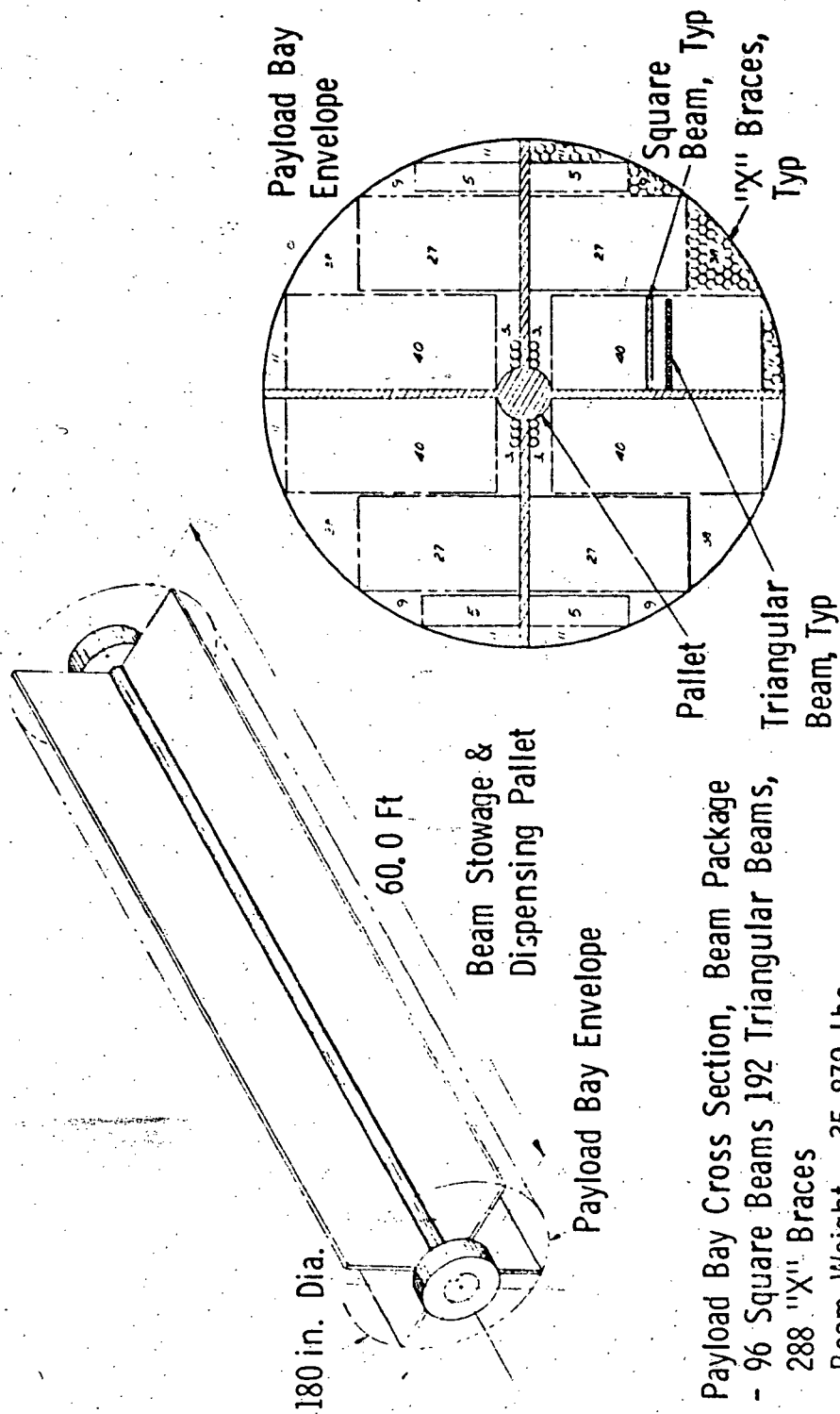
End Pivot Detail

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COLLAPSIBLE TRIANGULAR BEAM



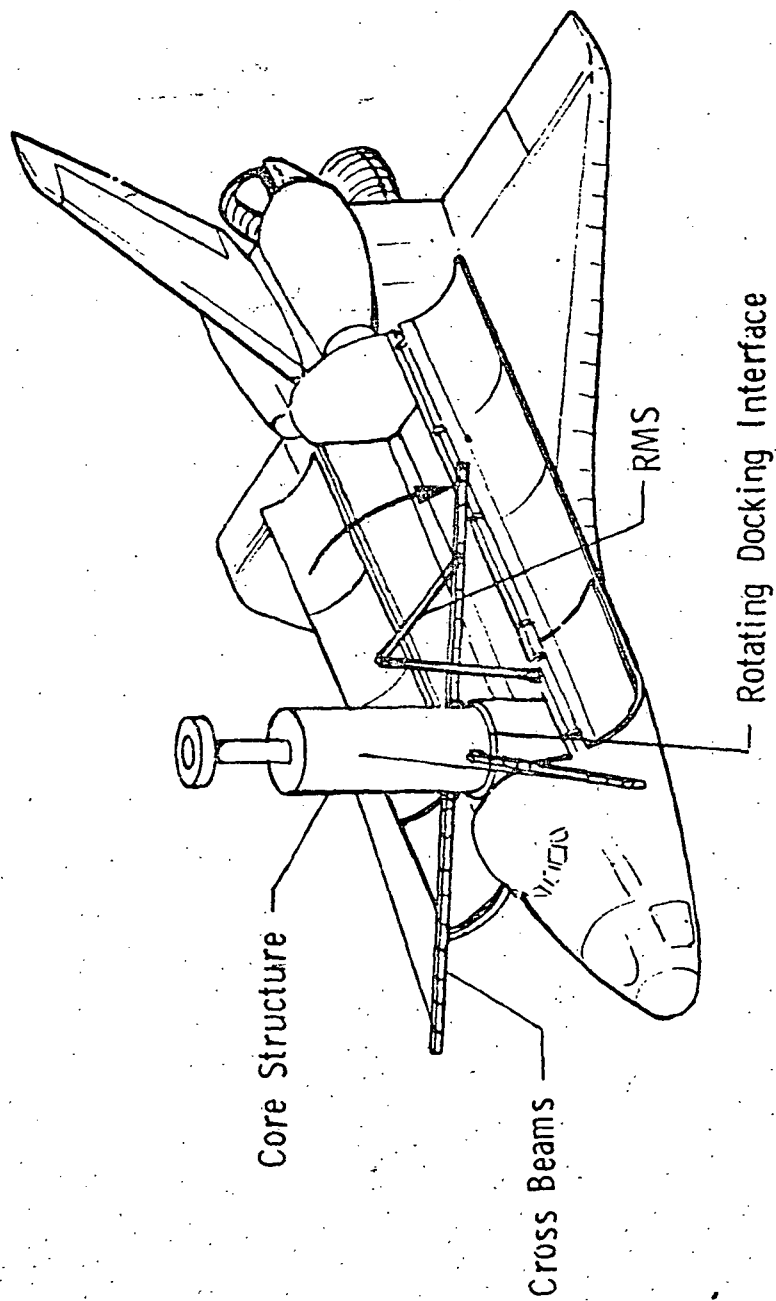
BEAM PALLET AND SHUTTLE PAYLOAD SECTION



- Payload Bay Cross Section, Beam Package
 - 96 Square Beams 192 Triangular Beams,
 288 "X" Braces
 - Beam Weight - 35,870 Lbs
 - Pallet Weight - 2,000 Lbs

MICROWAVE ANTENNA ASSEMBLY, SHUTTLE #1 STEP 2

Extend Cross Braces



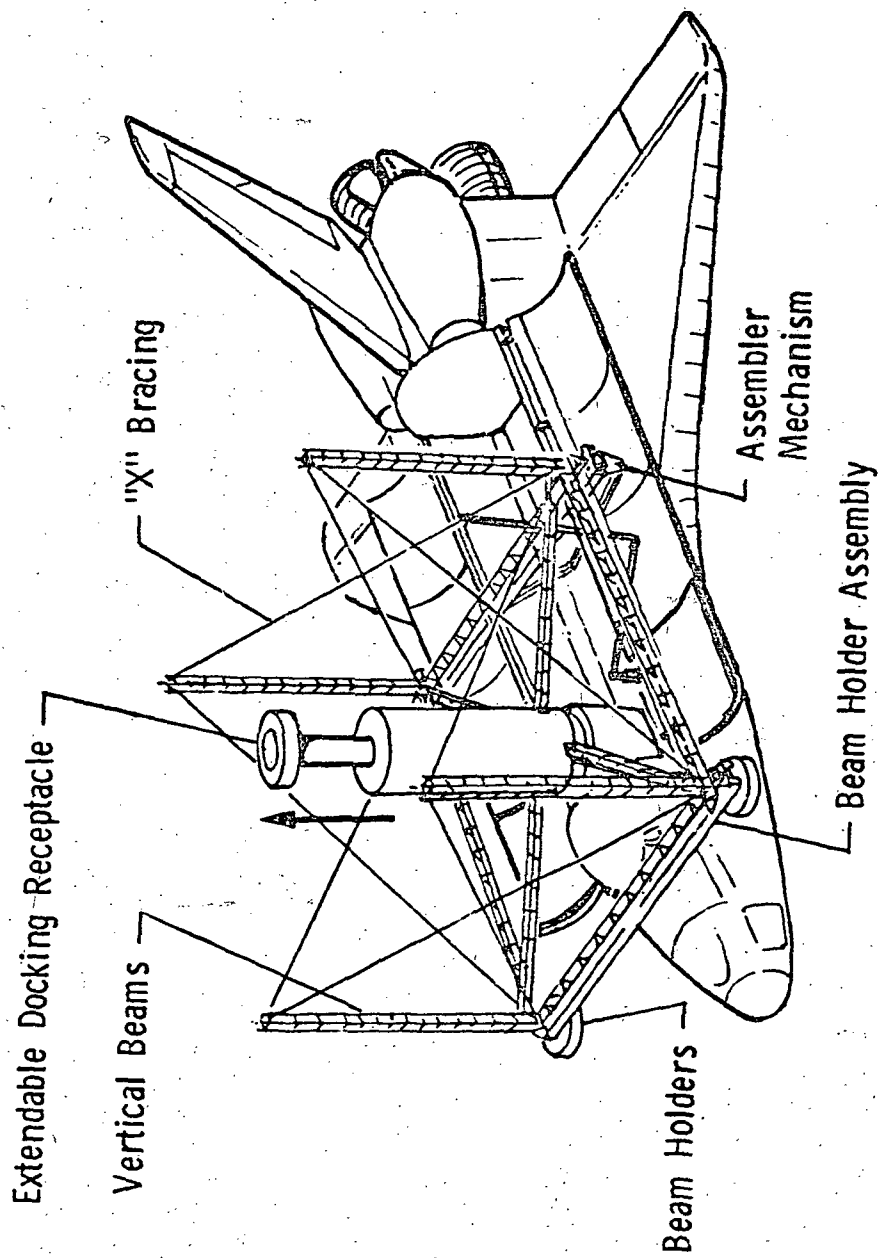
MICROWAVE ANTENNA ASSEMBLY, SHUTTLE #1, STEP 3

Step 3 consists of extracting the beams from the cargo bay and placing these lower triangular beams onto the alignment beams and welding them in place, one at a time.

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MICROWAVE ANTENNA ASSEMBLY SHUTTLE #1, STEP 4

Emplace Horizontal Beams, Cross Braces & Assemblers

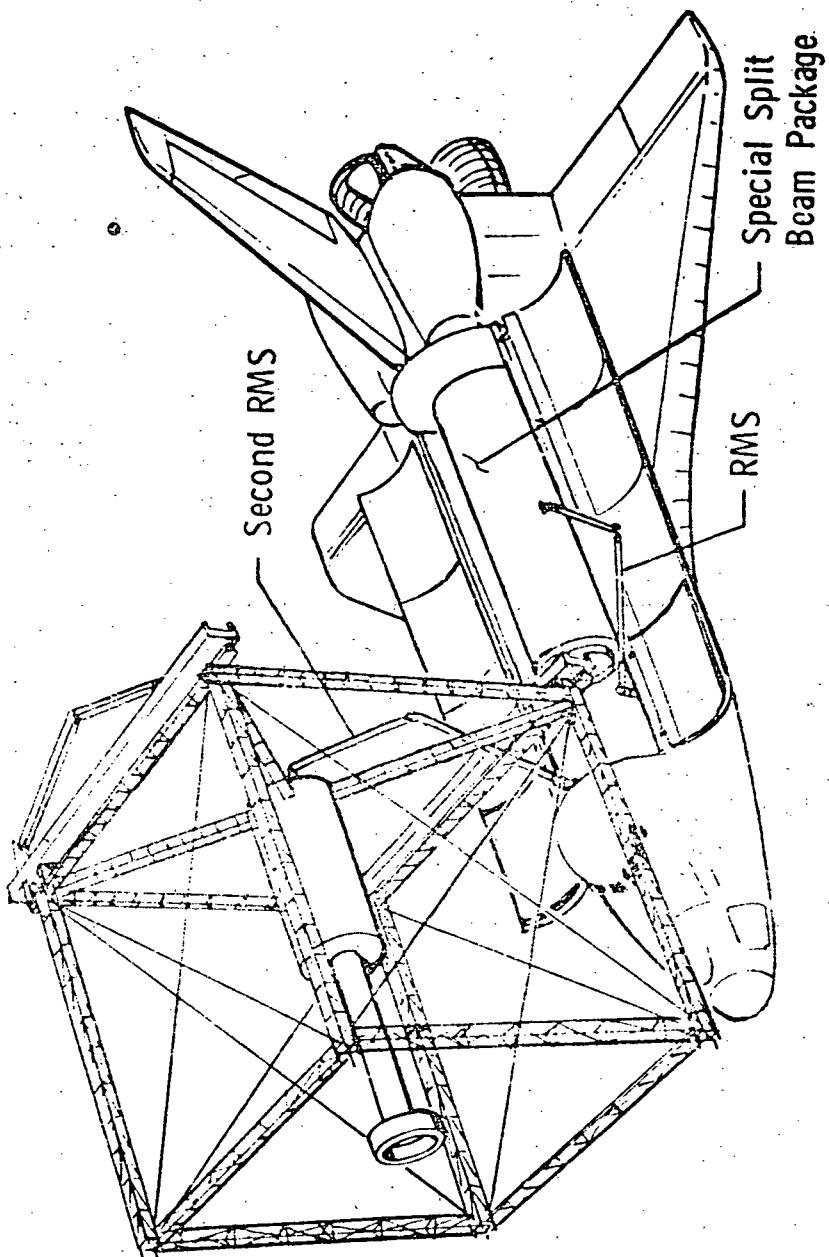


MICROWAVE ANTENNA ASSEMBLY, SHUTTLE #1, STEP 5

The antenna core structure is 60-ft deep, therefore the 50-ft long RMS cannot reach to the top to complete the core assembly. The central core has a docking port on each end so the total assembly can be undocked, rotated 130 deg and redocked so the assembly can be completed with the RMS. Step 5 shows the assembly of the top cap beams and mobile assembler mechanisms. The first antenna 60-ft cube is now complete and the first Shuttle has expended its cargo capacity. The 60-ft core assembly is now left in orbit and is stabilized by its own internal attitude stabilization system.

MICROWAVE ANTENNA ASSEMBLY, SHUTTLE #2, STEP 6

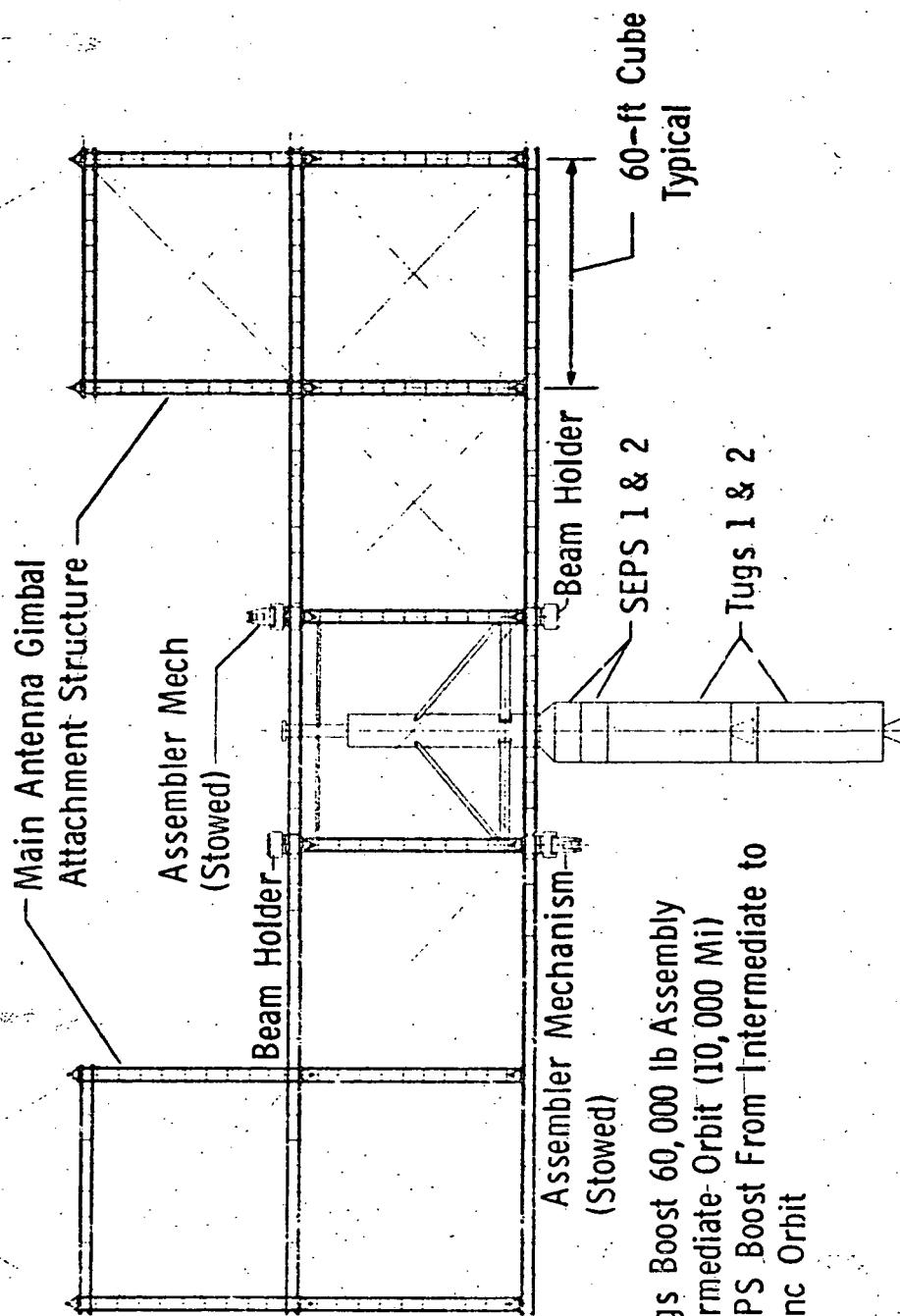
Install Beam Packages on Holders
Complete 60 ft. sq. Core Assembly With Assemblers



STEP 7 - MPTS ASSEMBLY

The mobile manipulators which can be controlled both from the Shuttle or the ground will continue to assemble 60-ft cubes in low earth orbit until 44 are assembled. This is the maximum load that two Tugs can boost to intermediate orbit (10,000 miles). From intermediate orbit, two SEPS will take the assembly to geosynchronous orbit.

STRUCTURE READY FOR TUG BOOST



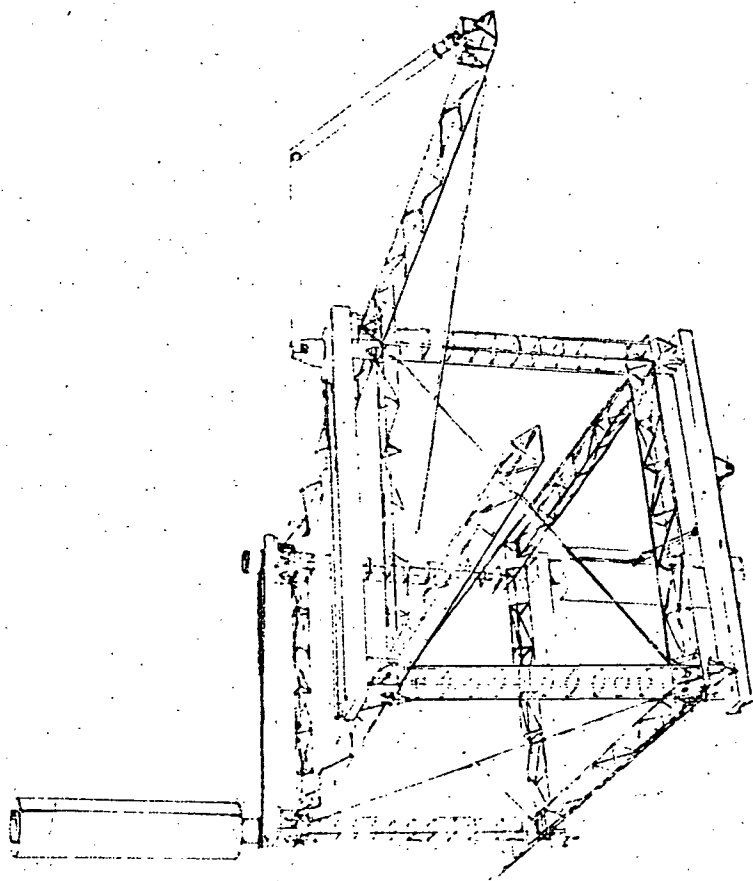
- Two Tugs Boost 60,000 lb Assembly to Intermediate Orbit (10,000 Mi)
- Two SEPS Boost From Intermediate to Geo-Sync Orbit

MICROWAVE ANTENNA SUPPORT STRUCTURE WEIGHT STATEMENT

This breakdown of structural components and weights shows the totals for the complete microwave antenna support structure. This structure is composed of 32,700 beam and tension tube members which weigh a total of 2,033,400 lbs. In addition to the structure weight, there will be at least two pairs of assemblers and beam holders, at 10,000 lbs and the core assembly at 10,000 lbs. This totals 2,053,400. The structure is made up of round tubes with a wall thickness of .057 in. which we believe to be conservative. It is interesting to note that for each reduction of .001 in. in tube wall thickness, the total structure can be reduced by 35,000 lbs.

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MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 1

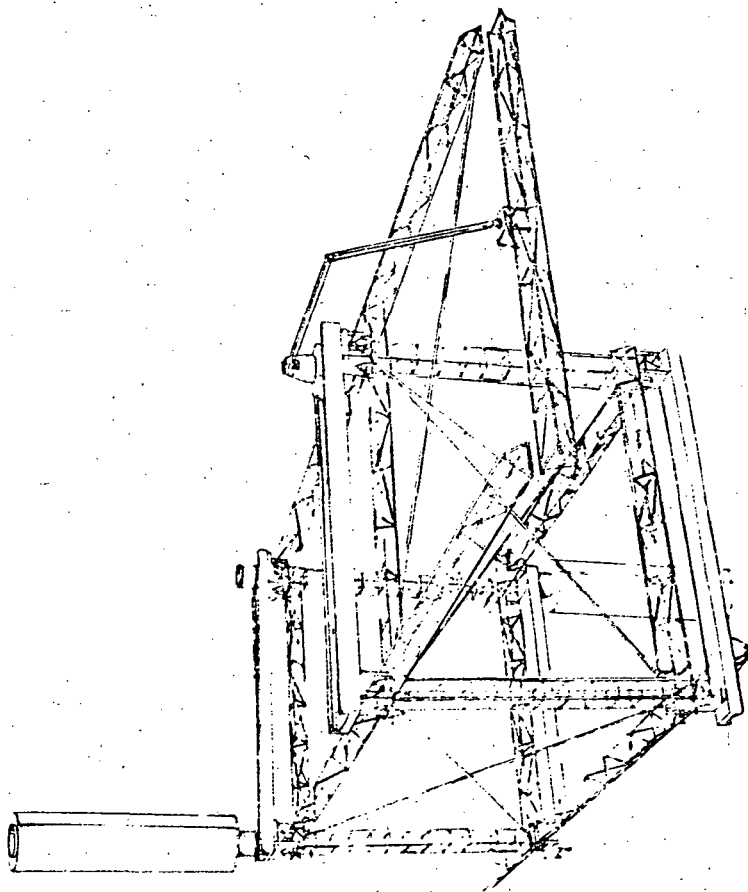


MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 2

Step 2 places the crossing, triangular beam at the outer beam ends. This beam is aligned and welded in place.

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MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 2

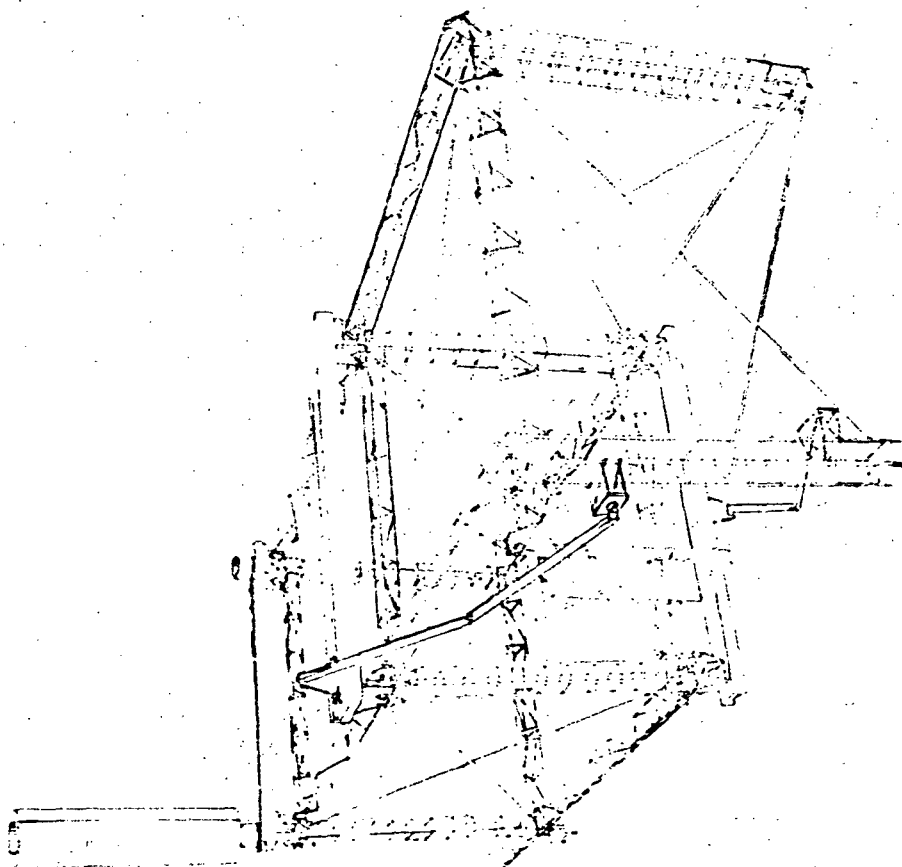


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MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 3

This step places the two vertical (square) beams on the cube end. Their ends are welded in place and again aligned with the cross braces. Both the top and bottom manipulators will be used for this task.

MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 3

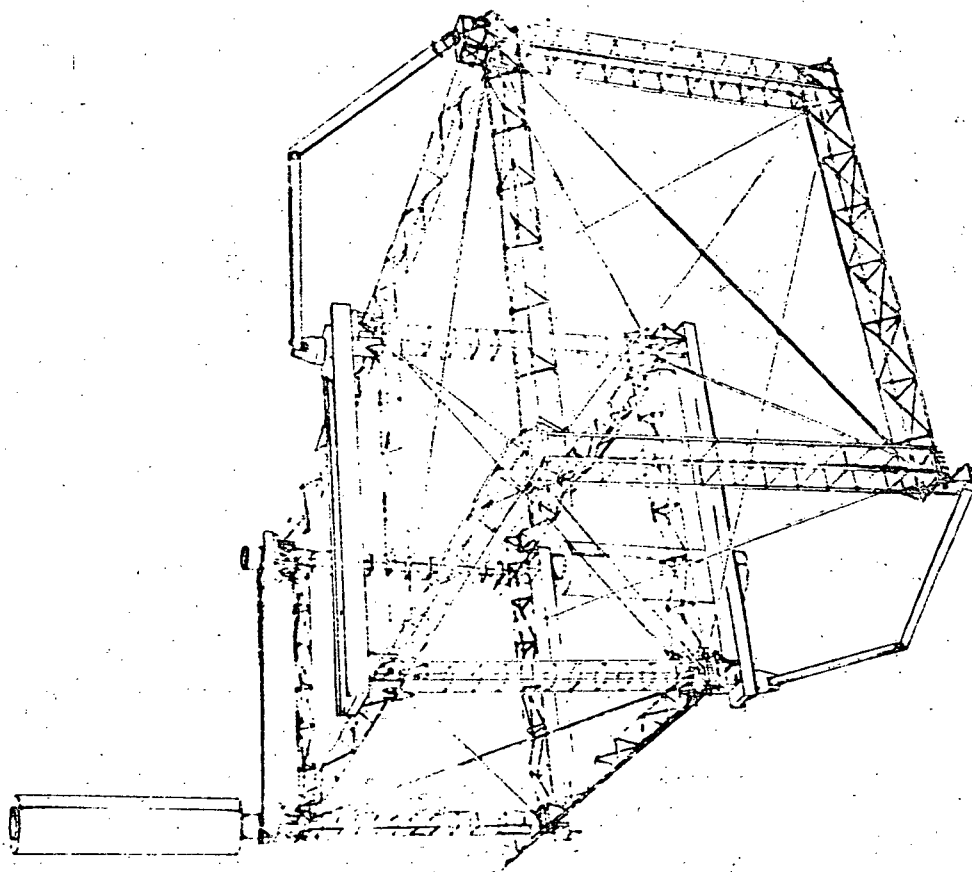


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MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 4

Step 4 places the lower triangular cross beam at the lower ends of the vertical beams. It is aligned and welded on each end.

MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 4



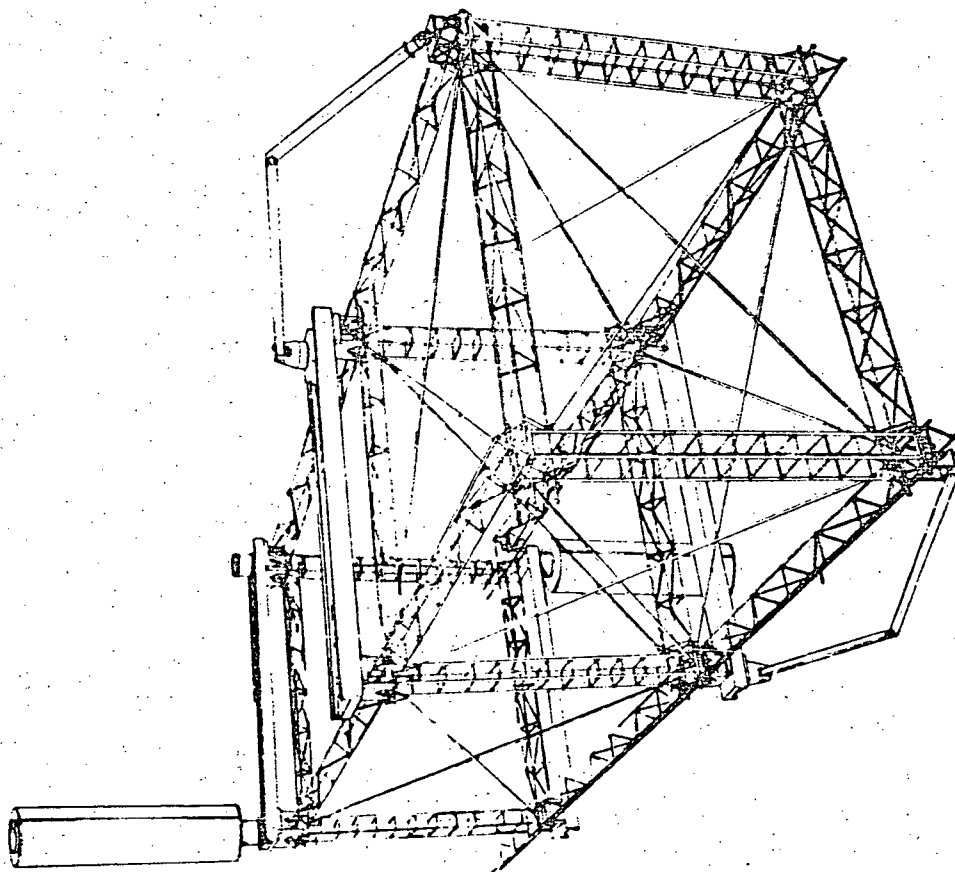
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MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 5

The two lower horizontal beams are now put into place. They are individually abutted to the adjoining beam end and welded. They are aligned on the outer end and also welded in place.

This completes the cube and the manipulators will now maneuver to the outer ends of this cube and start a new structure.

MICROWAVE ANTENNA ASSEMBLY SEQUENCE, STEP 5

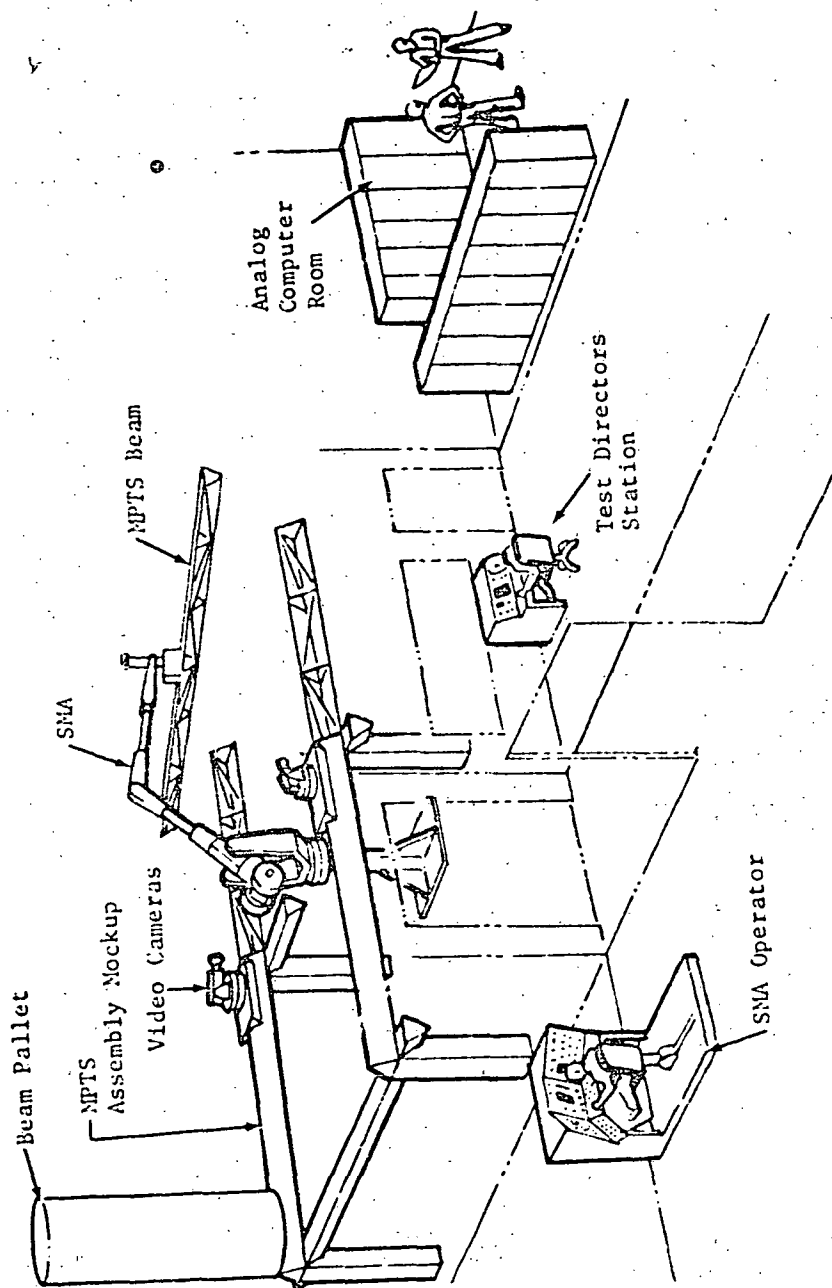


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STRUCTURE READY FOR TUG BOOST

The mobile assemblers will construct up to 44 60-ft cubes in low earth orbit. This assembly will then be boosted to intermediate earth orbit with two Tugs. The Tugs will return and two SEPS will boost the assembly to high earth orbit. This boost concept makes efficient use of the Tug/SEPS combination however, the method is time consuming.

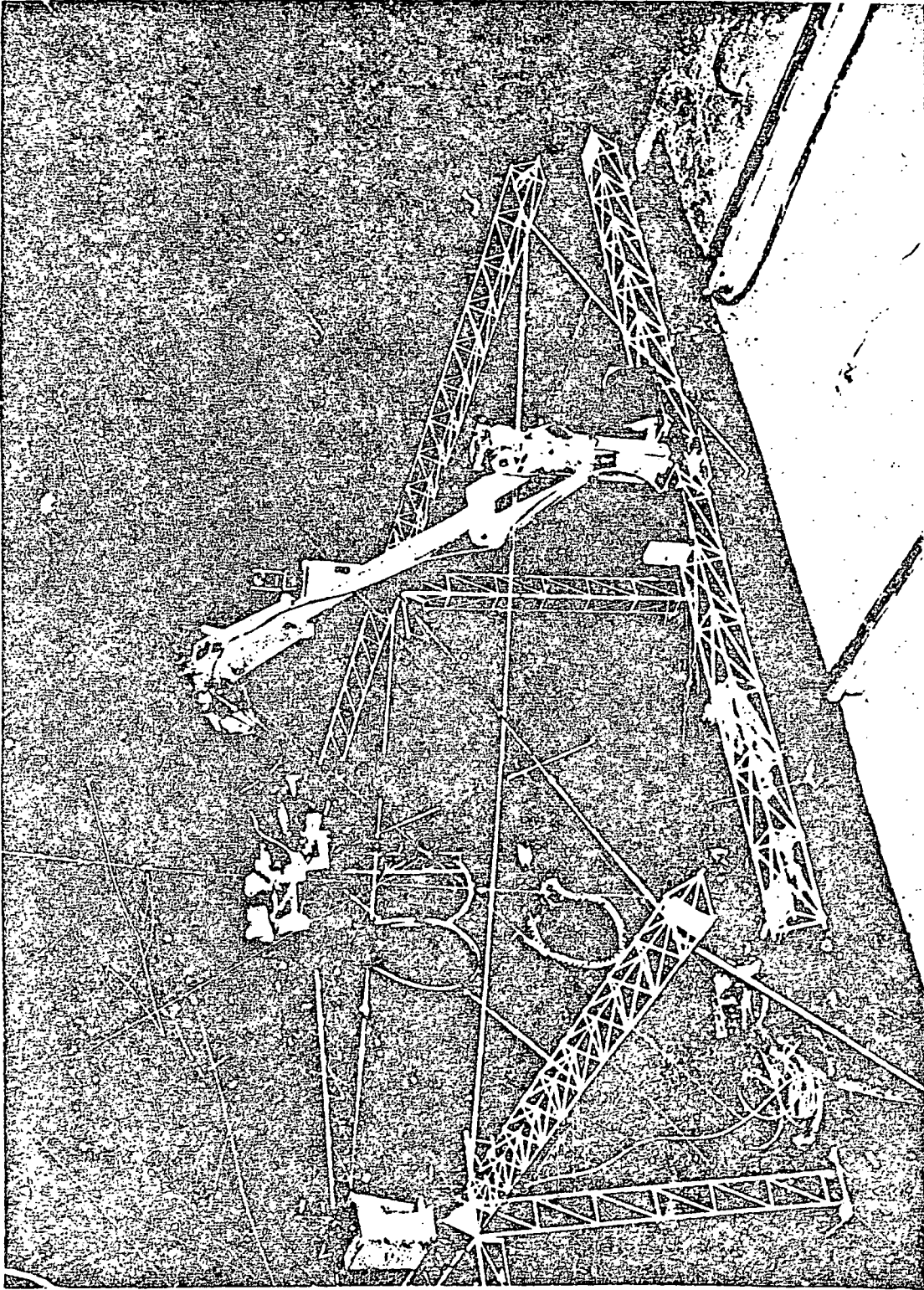
SIMULATION FACILITY



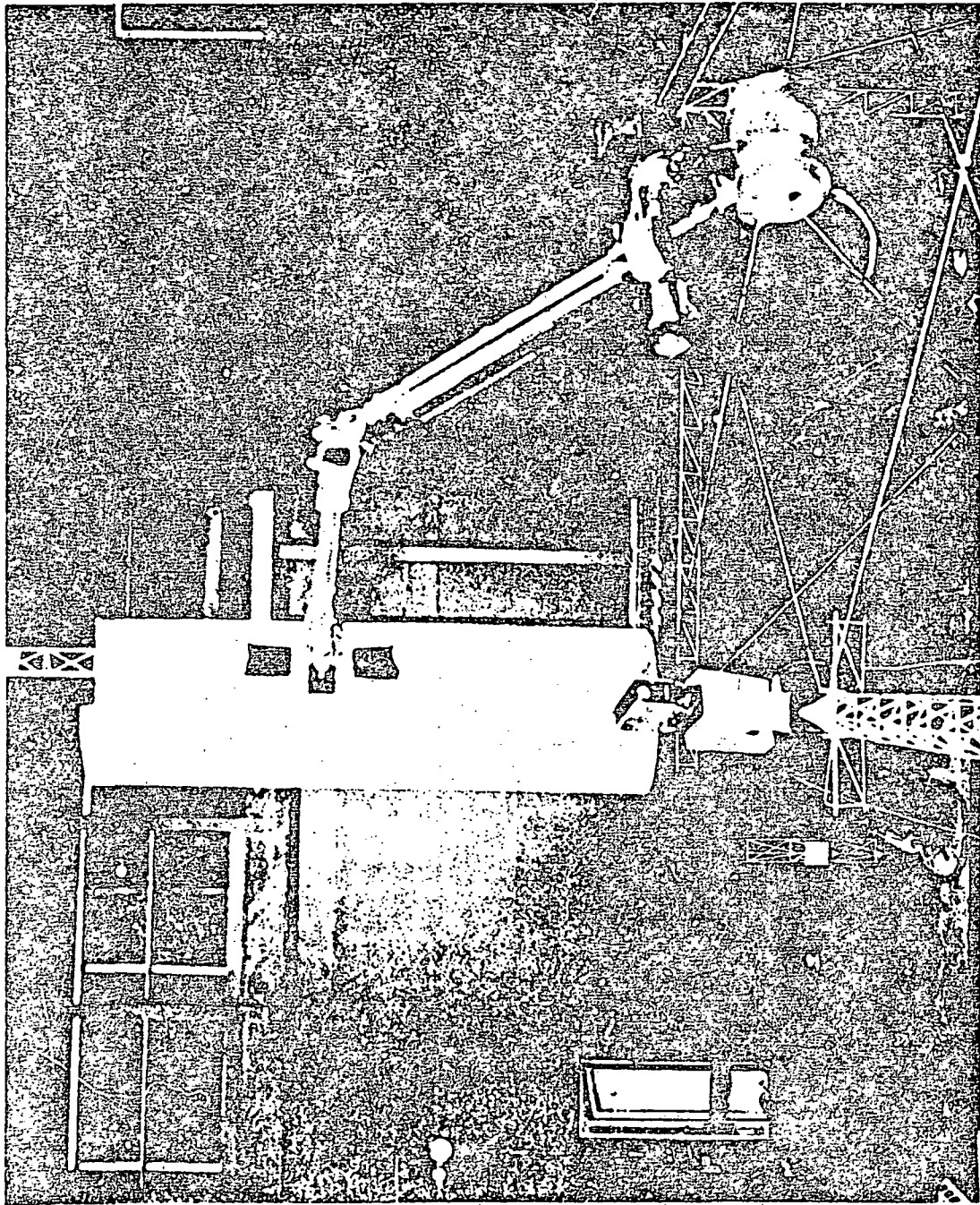
SLAVE MANIPULATOR ARM

The 12-foot counterbalanced slave manipulator arm (SMA) represents an approximate one-quarter scale working model of the Shuttle RMS for simulating and demonstrating payload handling, docking assistance, satellite assembly, and servicing. In simulating the 60-foot mobile assembler for MPTS assembly, the SMA is a one-fifth scale working model.

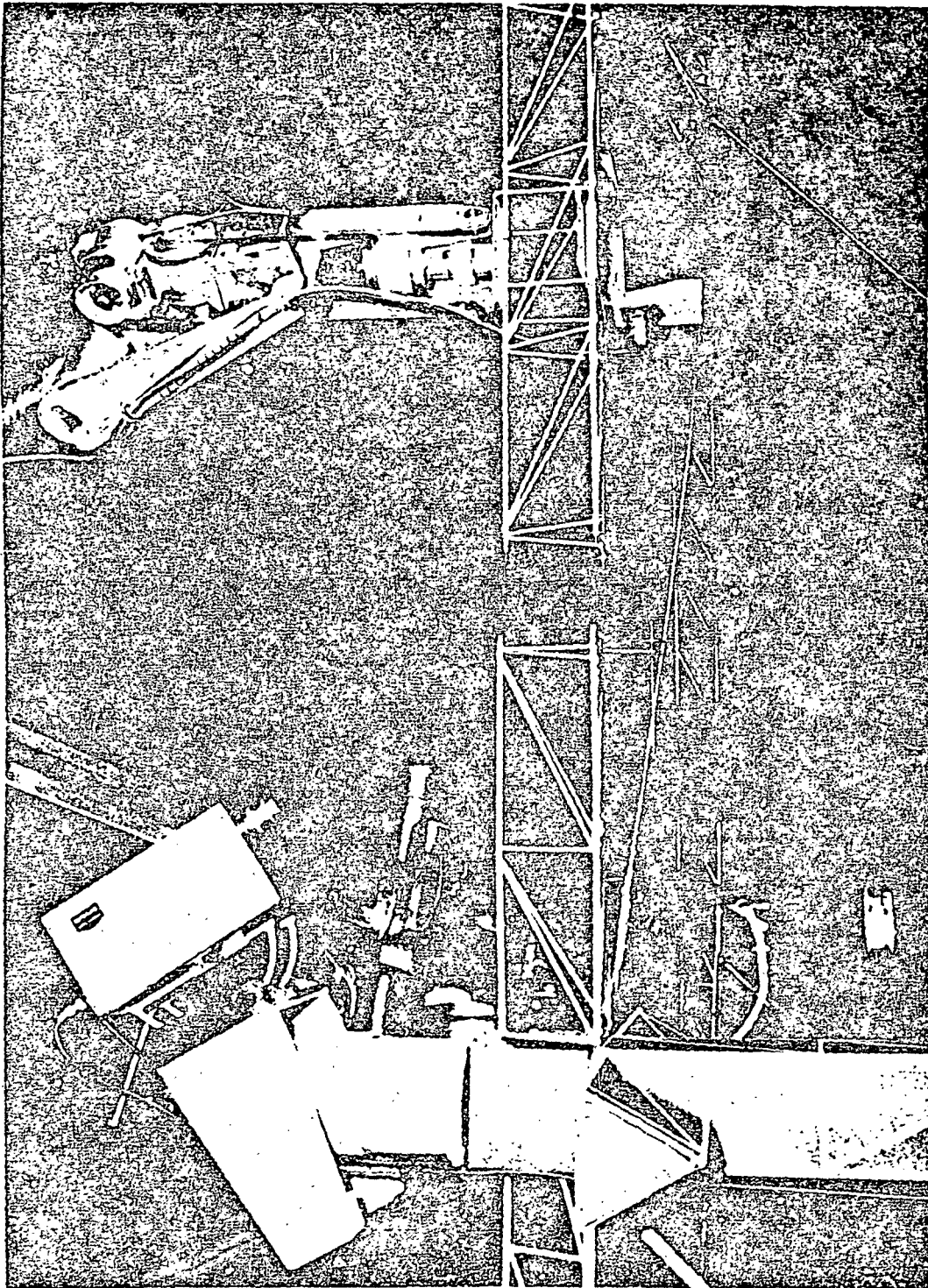
The SMA uses an articulated counterbalance scheme for shoulder and elbow and a self-counterbalanced design for the wrist. The articulated counterbalance scheme is essentially a second arm at the end of the shoulder extension with one or two counterbalance weights which are driven (via mechanical linkage) in phase with the lower arm (elbow to wrist). This system provides an arm whose shoulder and elbow torques need not, *in any orientation*, overcome the force of gravity on either the upper or lower arm, and whose motion is completely unrestricted.



MPTS BEAM EXTRACTION FROM PALLET



MPTS SINGLE ENDED BEAM ASSEMBLY



ABSTRACT

NEW SPACE INITIATIVES

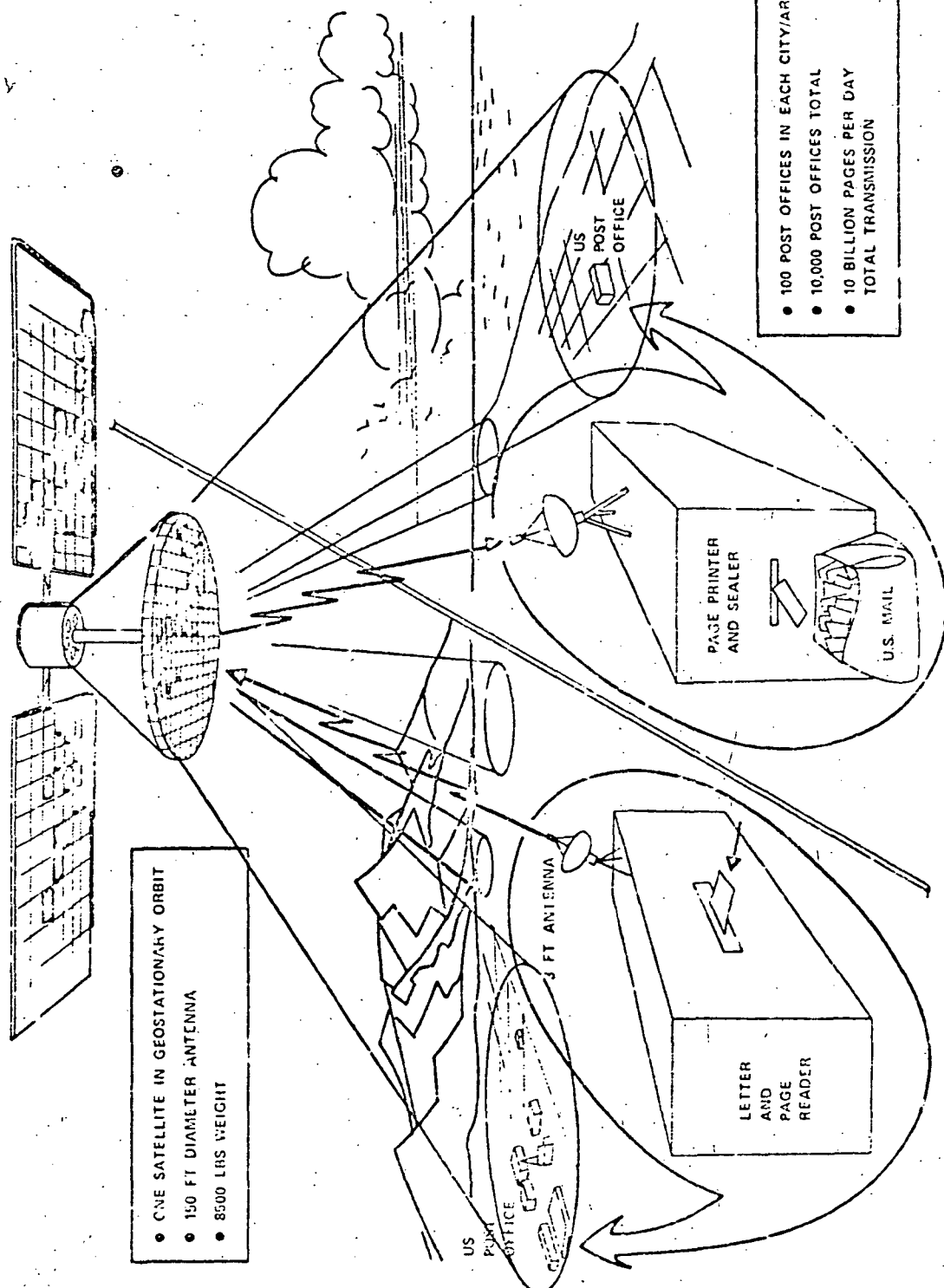
By

Mr. Ivan Bekey
The Aerospace Corporation

A number of concepts for space applications illustrating the range of satellite sizes and masses called for in providing earth-oriented services were identified and four examples were discussed. The characteristics of the entire set of initiatives were then examined. Correlations between projected area (size), orbital altitude, and mass were discussed. Very large and massive satellites were shown to be needed, as well as large but low density satellites, with the range of densities varying from 0.01 to 60 lb per ft² of projected area. Increases in pointing accuracy and control difficulty were also addressed.

Common features of the support needs of the initiatives were identified, consisting of their need for improved transportation, orbital assembly, orbital servicing, and reconfiguration. Needs for several candidate vehicles and facilities to provide the orbital support were quantified, with needs for orbital transfer vehicles, orbital assembly and servicing stages, and orbital support facilities for fabrication, warehousing, research, and test shown to be most needed by the entire set of initiatives. Manned habitats and life support systems would be an integral part of many of the needed systems, with the role of man being that of assembly, initialization, servicing, and modification of the satellites which would provide the earth-oriented services.

ELECTRONIC MAIL TRANSMISSION



- ONE SATELLITE IN GEOSTATIONARY ORBIT
- 150 FT DIAMETER ANTENNA
- 8500 LBS WEIGHT

- 100 POST OFFICES IN EACH CITY/AREA
- 10,000 POST OFFICES TOTAL
- 10 BILLION PAGES PER DAY TOTAL TRANSMISSION



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Night Illuminator

- 12 MIRRORS IN GEOSTATIONARY ORBIT
- EACH MIRROR 1000 ft DIAMETER
- STRETCHED THIN PLASTIC FILM

- TEN TIMES FULL-MOON ILLUMINATION (clear night)
- FULL-MOON EQUIVALENT (night)
- ILLUMINATED AREA 200 MILES DIAMETER

SUN

94

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DAY

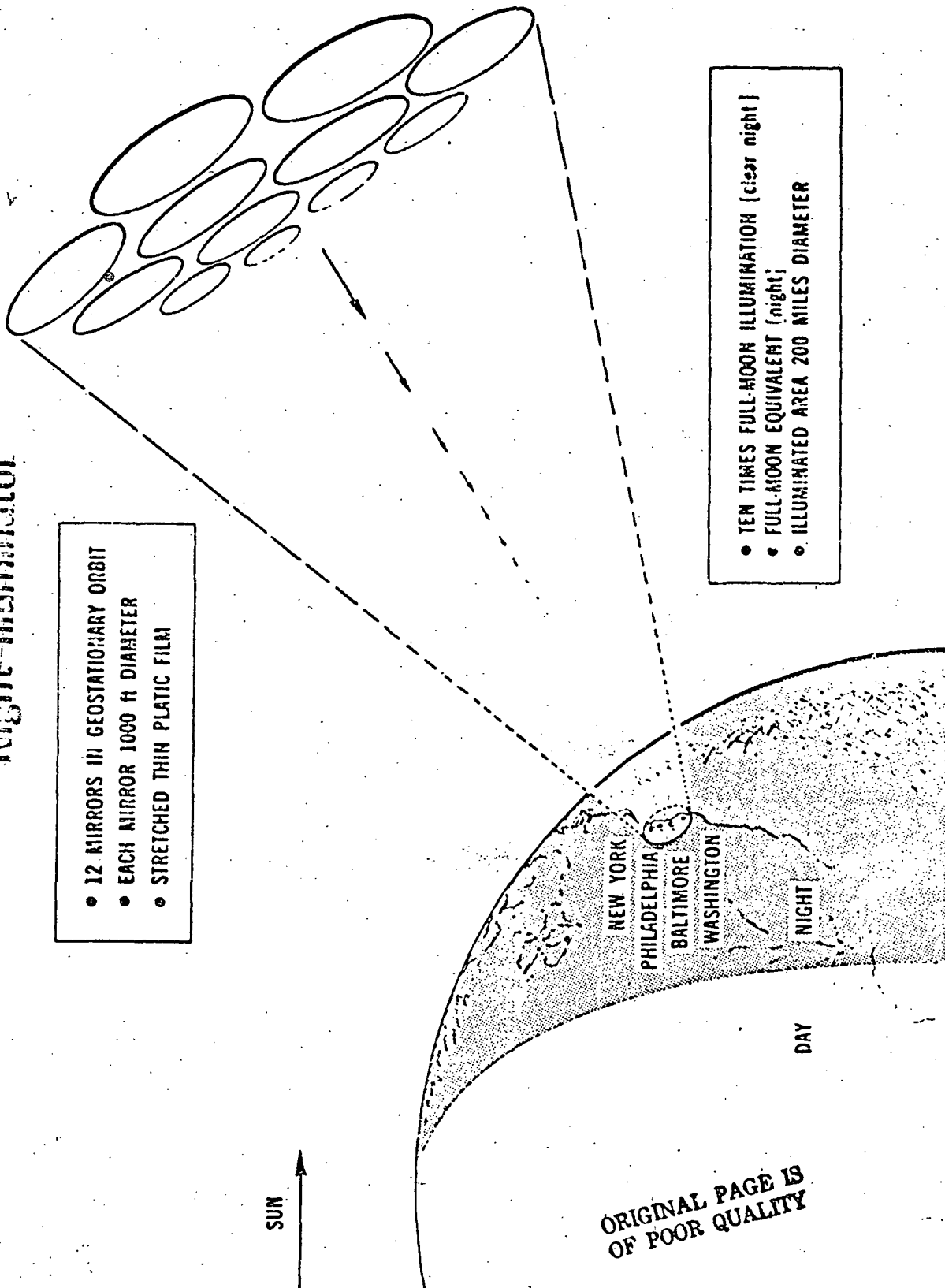
NIGHT

NEW YORK

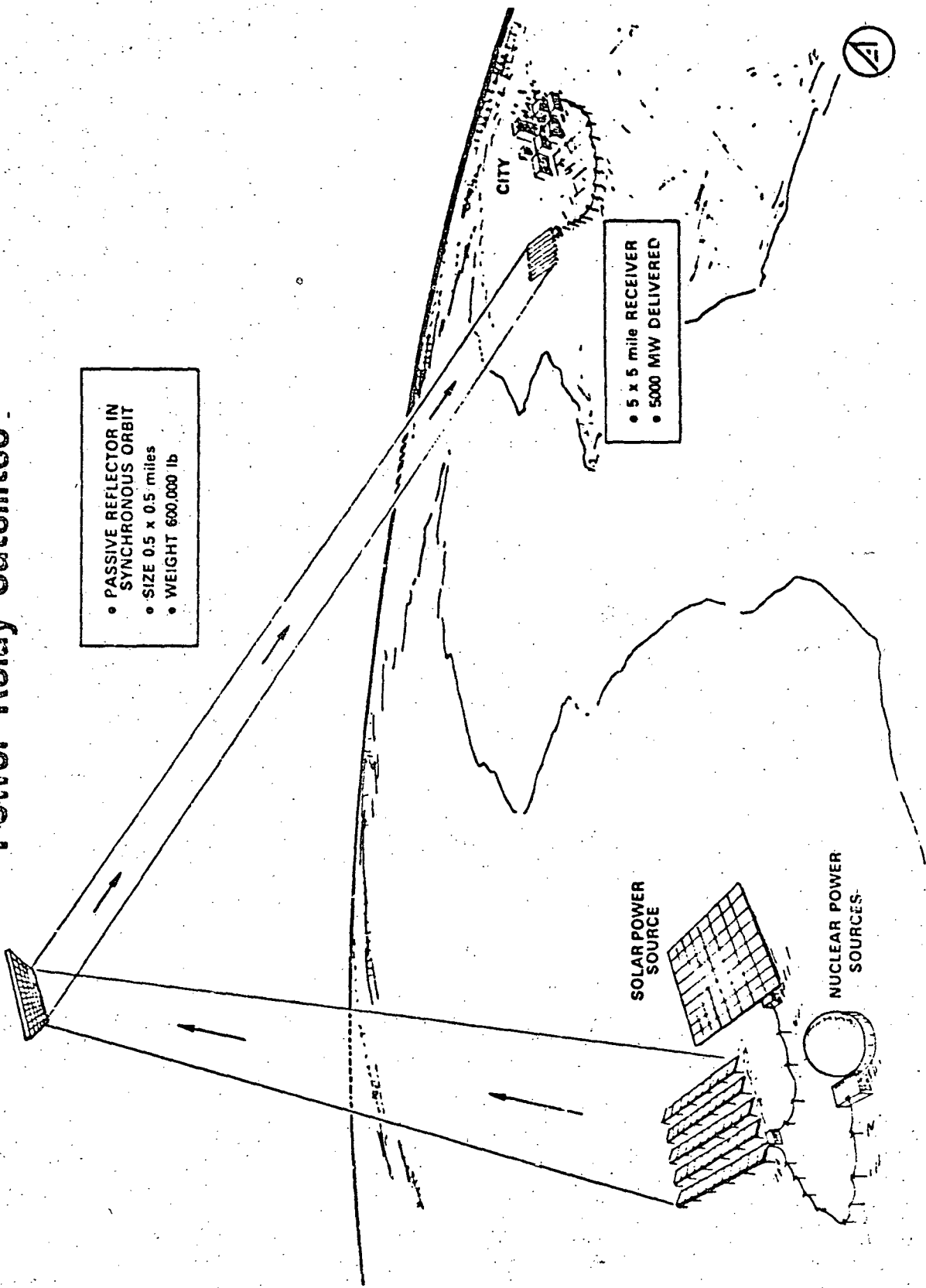
PHILADELPHIA

BALTIMORE

WASHINGTON



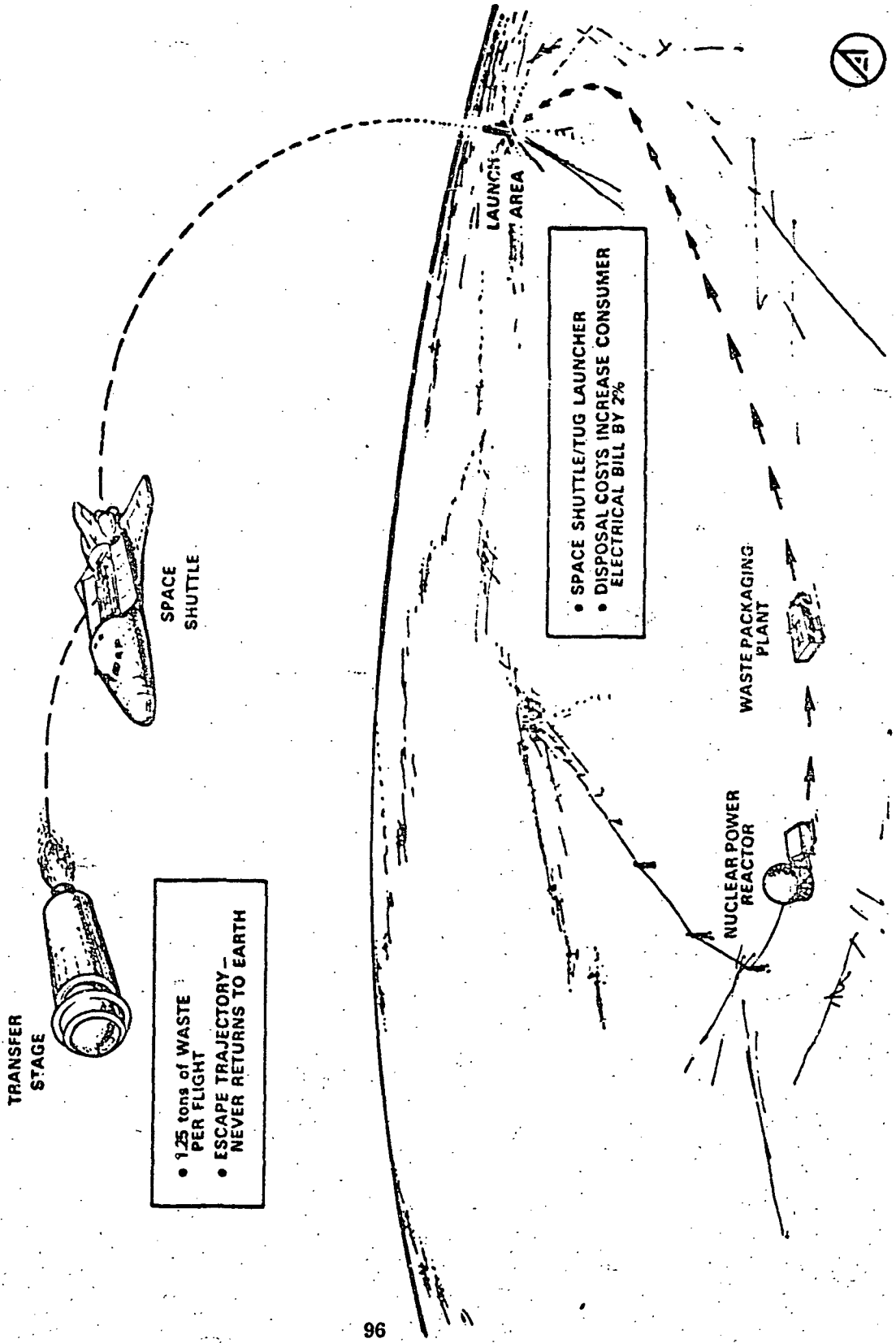
Power Relay Satellites

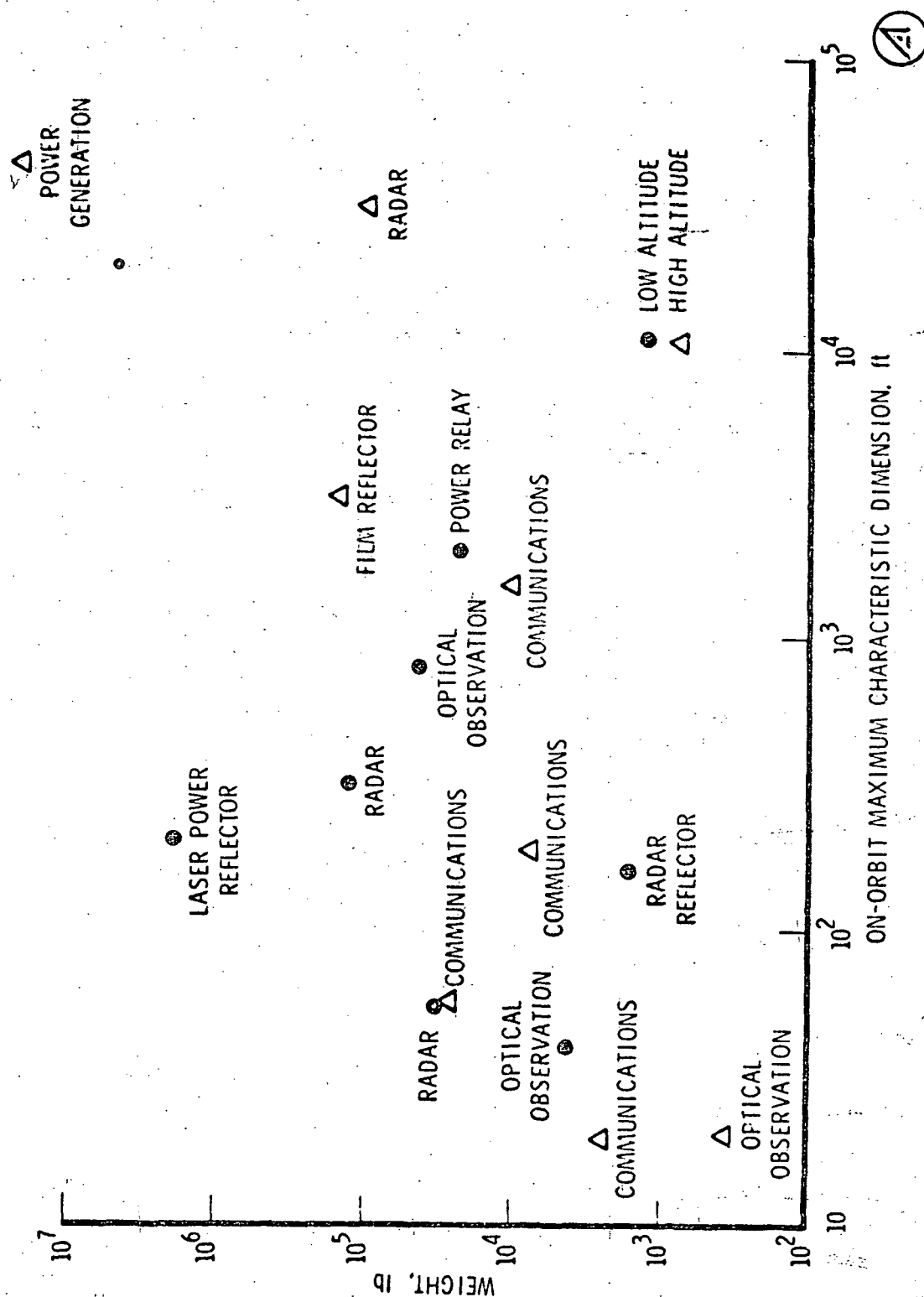


• PASSIVE REFLECTOR IN SYNCHRONOUS ORBIT
 • SIZE 0.5 x 0.5 miles
 • WEIGHT 600,000 lb

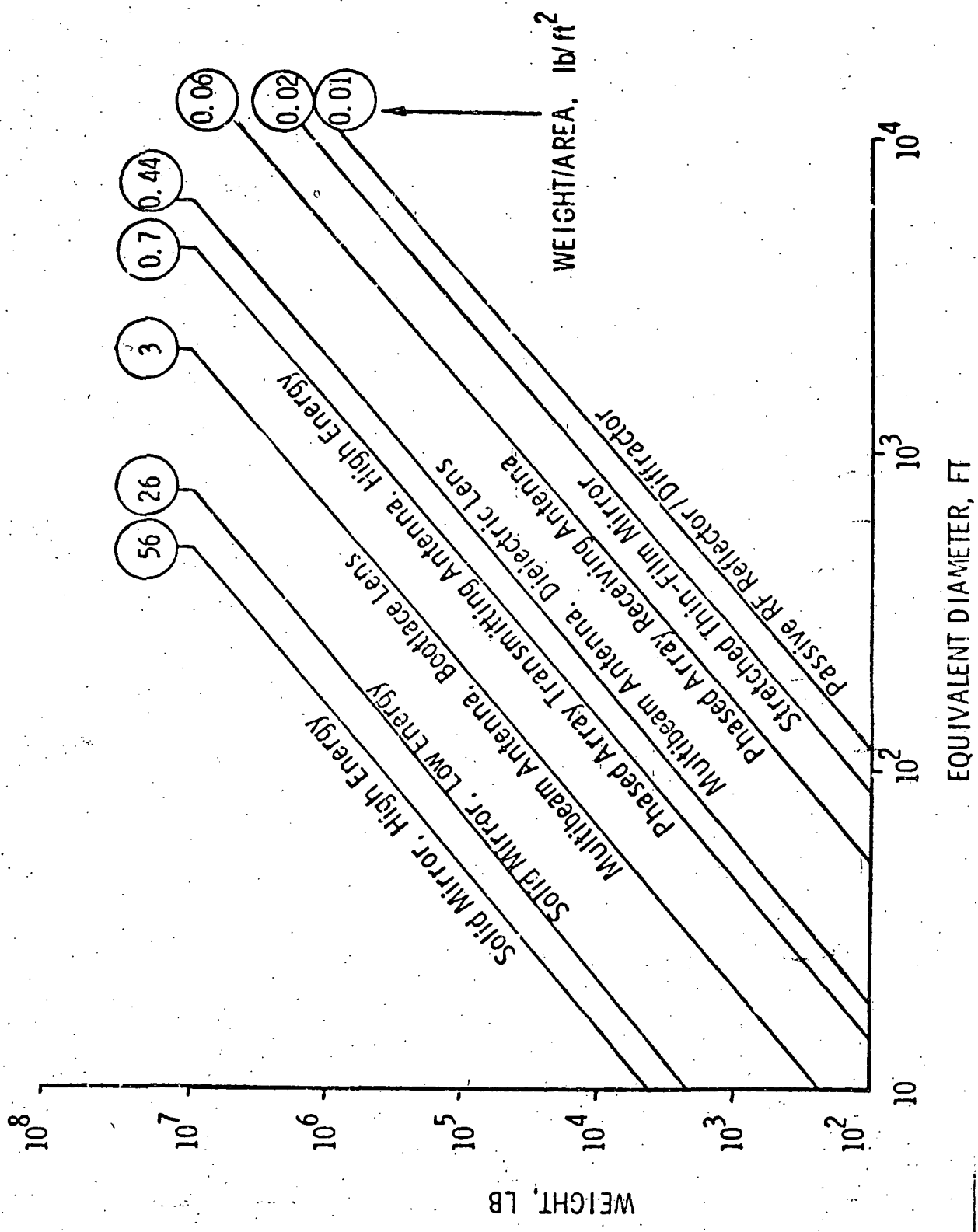
• 5 x 5 mile RECEIVER
 • 5000 MW DELIVERED

Nuclear Waste Disposal





LARGE STRUCTURES WEIGHT ESTIMATION



UNCLASSIFIED

FUTURE SPACE SYSTEM PARAMETERS

RELATED TO GUIDANCE AND CONTROL TECHNOLOGY

	CHARACTERISTIC MASS kg	CHARACTERISTIC LENGTH m	MOMENT OF INERTIA kg m ²	CHARACTERIST FREQUENCY sec ⁻¹
TYPICAL 1975 SATELLITE	10 ³	10.0	10 ⁵	10.0
TYPICAL 1975 DETECTOR	10 ²	0.1	1	
RIGID MIRRORS	10 ³	3.0	10 ⁴	
THIN-FILM MIRRORS	10 ³	100.0	10 ⁷	0.1
MICROWAVE STRUCTURE (PERSONAL COMMUNICATION)	10 ⁴	50.0	2.5 x 10 ⁷	
POWER GENERATOR, 10 ⁴ mW	10 ⁶	10 ⁴	10 ¹⁴	10 ⁻³

DESIRED ANGULAR POINTING ACCURACY

LASER APPLICATIONS $\theta = \lambda/D = 10^{-6}$
INTERFEROMETRIC OPTICAL ARRAY $\theta = 5 \times 10^{-9}$
LARGE MICROWAVE ANTENNAS $\theta = 10^{-4}$ to 10^{-6}

ON-ORBIT LIFETIME

UNSERVICED 5 YEARS
SERVICED TO 1-3 YEAR INTERVALS 10-30 YEARS

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Guiding Principles for Support Functions



LOW DENSITY
LARGE SATELLITES,
SPECIAL PRODUCTS
ARE POSSIBLE



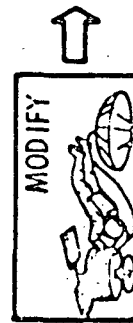
SMALL
TRANSPORTATION
STAGES ARE
ADEQUATE



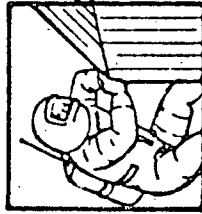
COMPLEX,
IMPRECISE
DESIGNS ARE
ALLOWED



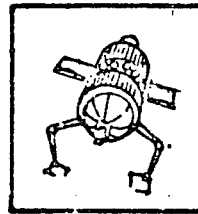
COMPLEX,
CHEAP,
"BATTLESHIP"
DESIGNS ARE
ADEQUATE



GROW,
ADAPT,
AVOID
OBSOLES-
CENCE



USE
MANNED AND
AUTOMATED
OPERATIONS



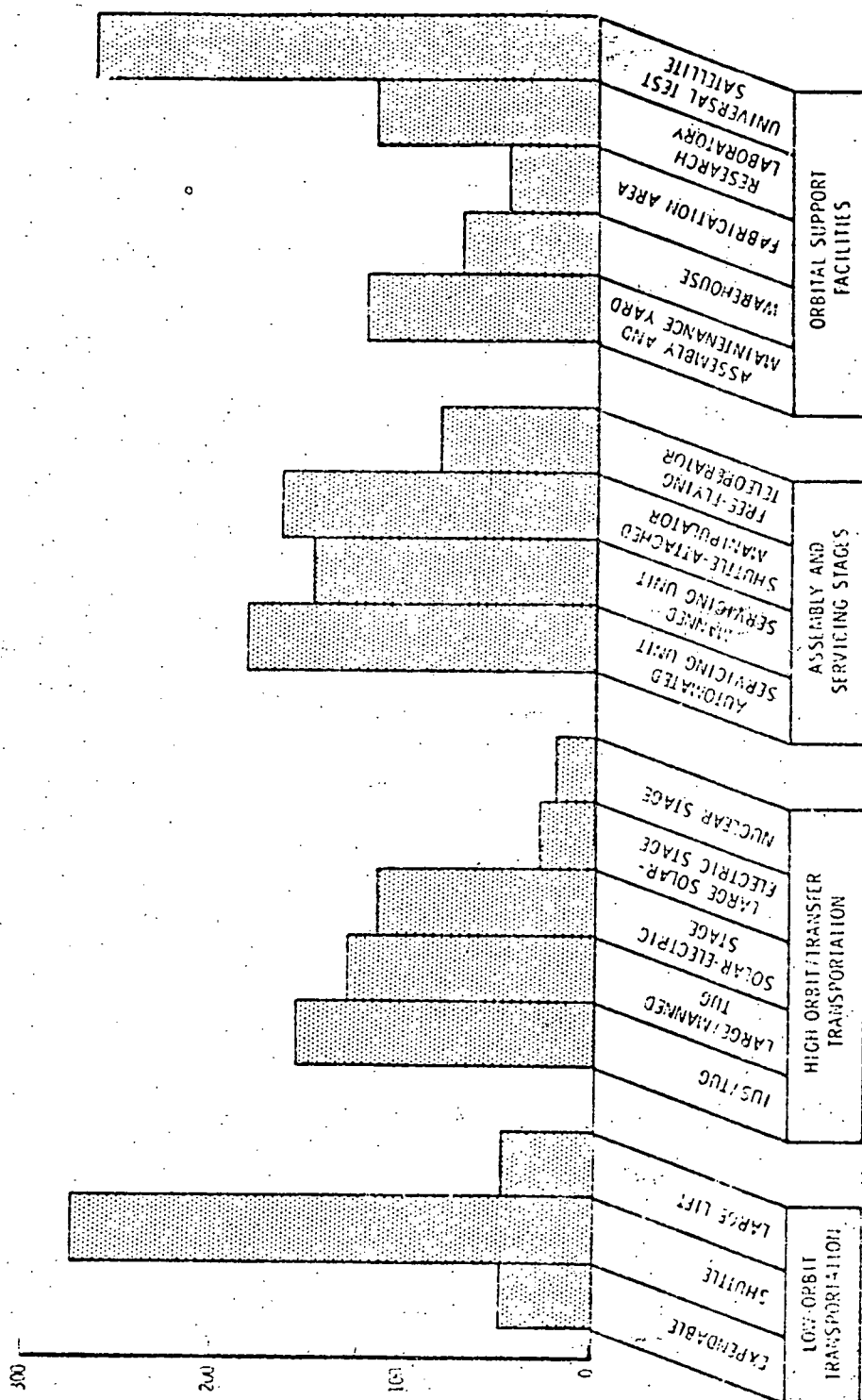
ORBITAL SUPPORT
FACILITIES REQ'D

- ASSEMBLY YARDS
- SERVICE STATIONS
- FACTORIES
- WAREHOUSES
- LABORATORIES
- HABITATS

ROLES OF MAN

- ASSEMBLER
- BUILDER
- REPAIRMAN
- OPERATOR
- RESEARCHER
- EXPLORER

Number of Mission Opportunities for Transportation and Support



ANTICIPATED NEEDS FOR BUILDING BLOCK VEHICLES AND FACILITIES

	NEAR-TERM		MID-TERM		FAR-TERM	
	1975	1980	1985	1990	1995	2000
Low-Earth Orbit Transportation Vehicles		Shuttle			Chemical LLV	Laser LLV
			T-III EXPENDABLES			
High-Orbit/Transfer Transportation Vehicles		IUS	Full Tug SEPS		Large Tug	Large SEPS
				Manned Tug Capsule		Nuclear
Orbital Operations Vehicles		Shuttle-Attached Manipulator	Automated Servicing Unit			
				Manned Servicing Unit Free-Flying Teleoperator		
Orbital Support Facilities		Spacelab	Universal Unmanned Test Satellite (STP BUS) Assembly and Maintenance Yard			
				Warehouse and Fabrication Plant	Permanent Research Lab	

SPACE INDUSTRIALIZATION PLANNING METHODOLOGY

by

A. N. Christakis, C. W. Hamilton and A. C. Robinson
Battelle Columbus Laboratories

ABSTRACT

Industrialization of space consists of the production of economically valued goods and services based on exploitation of extraterrestrial energy and materials resources, and of the unique properties of the extraterrestrial environment itself. Exemplary space produced goods and services include pharmaceutical, optics, micro-electronics, alloys, solar energy, communications, and earth resources and phenomenological information. It is envisioned that in the far-future course of such industrialization, permanent habitations will be established on the moon and in space. These habitats will be "industrial" centers supplying personnel; logistic engineering and operations support; and materials mined on the moon and asteroid belt.

Effective planning of this space industrialization venture offers challenges to the planner paralleling those of industrialization to the technologist. Of special note are problems of (1) quantitatively rationalizing near and far-future objectives and programs for achieving them, (2) building a credible planning data base out of largely normative inputs, (3) creating efficient participative planning mechanisms spanning important industry, government and public interest interfaces, (4) matching NASA-promulgation of staged evolution of facilities and logistic capability with concomitant growth and adjustment of industry infrastructure required for production of goods and services, and (5) seeking affordable and equitable long term financing arrangements for what may be the world's most capital intensive venture.

To systematically treat these and related aspects of the space industrialization, a plan for planning is proposed which consists of two interlocking planning methods. The first method is systems dynamics - a tool for quantitatively modeling the time-varying behavior of complex systems. For space industrialization planning, a suitable systems dynamic model will consist of three strata: (1) a forecasting stratum describing variables such as economic, resource, environment, industry output in a two-sector world model, (2) an industrialization requirements stratum describing industry infrastructure capabilities pertinent to space industrialization, and (3) a NASA decision stratum describing the staged evolution of space facilities and logistic systems. The second method consists of structural algorithms to be used in generating and organizing a normative data base out of which the systems dynamics will be derived. These algorithms include Interpretive Structural Modeling, Delphi and Cross-Impact Simulation, and are well suited for interactive workshops.

use in integrating study results and expert judgement. These means will be used to initially formulate and order objective hierarchies, program elements, developmental requirements, and intra-and inter stratum relationships. This normative information in conjunction with related quantitative study findings will be used to define and calibrate a dynamic model of the space industrialization process.

The planning knowledge captured by these methods will then make possible:

(1) assessment of the compatibility of short and long range objectives and their implied programmatic sequences, (2) identification of "natural" plateaus in the staged industrialization process at which points gains can be consolidated, future direction reassessed, etc., (3) design of easily executed simulation experiments to test alternative developmental options, and (4) efficient guidance of detailed product/service-specific-investigations and consequent mission planning.

SPACE INDUSTRIALIZATION

PLANNING METHODOLOGY

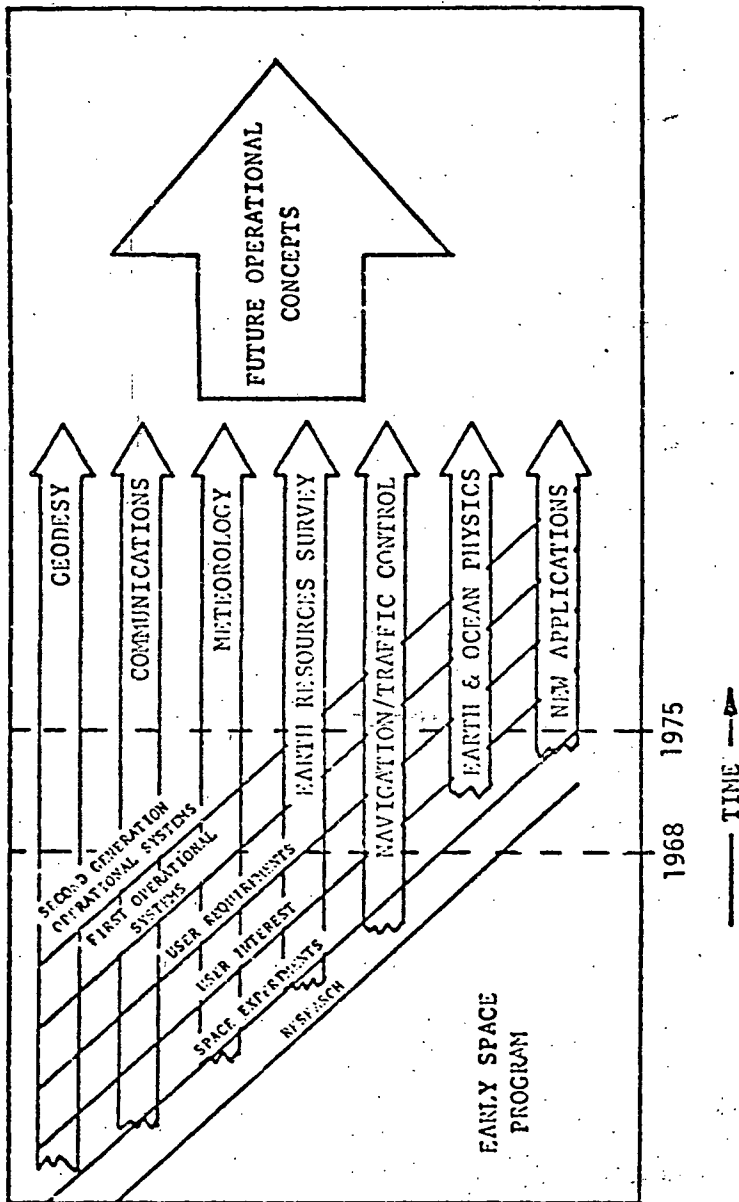
SPACE INDUSTRIALIZATION

TO PRODUCE ECONOMICALLY VALUED

- PRODUCTS
- SERVICES

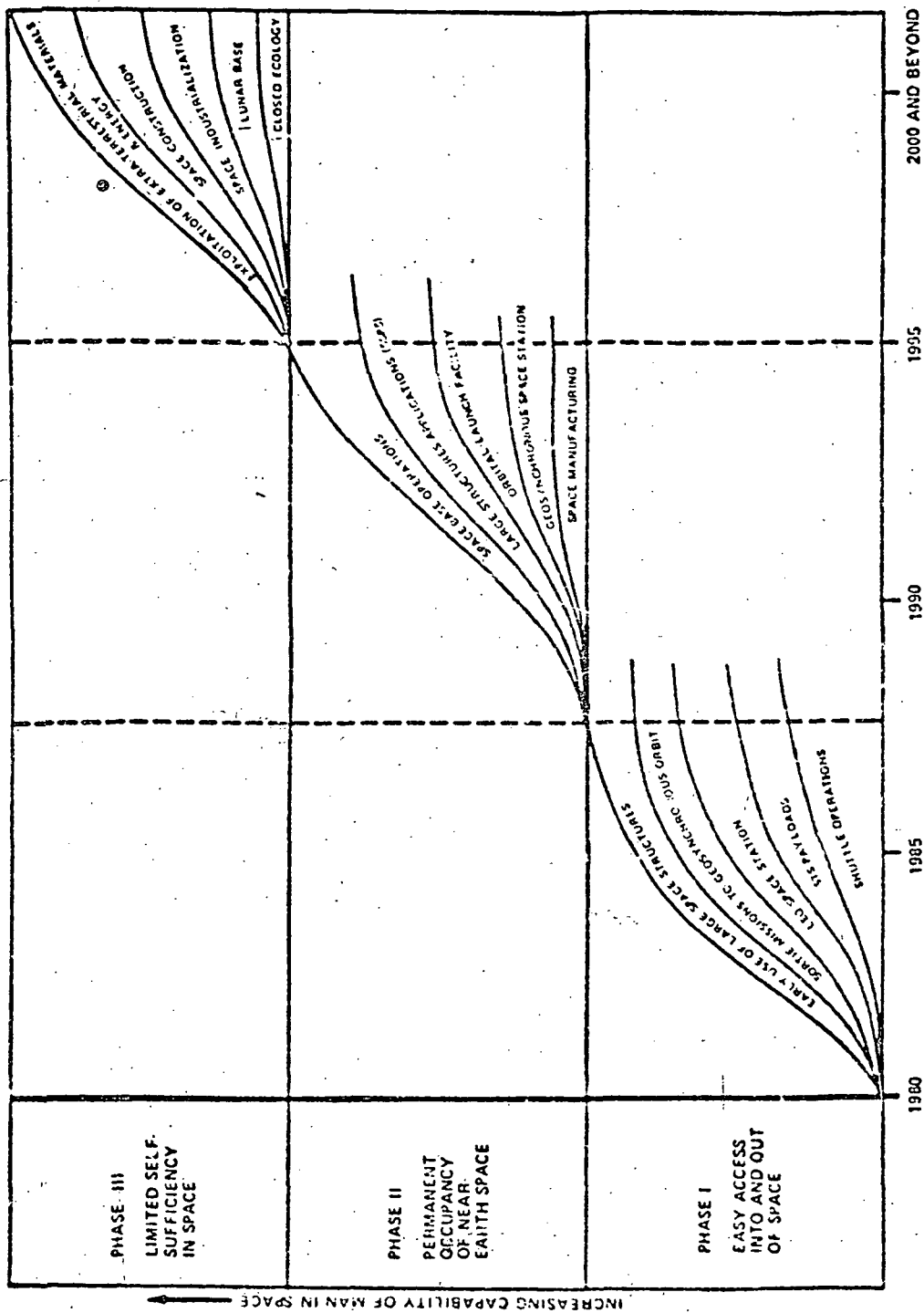
THROUGH THE UTILIZATION OF EXTRATERRESTRIAL

- ENERGY RESOURCES
- MATERIAL RESOURCES
- ENVIRONMENTS

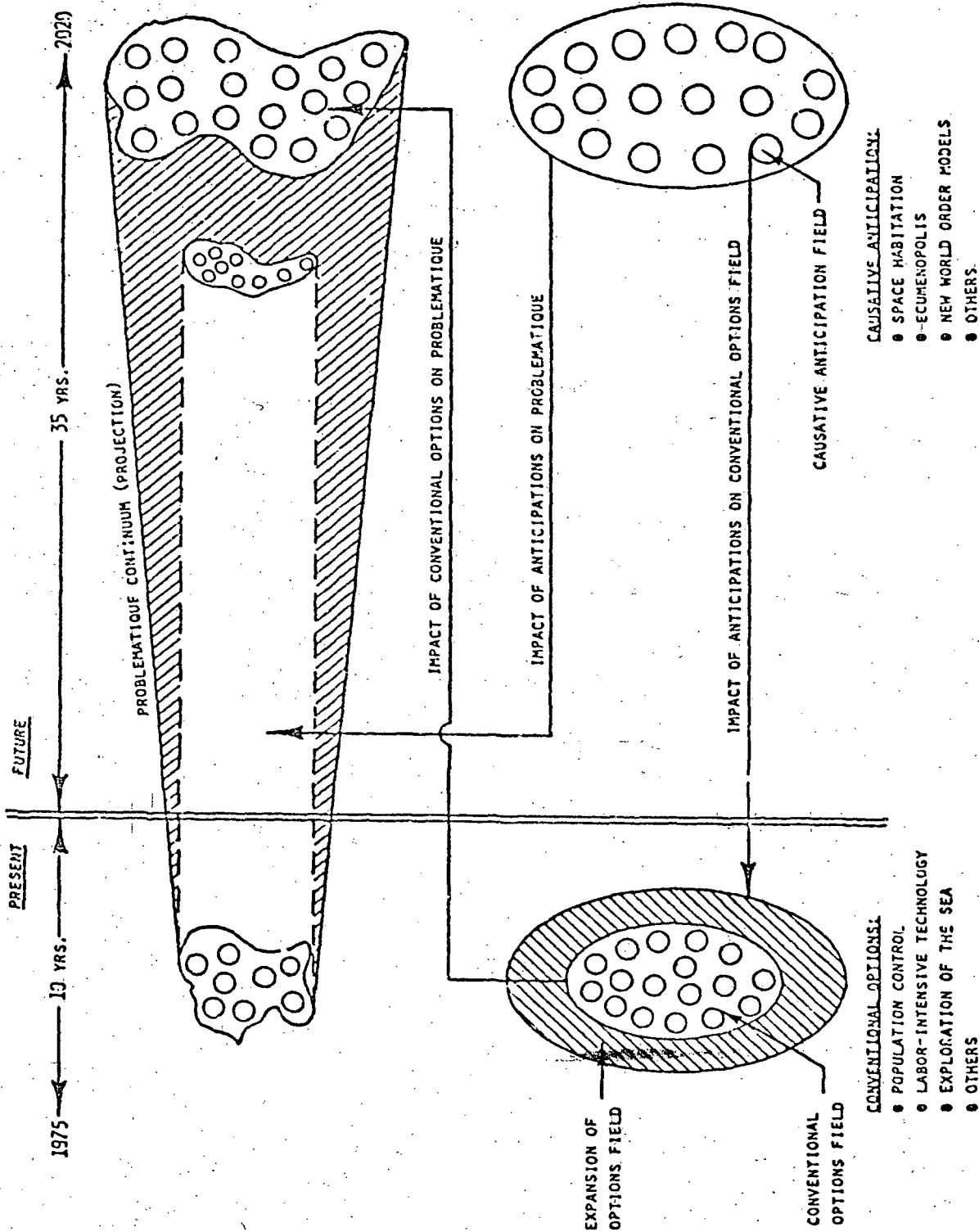


PHASED EVOLUTION OF SPACE APPLICATIONS

MAN'S PROGRESS IN SPACE



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1-17-76



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OVERVIEW OF THE RELATIONSHIPS BETWEEN GLOBAL PROBLEMATIQUE,
CONVENTIONAL OPTIONS, AND CAUSATIVE ANTICIPATIONS

SPACE INDUSTRIALIZATION:

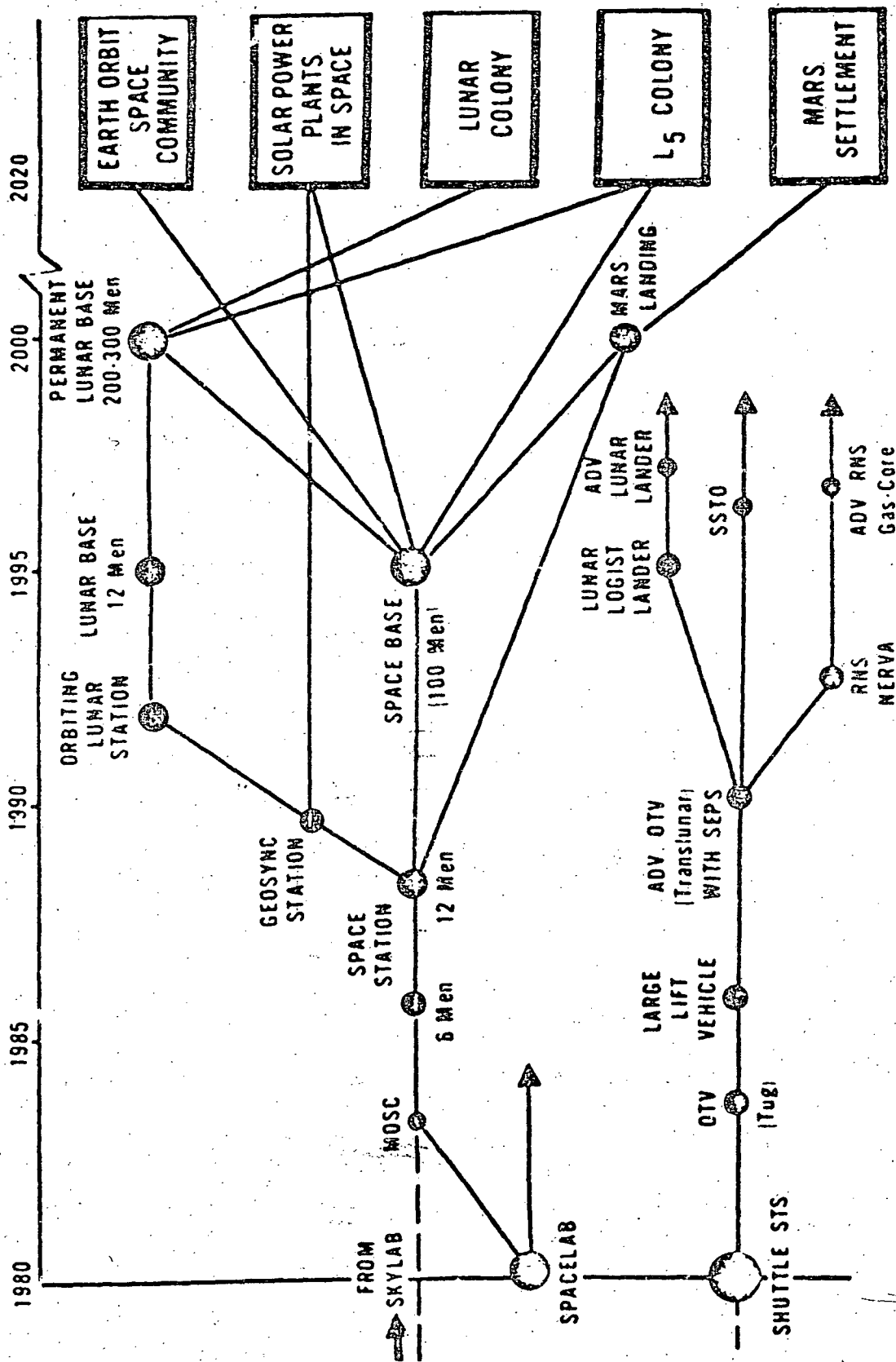
A PLAN FOR PLANNING

DESIRED ATTRIBUTES

PLANNING PROBLEMS

- | | |
|------------------------|---|
| • OUTPUT GOAL-DIRECTED | • CREDIBILITY OF GOALS FORUMATION |
| • NORMATIVE | • INFORMATION VALIDITY |
| • PROGRAM CONSISTENCY | • DYNAMICS OF PRODUCT/CAPABILITY/RESOURCE FLOWS |
| • ADAPTATIVE | • RESPONSE TO FUTURE EVENTS WITHOUT DESTRUCTIVE LOSS OF PLAN CONTINUITY |

EVOLUTIONARY PATHS TO FAR-FUTURE SPACE ENDEAVORS



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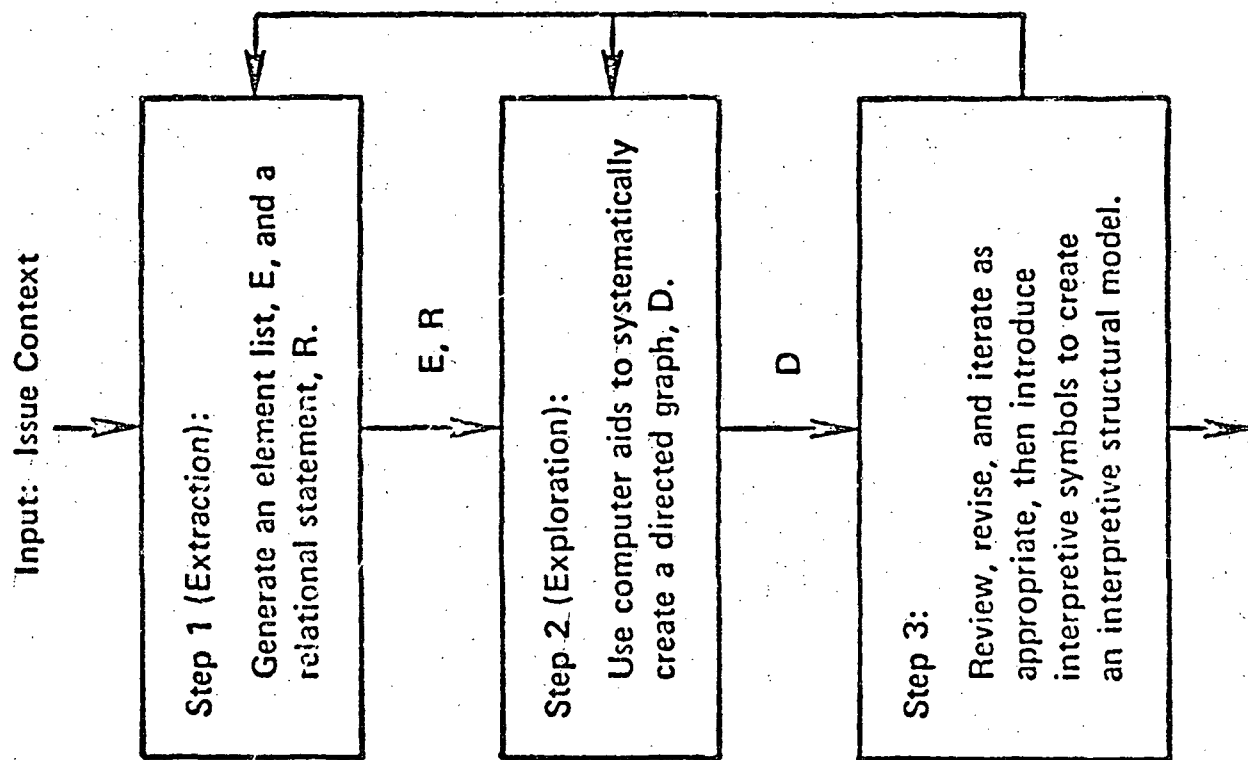
TYPICAL INDUSTRIALIZATION REQUIREMENTS

- FACILITY LOCATION. LEO, GEO, Lunar Base
- LOGISTIC SYSTEMS SUPPORT Transportation, Material Handling
- RAW MATERIALS SUPPLY
- ENERGY Installation, Manufacturing, Habitation
- ENVIRONMENT. Manufacturing and Habitation
- ENGINEERING AND OPERATIONS
- PERSONNEL
- MANAGEMENT SYSTEMS Industry Control, Industry/Government Interfaces
- FINANCING. Development and Operations



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THE BASIC OPERATIONAL STEPS FOR APPLICATION OF THE ISM TECHNIQUE



APPLICATION OF ISM TO SPACE INDUSTRIALIZATION FUTURE PLANNING

SPACE INDUSTRIALIZATION PLANNING STRATA

- FAC - Facilities and Logistic Systems
- PRO - Products & Services
- CAU - Industry-Economic & Socio-Demographic Factors
- RES - Resource Requirements and Availability

SPACE INDUSTRIALIZATION IMPACTING AND IMPACTED RELATIONSHIPS

- ng - "Next Generation of"
- ef - "Made Commercially Feasible By"
- nc - "Necessary Condition For"
- sc - "Significant Contribution To"
- pr - "Propagated By"

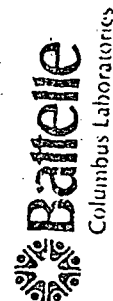
	FAC	PRO	CAU	RES
FAC	ng	cf nc	-	nc
PRO		ng	sc nc	cf
CAU			pr	pr nc
RES				pr

INTRA-STRATA STRUCTURES

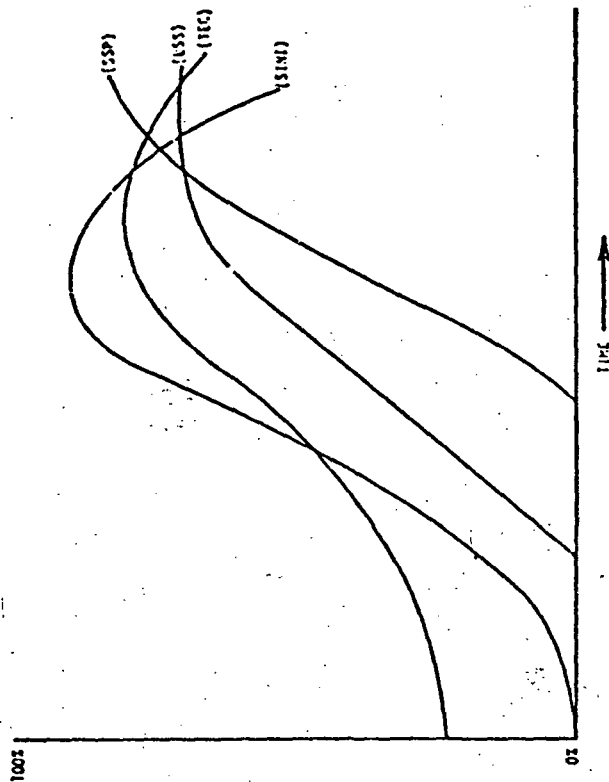
- Objectives Tree
- Facilities Evaluation Ordering
- Product Growth Sequence

BETWEEN-STRATA STRUCTURES

- Relevance Tree
- Facility/Product Capability
- Product/World Problem Interaction



KSIM: A CROSS IMPACT SIMULATION METHOD FOR INVESTIGATING COMPLEX SYSTEMS



	TERRESTRIAL ENERGY COST	SPACE INDUST. NET INVESTMENT	LARGE STRUCTURES IN SPACE	SPACE SOLAR PLAN
(SINI) SPACE INDUST. NET INVESTMENT	0	0	0	0
(LSS) LARGE STRUCTURES IN SPACE	0	0	0	0
(SSP) SPACE SOLAR POWER	0	0	0	0

NORMALIZED RANGE OF CROSS-IMPACT VARIABLES

$$SSP(t + \Delta t) = SSP(t) \cdot \exp \left\{ \frac{1 \cdot \Delta t \sum \text{negative impact terms}}{1 \cdot \Delta t \sum \text{positive impact terms}} \right\}$$

SYSTEMS DYNAMICS PLANNING:

SUMMARY OF KEY ATTRIBUTES

- COMPATIBLE SHORT-AND LONG RANGE PLANNING
- INTEGRATION OF GLOBAL NEEDS/INDUSTRY REQUIREMENTS/NASA DECISION STRATA
- CAPABILITY TO TEST PLAN OPTIONS THROUGH DYNAMIC SIMULATION EXPERIMENTS
- EASY TO UPDATE AS NEW INFORMATION BECOMES AVAILABLE

A I A A / M S F C S Y M P O S I U M

o n

" S P A C E I N D U S T R I A L I Z A T I O N "

° Session on

S P A C E T R A N S P O R T A T I O N

Session Chairman : Gerald W. Driggers, Southern Research Institute

Co-Chairman : Peter Paul Plank, Martin-Marietta Aerospace Corporation

Presenters and Papers :

Les Fero	Overview
Gordon Woodcock	Advanced Space Transportation System Requirements
Luther T. Spears, Jr.	Shuttle Booster/Propulsion Growth Concepts
John Decker, B. Z. Henry, and C. Eldred	Advanced Earth Orbital Transportation Systems Technology
Rudi Haefeli	Single-Stage-to-Orbit Vehicles Using Technology Projections
Rudi Beichel	Liquid Propulsion System Effects on Design of Large Vehicles
R. Eugene Austin	Orbital Transfer Vehicle Concepts
J. P. Hethcoat and J. White	Aeromaneuvering Orbit Transfer Vehicles for the Space Transportation System

Wednesday afternoon, May 26, 1976

ADVANCED SPACE TRANSPORTATION OVERVIEW

By

Lester K. Fero
Advanced Programs Office
NASA Headquarters

Future Space Transportation was described as a system evolving from the present STS by exploiting orbital assembly and refueling of upper stages carried in the Shuttle bay. Shuttle Growth Studies were described as an examination of booster options for further cost reduction through full reusability and possible replacement of the Solid Rocket Boosters with Liquid Boosters. A Shuttle derived Heavy Lift Launch Vehicle was also described based on Shuttle Growth status in the mid - 1980's.

Commercial utilization of space was described as highly dependent on reduced transportation costs along the lines mentioned in the "Outlook for Space" report. The importance of technological progress in propulsion, structural and operational systems were cited as keys to reduced transportation cost in addition to full reusability.

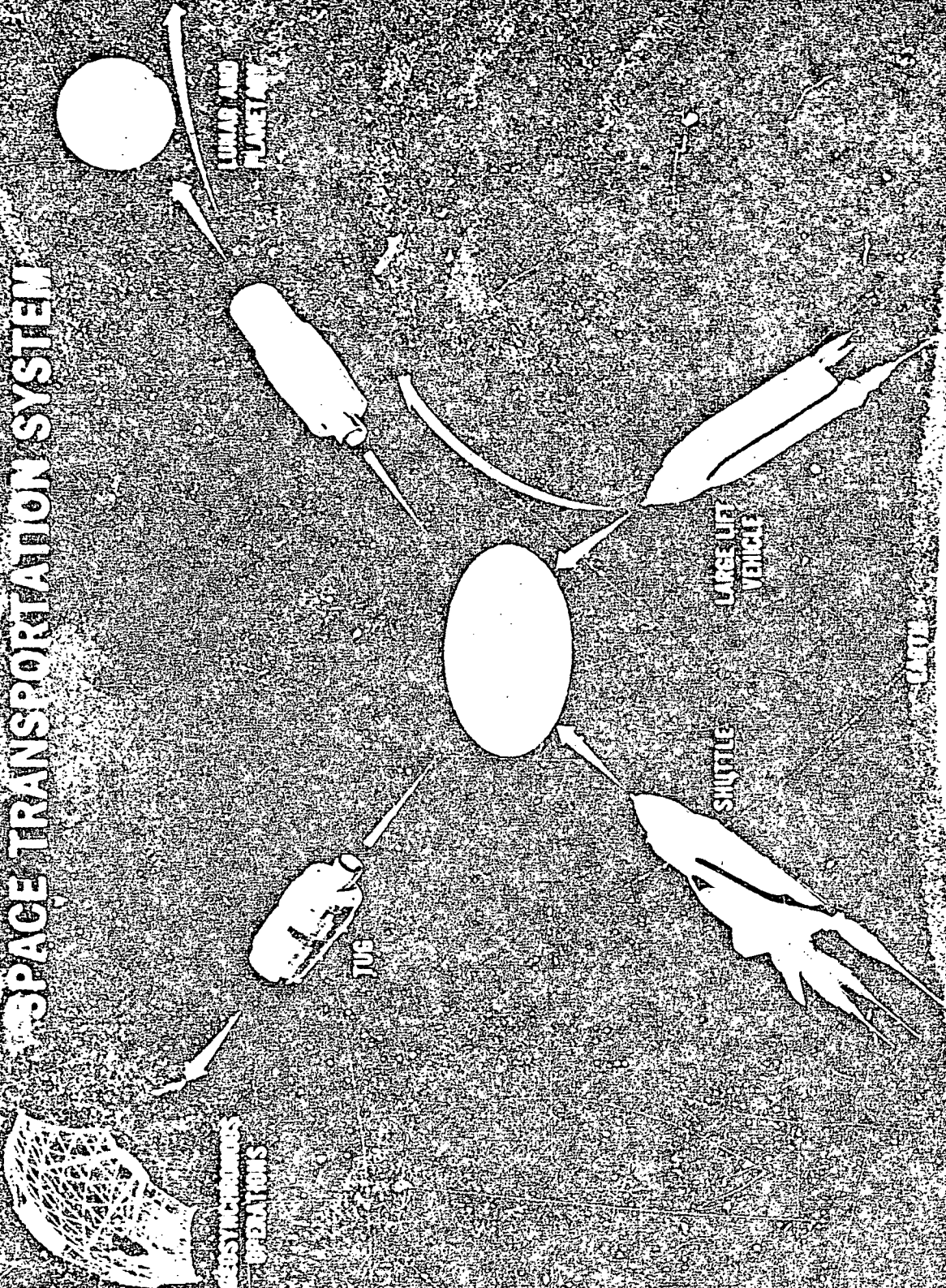
A scenario for needed transportation developments was described for earth orbit missions. It included a family of Orbit Transfer Vehicles, Heavy Lift Vehicles, and an Advanced Vehicle which could be a single stage to orbit concept or "Space Express" launched from and landed at multiple sites for easy commercial access.

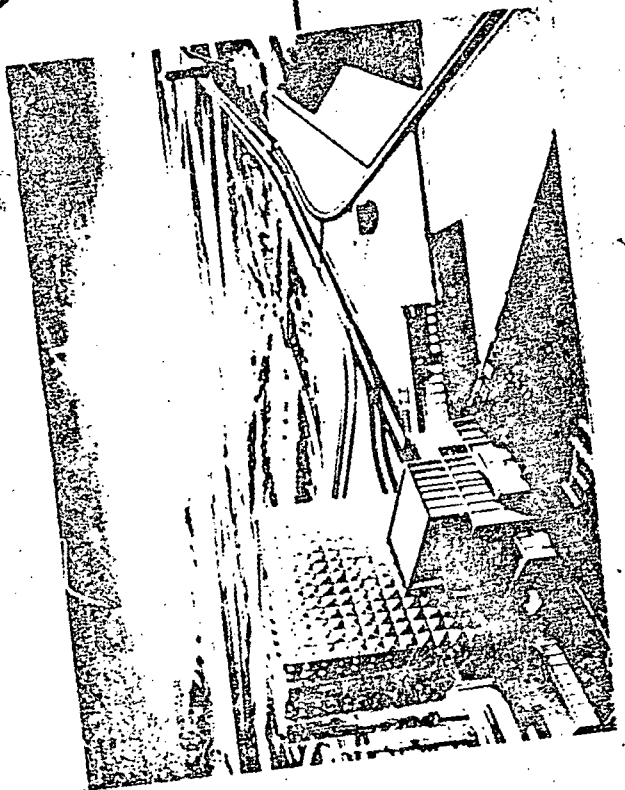
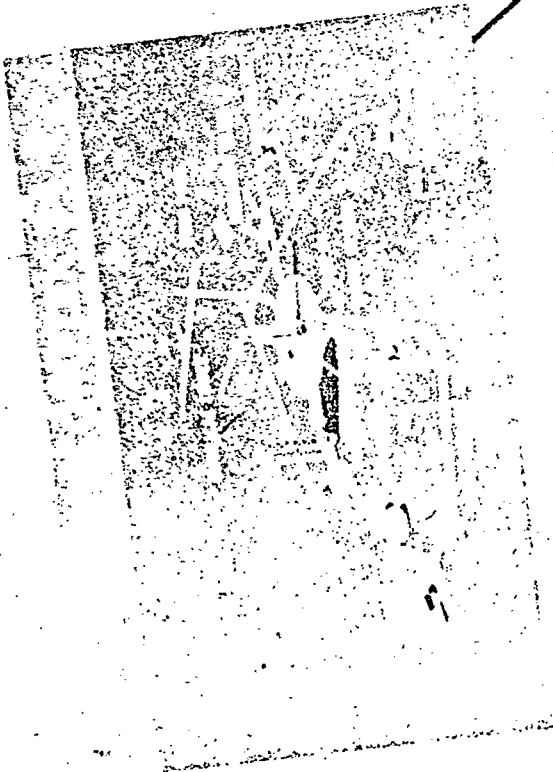
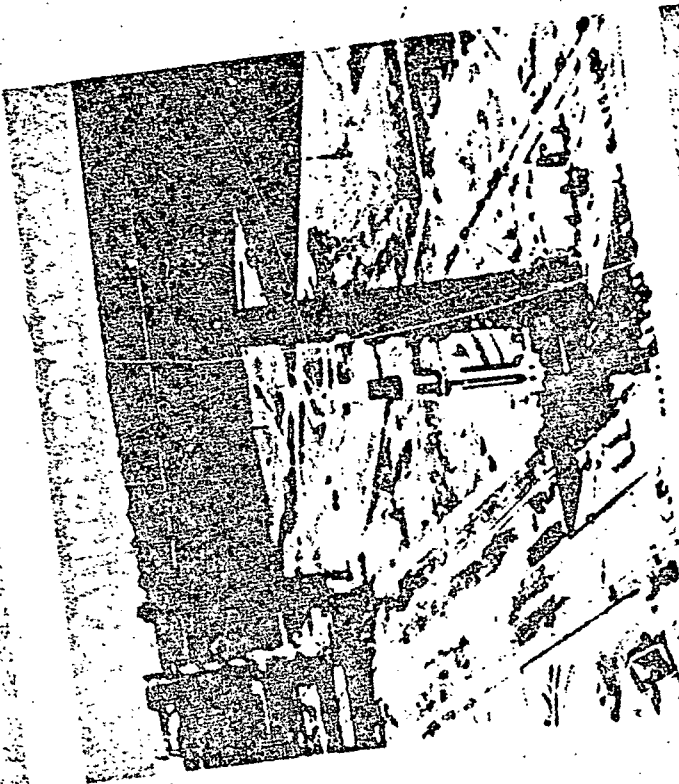
SPACE TRANSPORTATION OVERVIEW
FOR
SPACE INDUSTRIALIZATION SYMPOSIUM
AT MSFC
MAY 26, 1976

Lester K. Fero
Advanced Programs, OSF
NASA Headquarters

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SPACE TRANSPORTATION SYSTEM

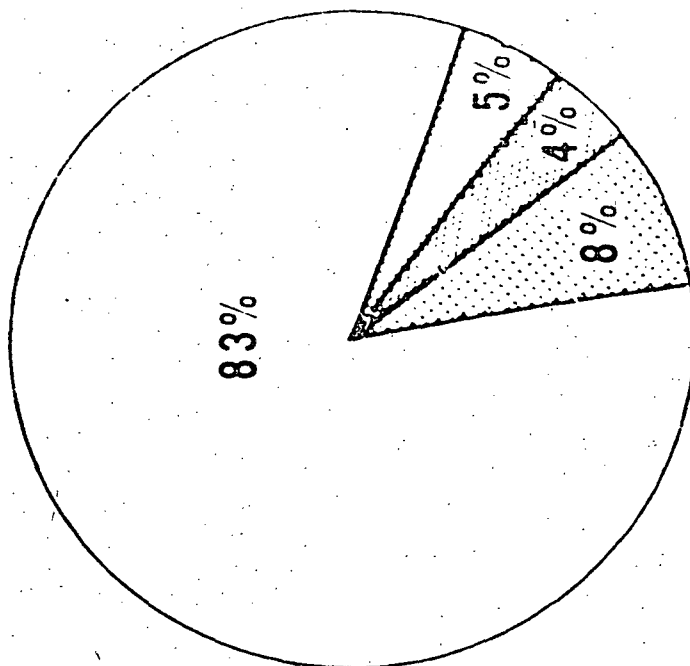




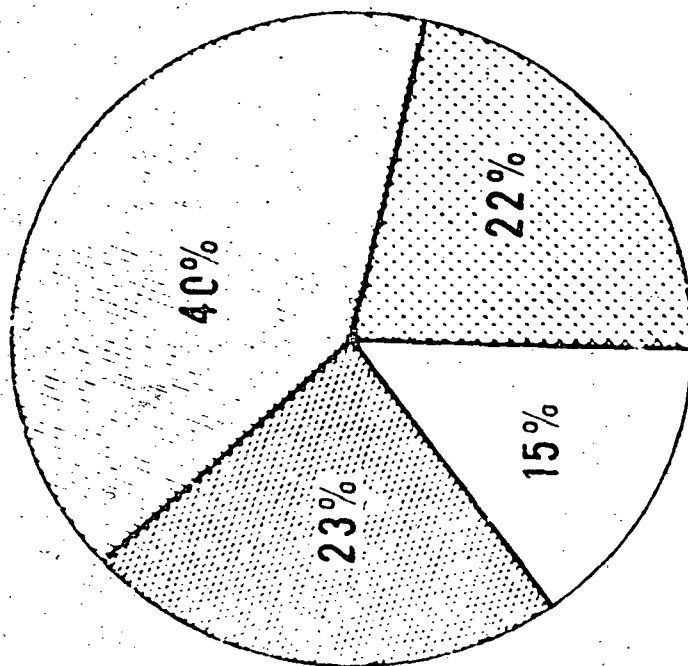
	CY66	CY67	CY68	CY69	CY70
SAT IB	6	8	3	8	8
SAT V		5	12	16	16
TOTAL	6	13	20	24	24

SHUTTLE SYSTEM COST ELEMENTS

INVESTMENT



OPERATING COSTS



ORBITER

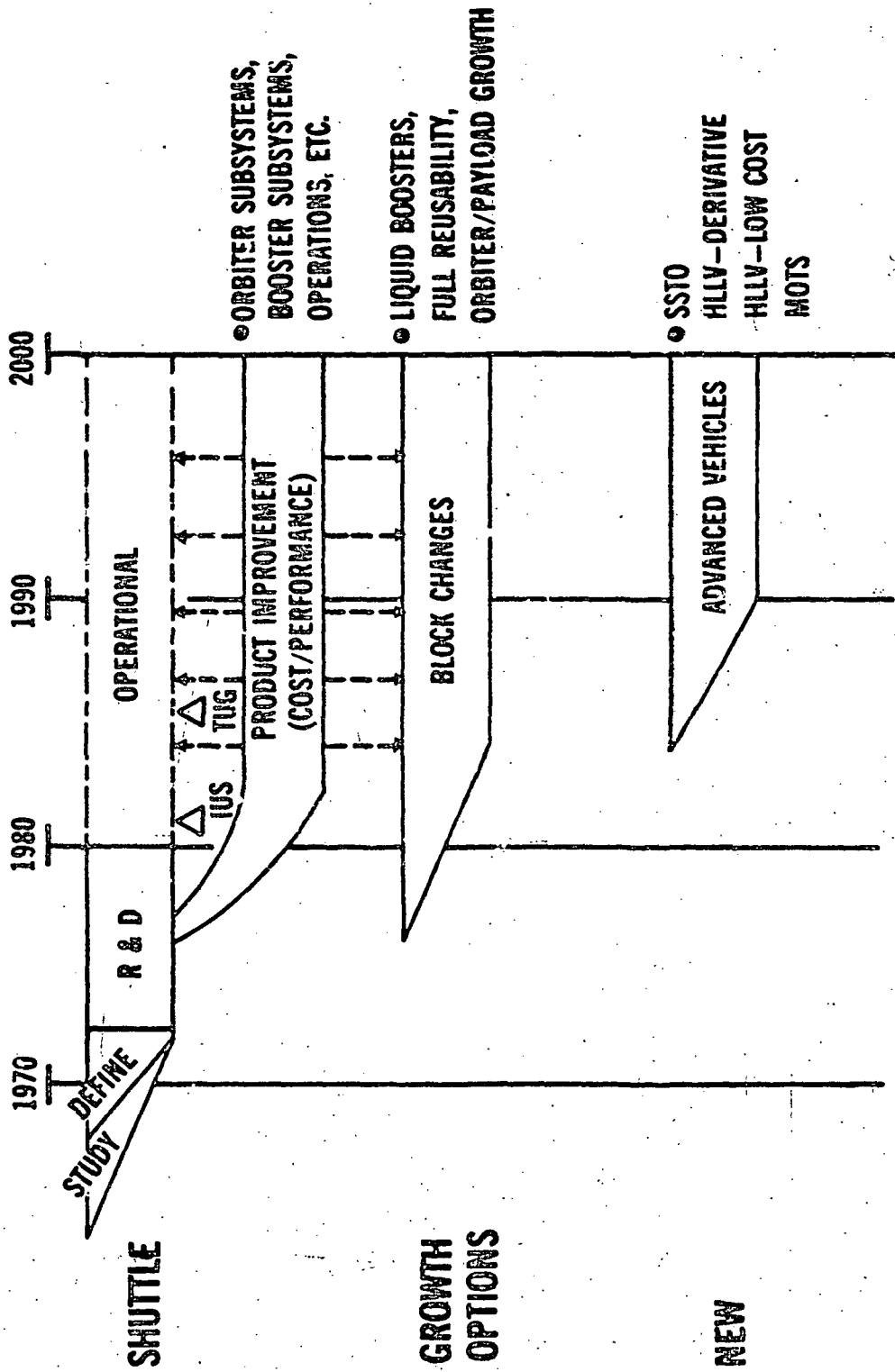
EXTERNAL TANK

SOLID ROCKET BOOSTER

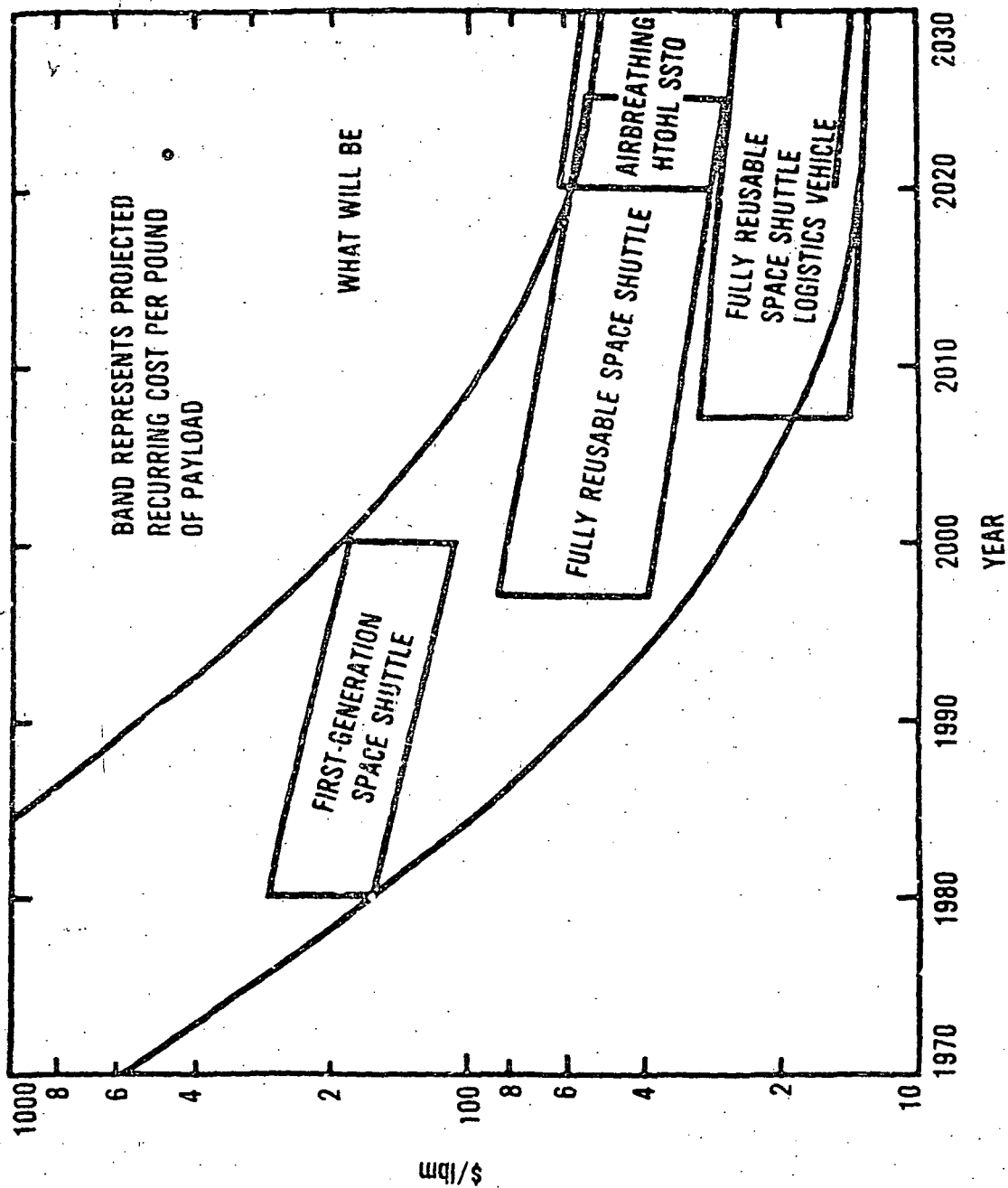
LAUNCH, LANDING, AND OPERATIONS FACILITIES

NASA HQ MT76-809 (1)

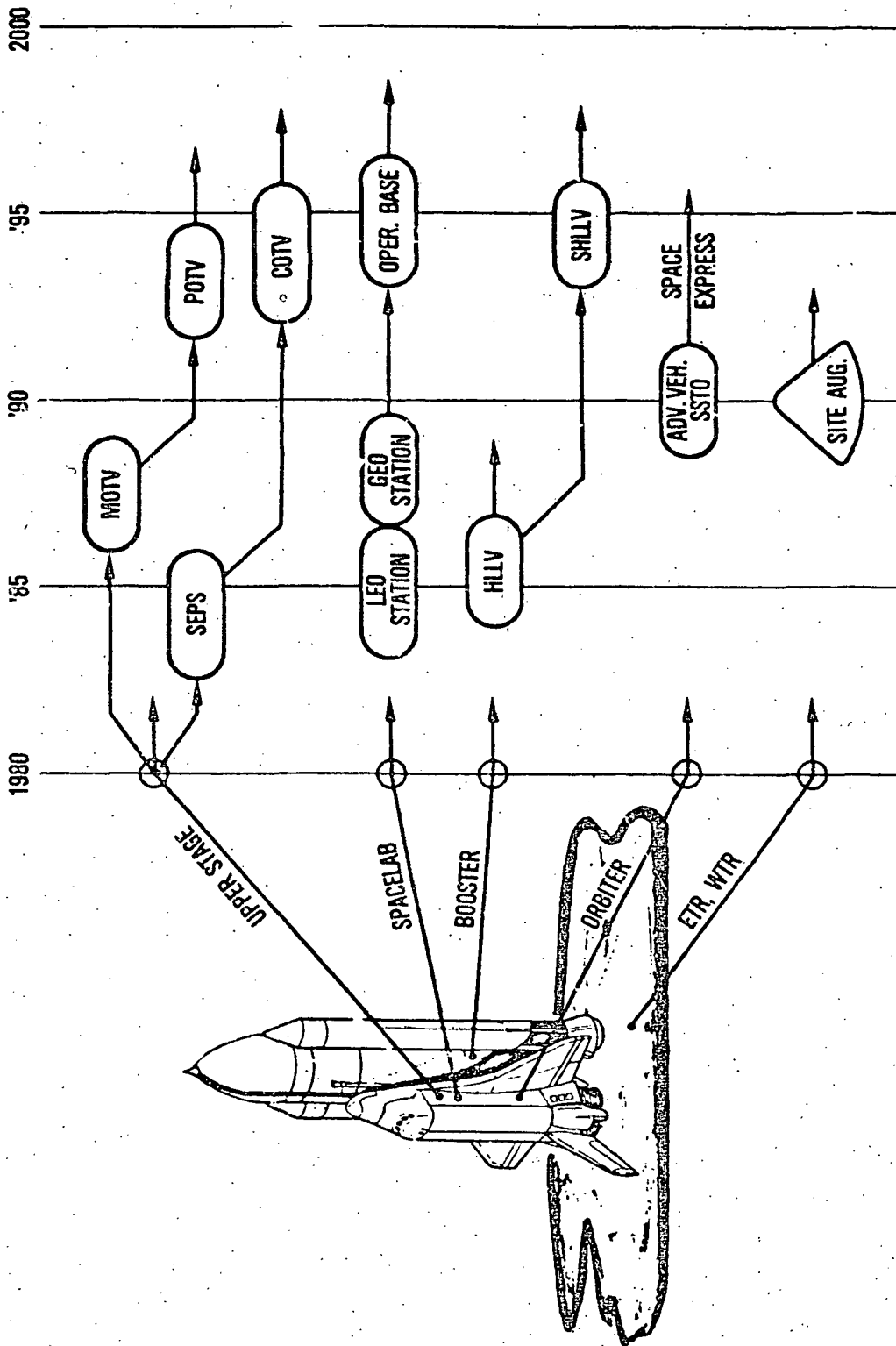
SHUTTLE GROWTH



NASA HQ MT 75-7017(1)
6-16-75



ADVANCED SPACE TRANSPORTATION SYSTEM



ADVANCED SPACE TRANSPORTATION

OBSERVATIONS BY ADVOCATES:

O COMMERCIAL UTILIZATION OF SPACE HIGHLY DEPENDENT ON REDUCED TRANSPORTATION

COSTS

O REDUCED TRANSPORTATION COSTS KEYED TO TECHNOLOGICAL PROGRESS IN PROPULSION

STRUCTURAL AND OPERATIONAL SYSTEMS

O OVERALL NATIONAL NEEDS BENEFIT FROM INCREASED OPERATIONAL FLEXIBILITY/

CAPABILITY

SPECIAL PURPOSE NEEDS MAY DICTATE UNIQUE VEHICLE CONCEPTS AND OPERATING

CHARACTERISTICS

C ADDITIONAL SYSTEMS ENGINEERING STUDIES NECESSARY TO IDENTIFY/CLARIFY THE

FOCUS OF ADVANCED TRANSPORTATION TECHNOLOGY/PLANNING

FUTURE SPACE TRANSPORTATION REQUIREMENTS

This briefing provides a synopsis of transportation requirements for advanced space mission in the 1985-2000 time frame. It is based on the Future Space Transportation Systems Analysis Study, Contract NAS9-14323, being conducted for NASA-JSC by Boeing Aerospace Company. This study has identified and assembled data on transportation requirements for missions ranging from low Earth orbit space stations to satellite power systems. The missions have been grouped into four scenarios representing a range of potential space futures.

Aggregate requirements, as well as traffic models, for each of the scenarios are shown in the briefing charts. A range of potential transportation options have been considered, from use of the shuttle in its presently-planned or uprated configurations to large new systems. A variety of orbit transfer systems have been considered, with most effort on LO_2/LH_2 vehicles; they are found to be the most promising option in all but a few cases.

The launching and orbit transfer of satellite power systems has been analyzed separately, as this requirement merits unique treatment. The most economical system found by this study has been a large fully reusable Earth launch vehicle for freight transport to low Earth orbit and self-powered electric transfer (the satellite modules themselves generate the electric power for the electric propulsion) from LEO to GEO. The use of LO_2/LH_2 orbit transfer vehicles for LEO-GEO transfer of payloads, with satellite construction at GEO, was found to be a higher cost, but lower technical risk, economically acceptable option.

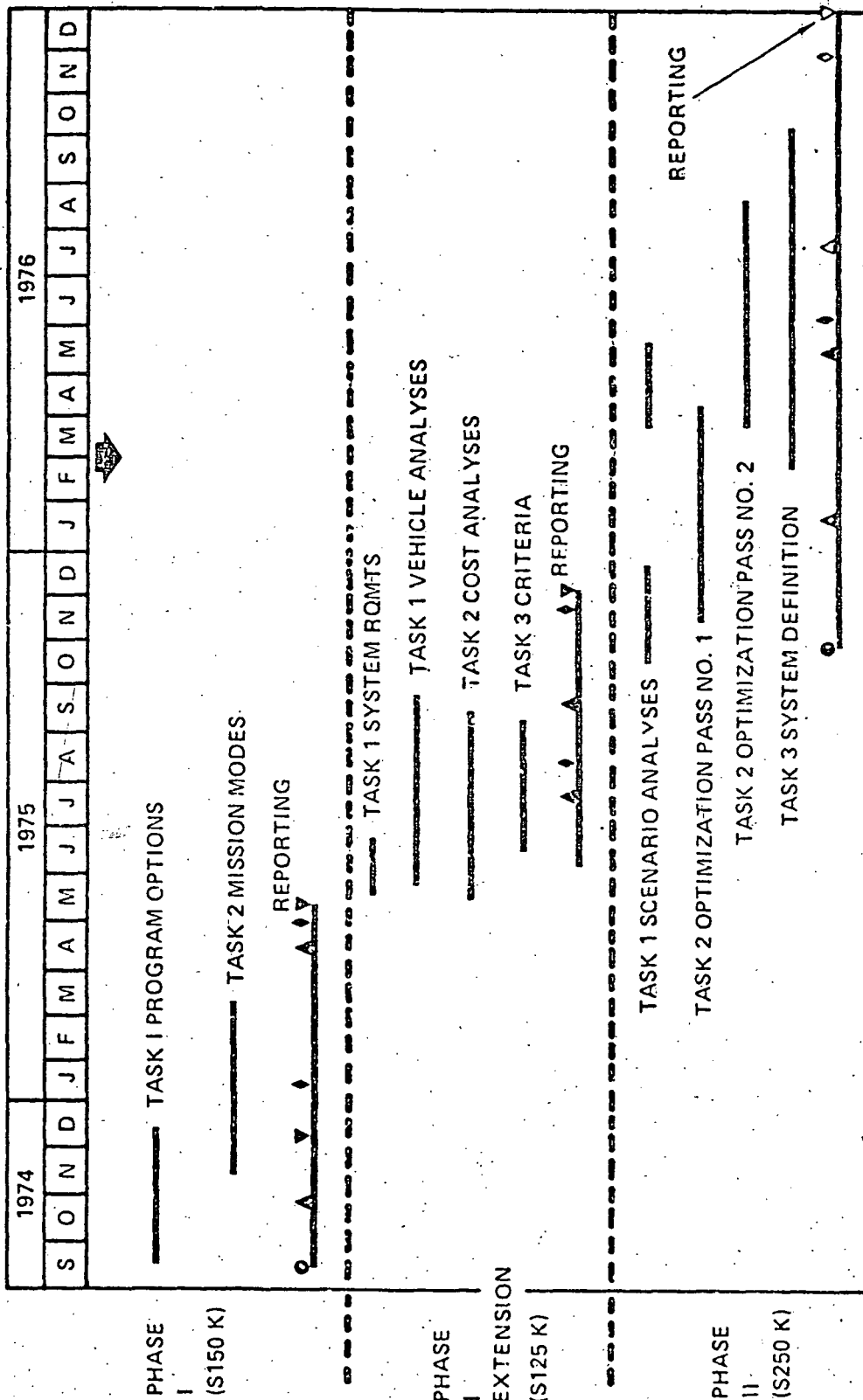
Study Objectives

BOEING

- Define potential transportation requirements resulting from a range of potential future space mission options
- Identify potential mission/transportation modes and system options capable of satisfying the requirements
- Define these mission/transportation modes and systems
 - Vehicle characteristics
 - Performance
 - Cost
- Synthesize and select, from these defined options, optimized transportation systems for a range of potential space program evolutions
- Define adaptive evolutionary strategies for future space transportation capability development

Future Space Transportation Systems Analysis Schedule Overview

BRIEFING

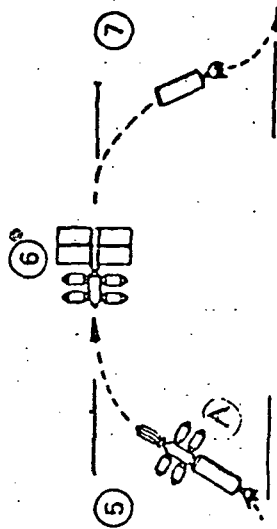
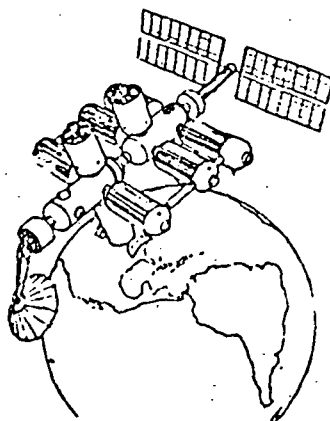


FSTSA Phase I

BOEING

MISSION OPTIONS AND
REQUIREMENTS

TRANSPORTATION MODES
AND OPERATIONS ANALYSIS



NOT TO SCALE

<1 DAY | <1 WEEK | <1 DAY

PAYLOADS	FEATURES	MASS (LB) (LARGEST)	SIZE (FT) (LARGEST)
STATION MODULES	• 8 MAN • 9 MODULES	48,000	14 X 42
CREW TRANSFER VEHICLE	• 4-8 MEN • 2 WK CAPAB	15,000	14 X 14
RESUPPLY MODULE	• 180 DAY CAP. • REUSABLE	39,000	14 X 37

(6)

(5)

- STOW SOLAR ARRAY
- DELIVER CLUSTER (A) TO GEO WITH OTV
- DEPLOY SOLAR ARRAY
- ACTIVATE ALL SUB SYSTEMS
- CHECKOUT

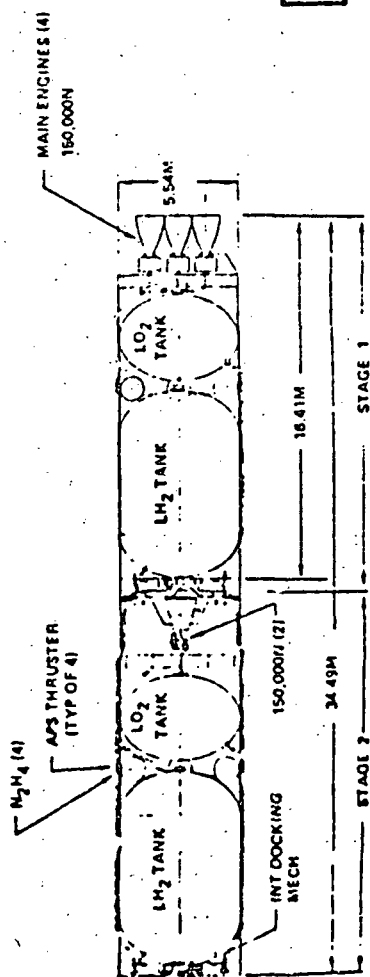
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FUTURE SPACE TRANSPORTATION SYSTEMS

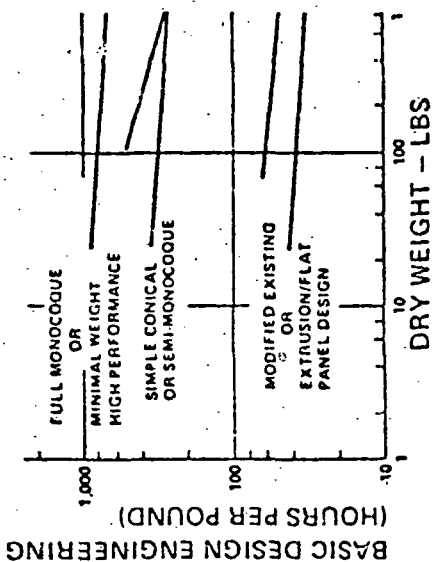
FSTSA Phase I Extension

BEING

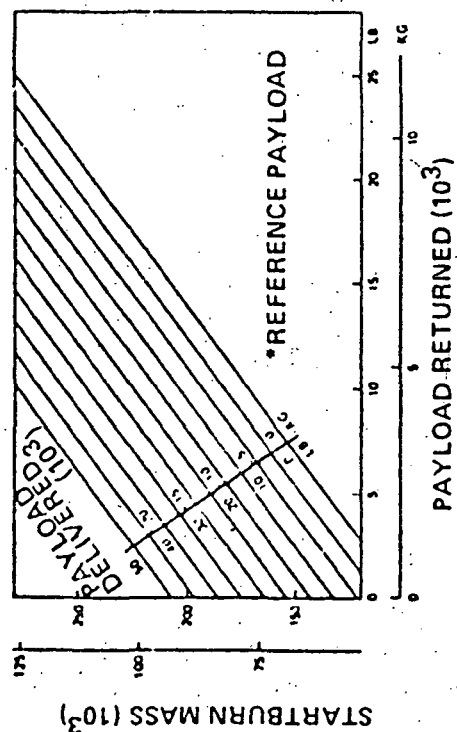
CONFIGURATIONS



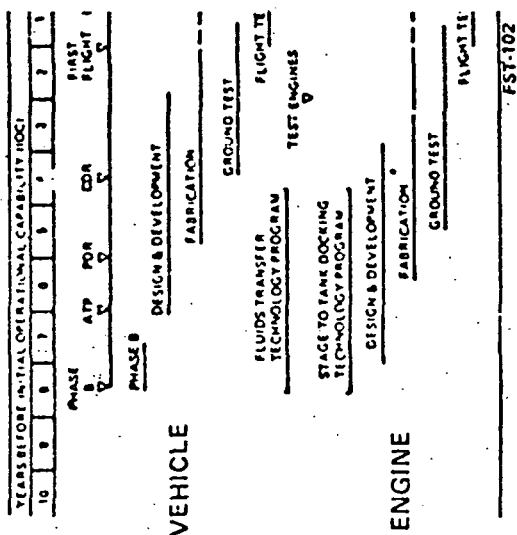
COST



MASS & PERFORMANCE



PROGRAMMATICS



FSTSA Phase II

BEING

SCENARIOS

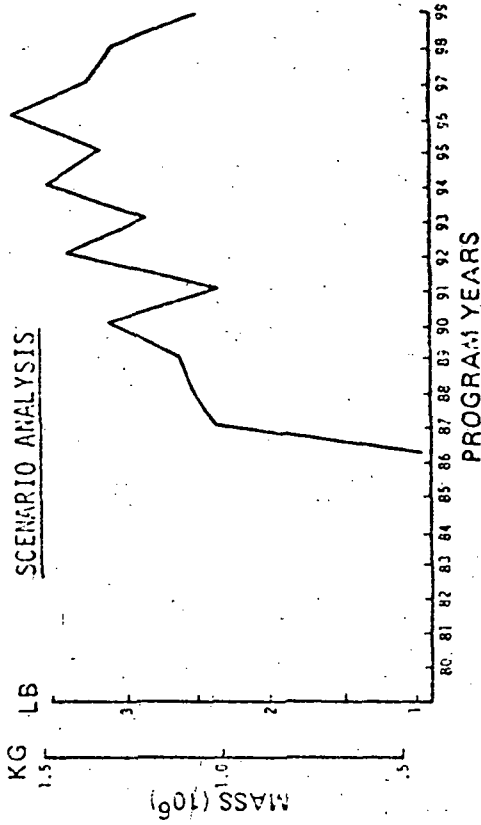
SCENARIO NO. -----

AUTOMATED PAYLOADS -----

SPACE STATION -----

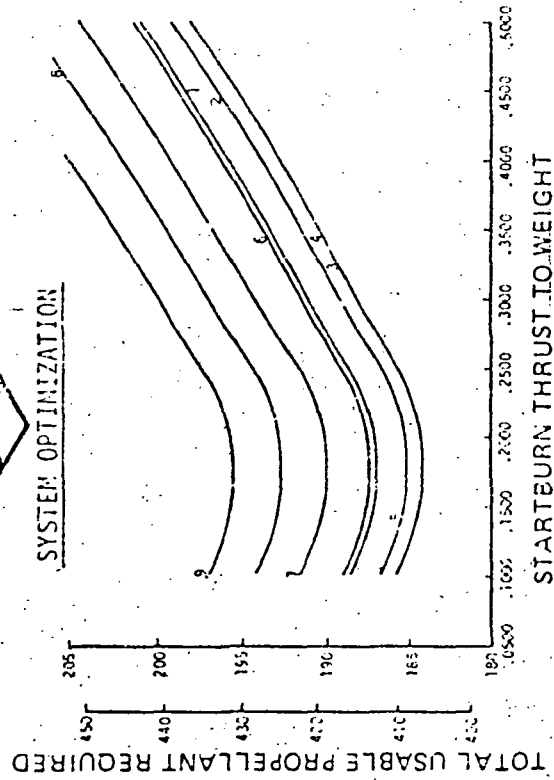
GEO SORTIE -----

PILOT PLANT -----

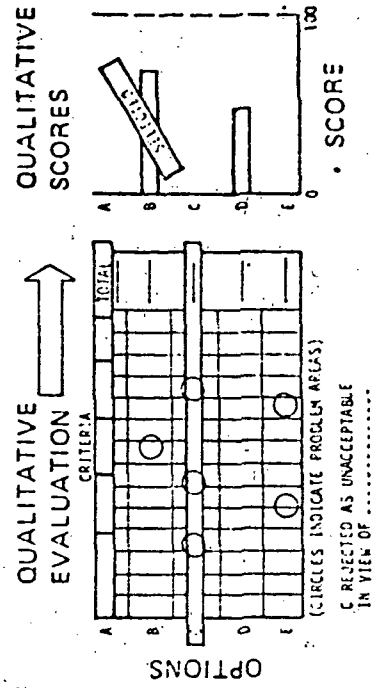


133

SYSTEM OPTIMIZATION



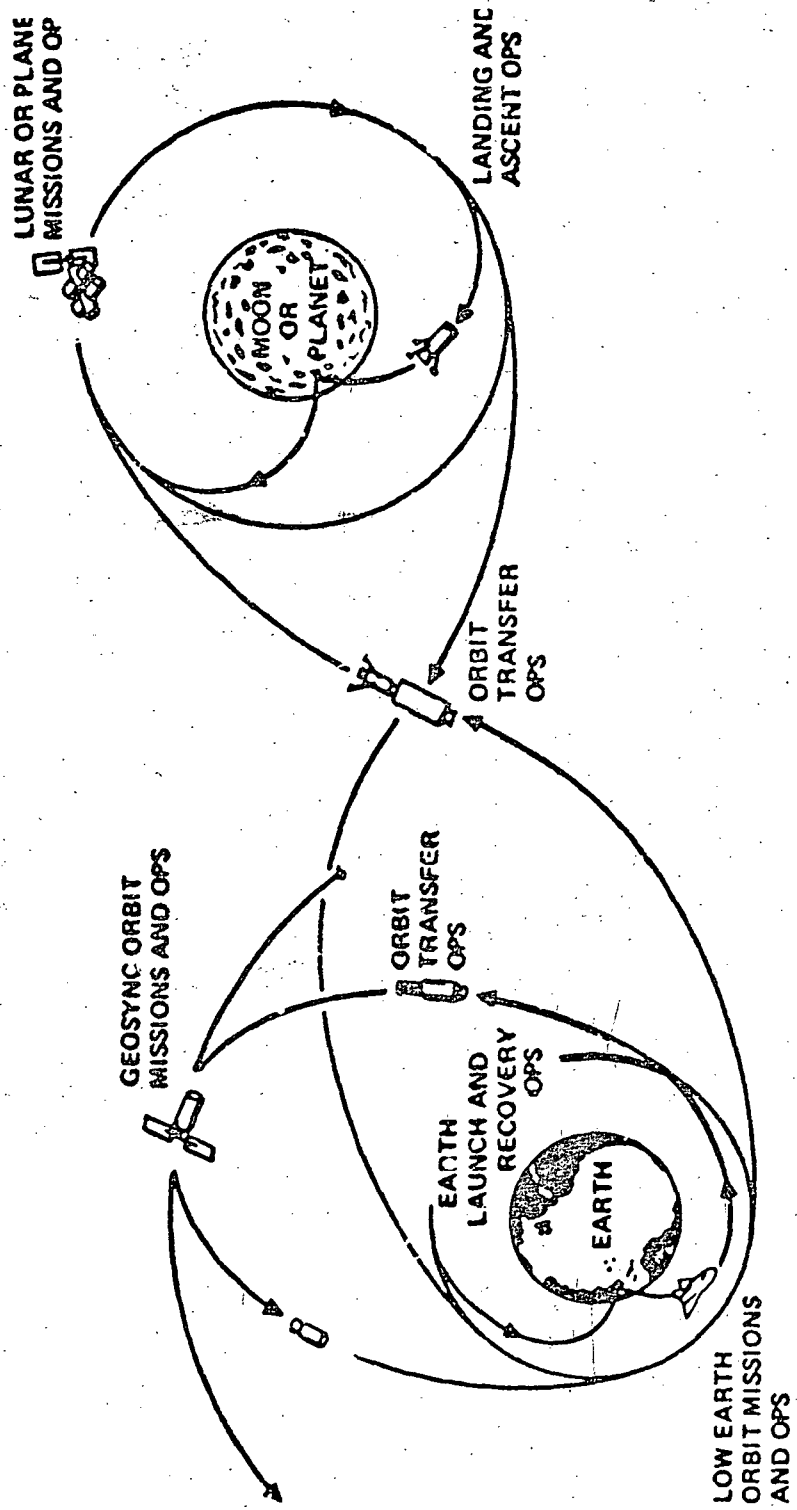
SYSTEM SELECTION



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Mission Transportation Operations

BOEING

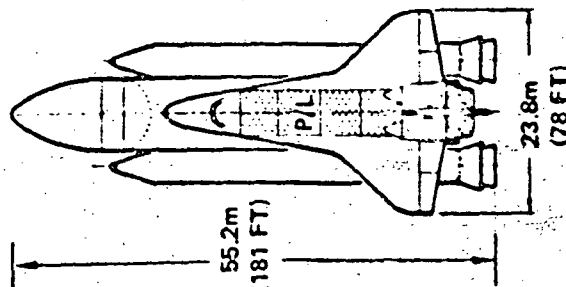


FUTURE
SPACE
TRANSPORTATION
SYSTEMS

Earth Launch Vehicle Candidates

DOE

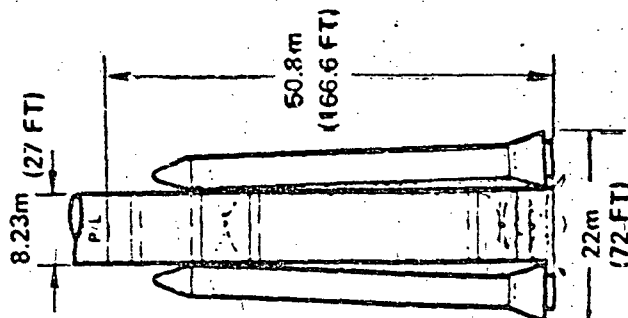
SPACE SHUTTLE



- PAYLOAD 25 000 KG*
@ 270-NM (55,000 LB)*
28.5 DEG

- GLOW 1.91 KG
(106) (4.2 LB)
- WITH ONE OMS KIT

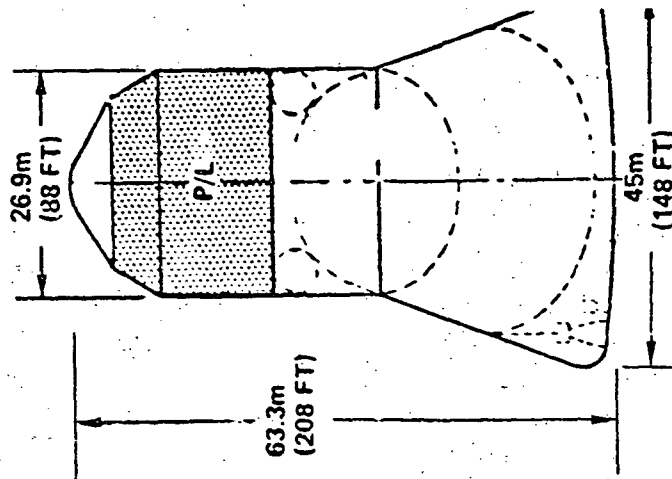
HLV



- W/2 SRB 72 270 KG
(159,000 LB)
- W/4 SRB 110 910 KG
(244,000 LB)

- W/4 SRB 3.2 KG
(7.09 LB)

LC HLV



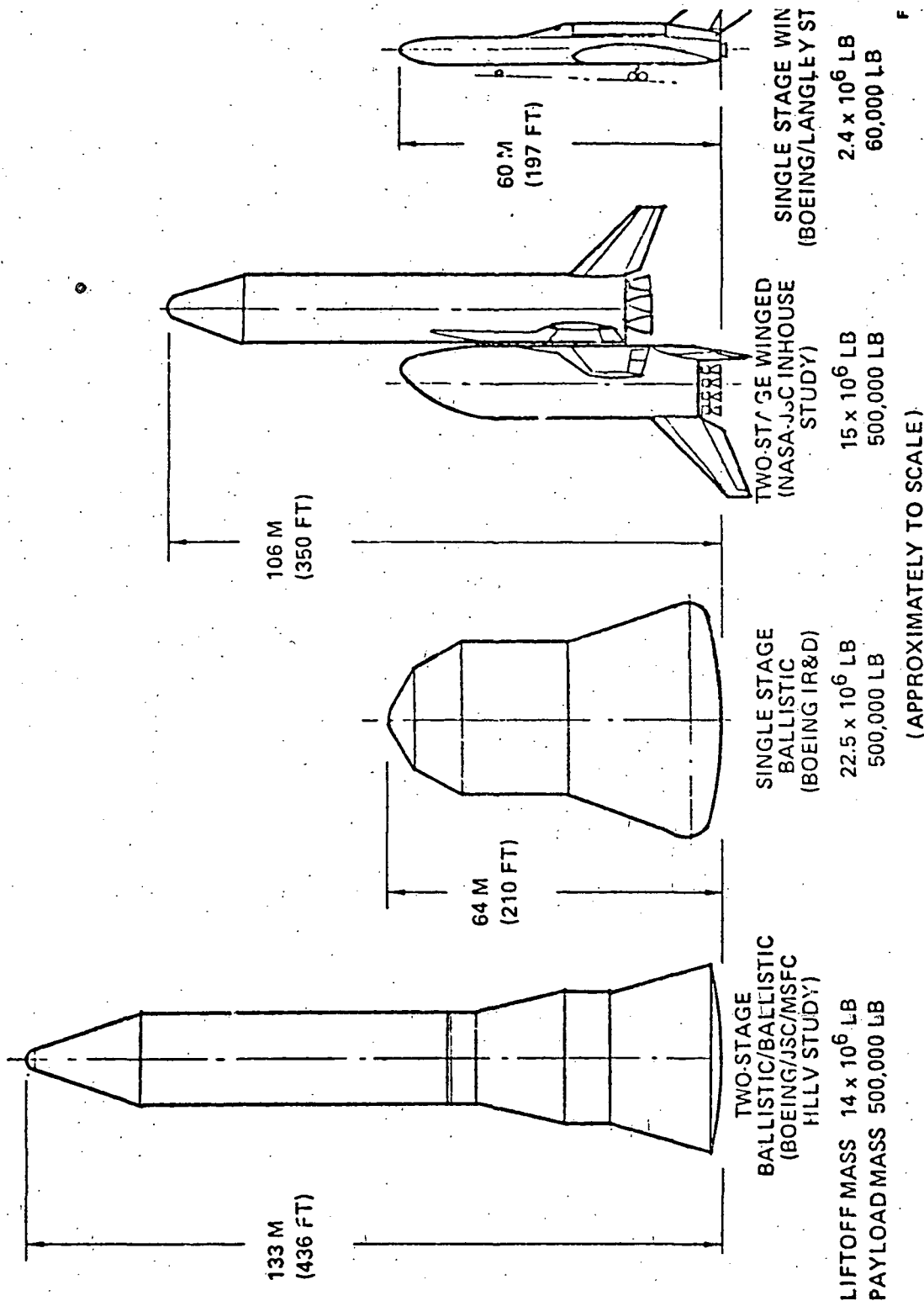
- 227 000 KG
(500,000 LB)

- 10.33 KG
(22.7 LB)

Low Earth Orbit Freighter Options

Scenario 4 – Satellite Power Commercial Phase

BOEING

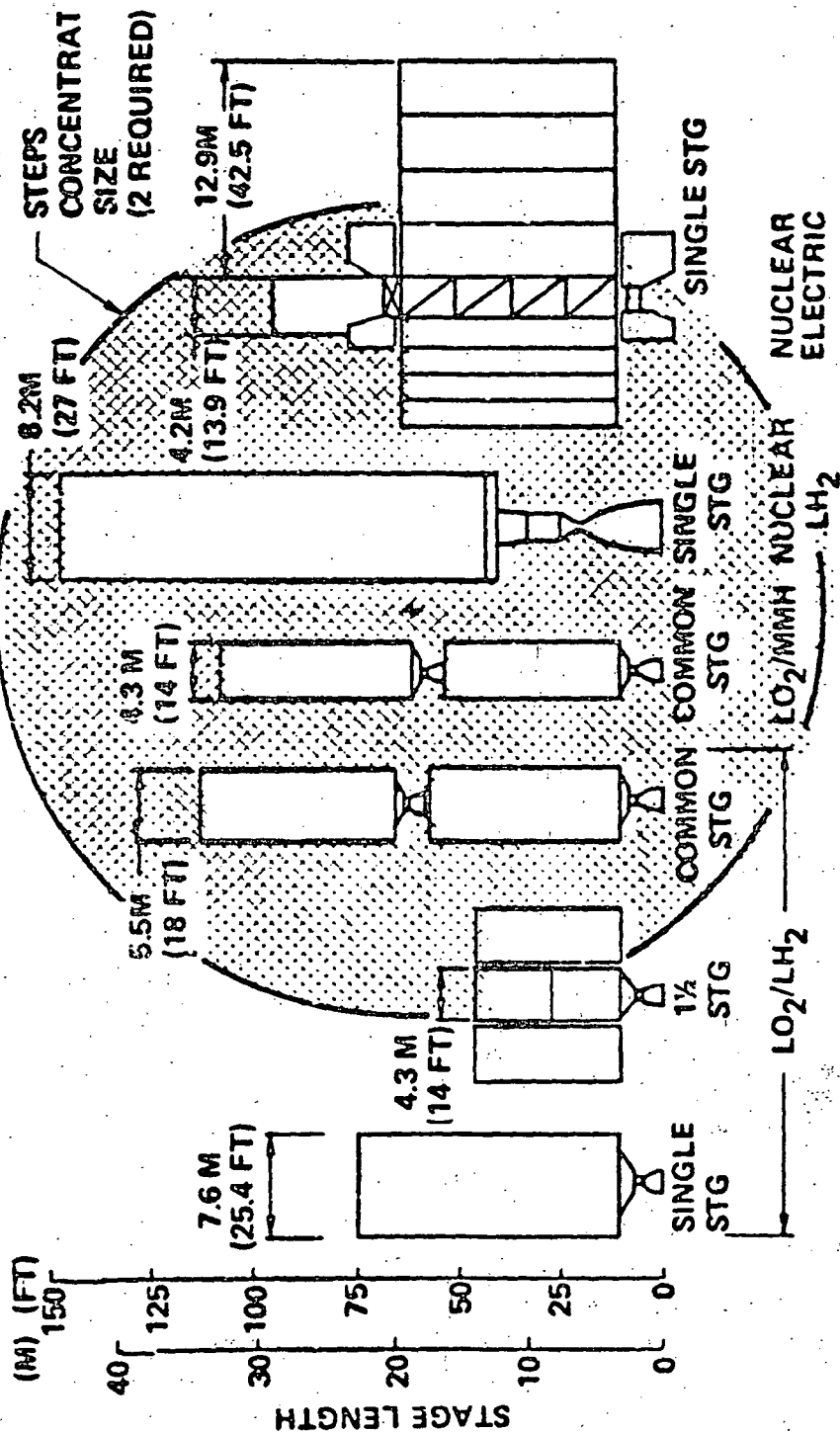


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OTV Concepts and Size Comparison

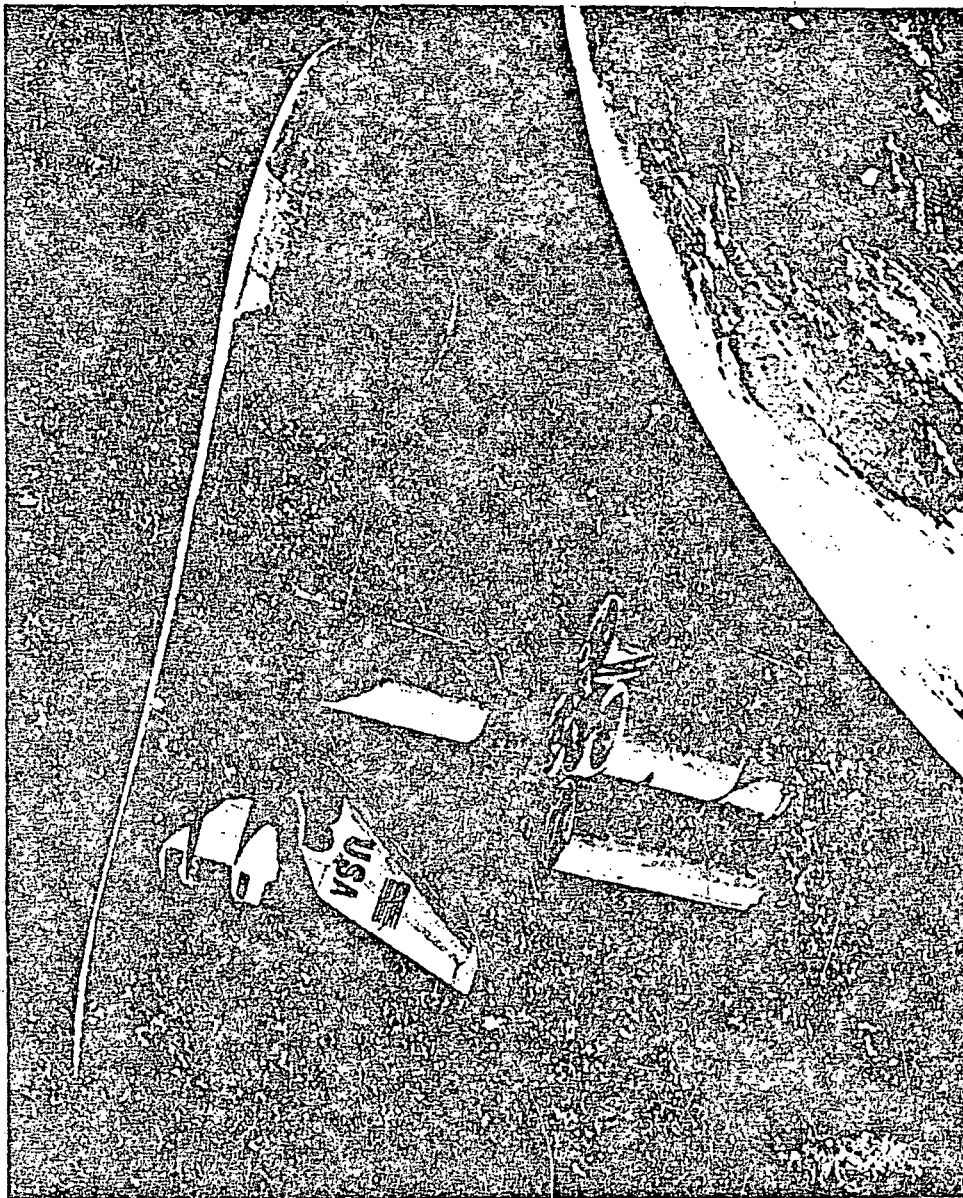
GSS Mission

BBB/A



1-1/2 Stage LO2/LH2 OTV

BOEING



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Common Stage LO₂/LH₂ OTV Configuration GSS Mission

BDF

STAGE TO STAGE DOCK
SYSTEM (4 PLACES)

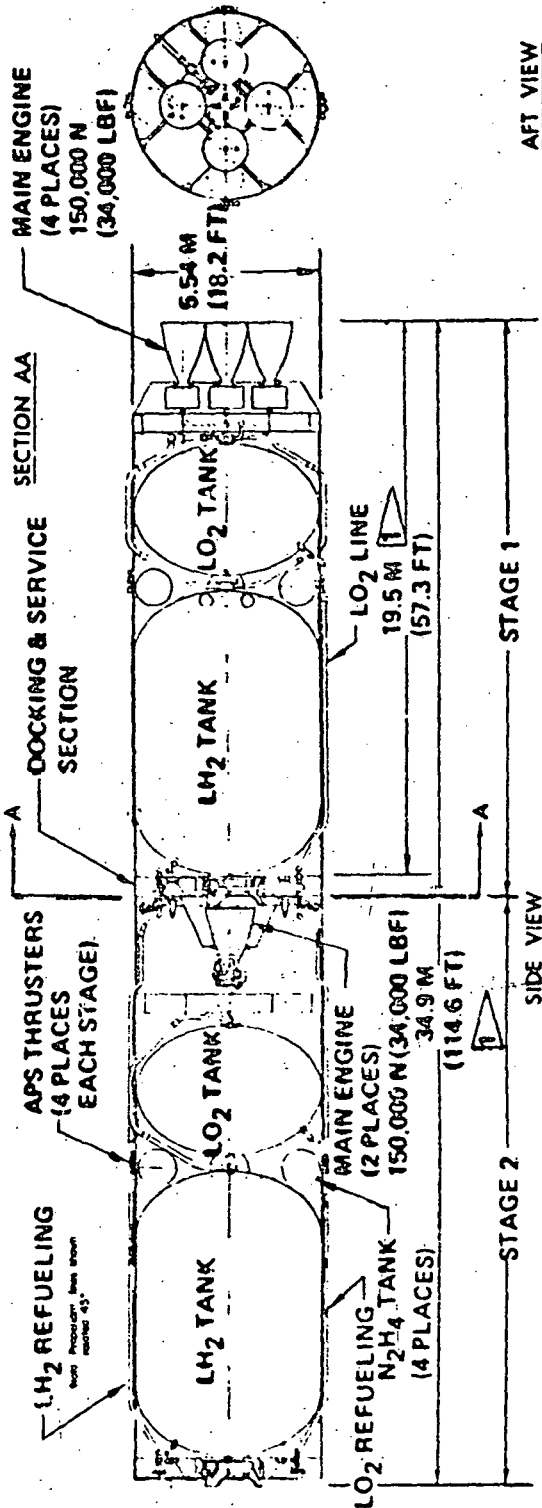
SERVICE PANEL
(2 PLACES)

FUEL CELL
REACTANTS

FUEL CELL
(2 PLACES)

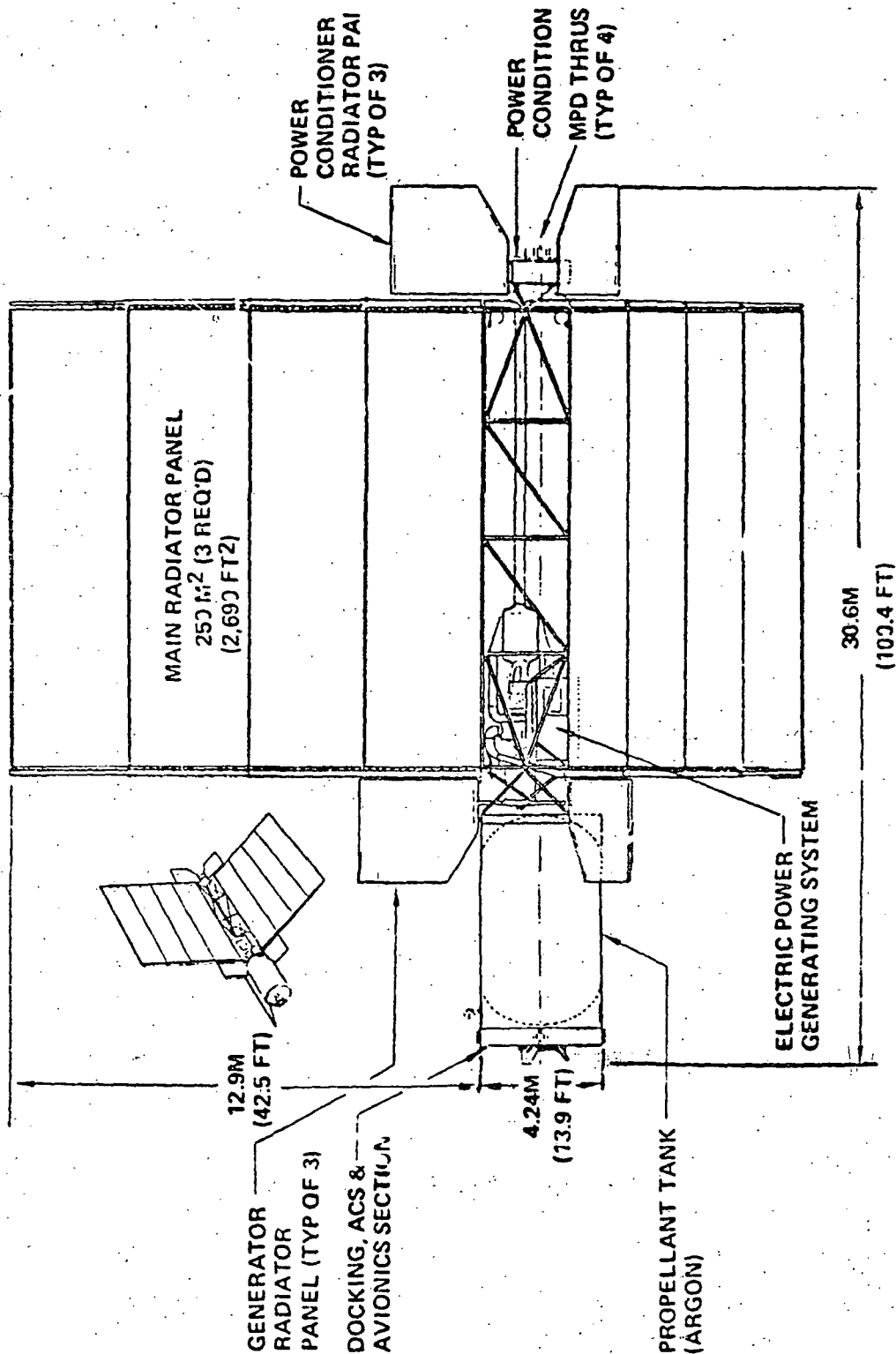
INT. DOCKING MECH

Indicated dimensions reflect mission propellant requirements as determined by analysis of this vehicle. Main propellant tanks and total stage lengths are not to scale



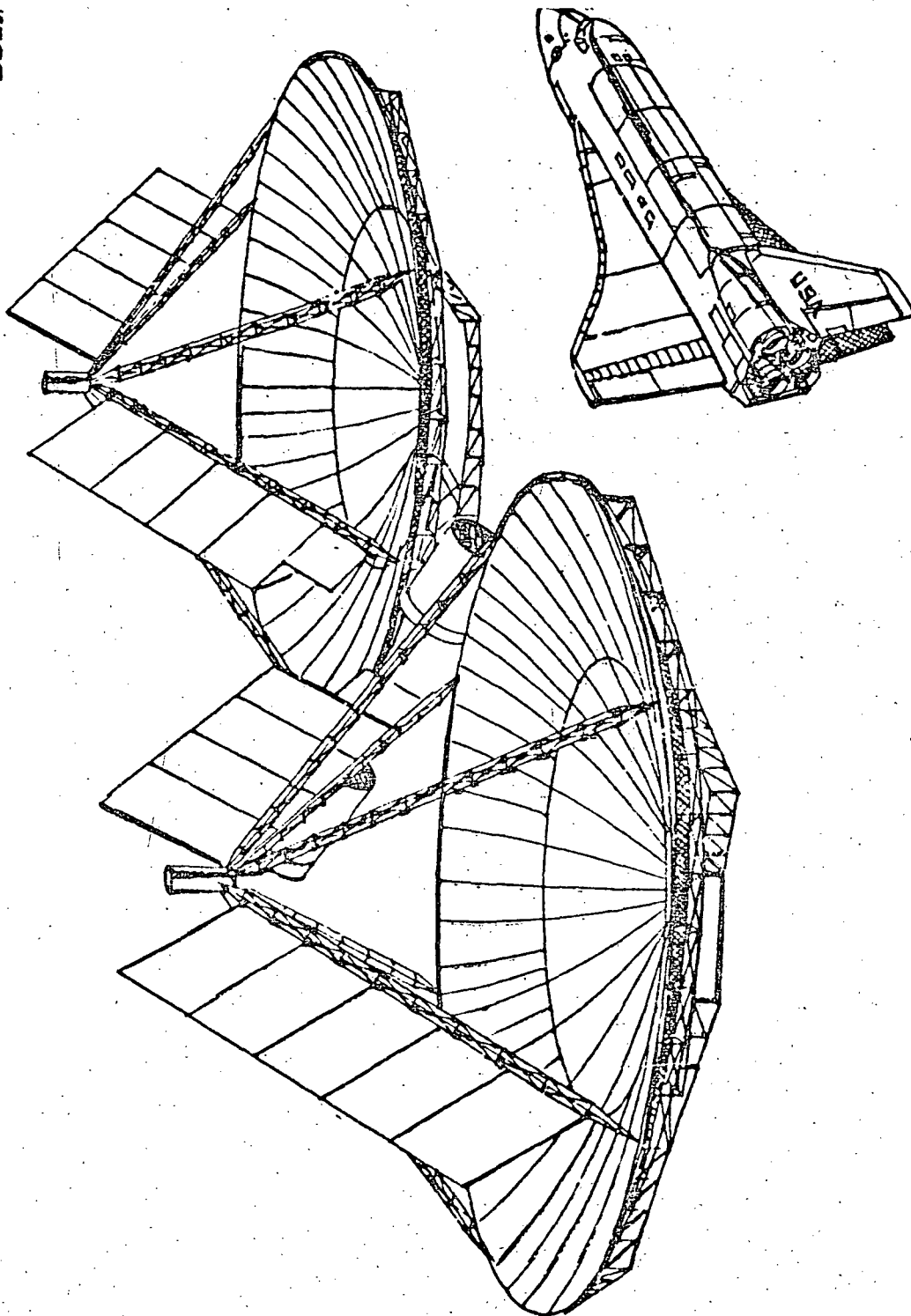
Nuclear Electric OTV

BDFI



STEPS OTV Configuration

SDCI



FUTURE
SPACE
TRANSPORTATION
SYSTEMS

1-1/2 Stage LO2/LH2 LTV

BOEING



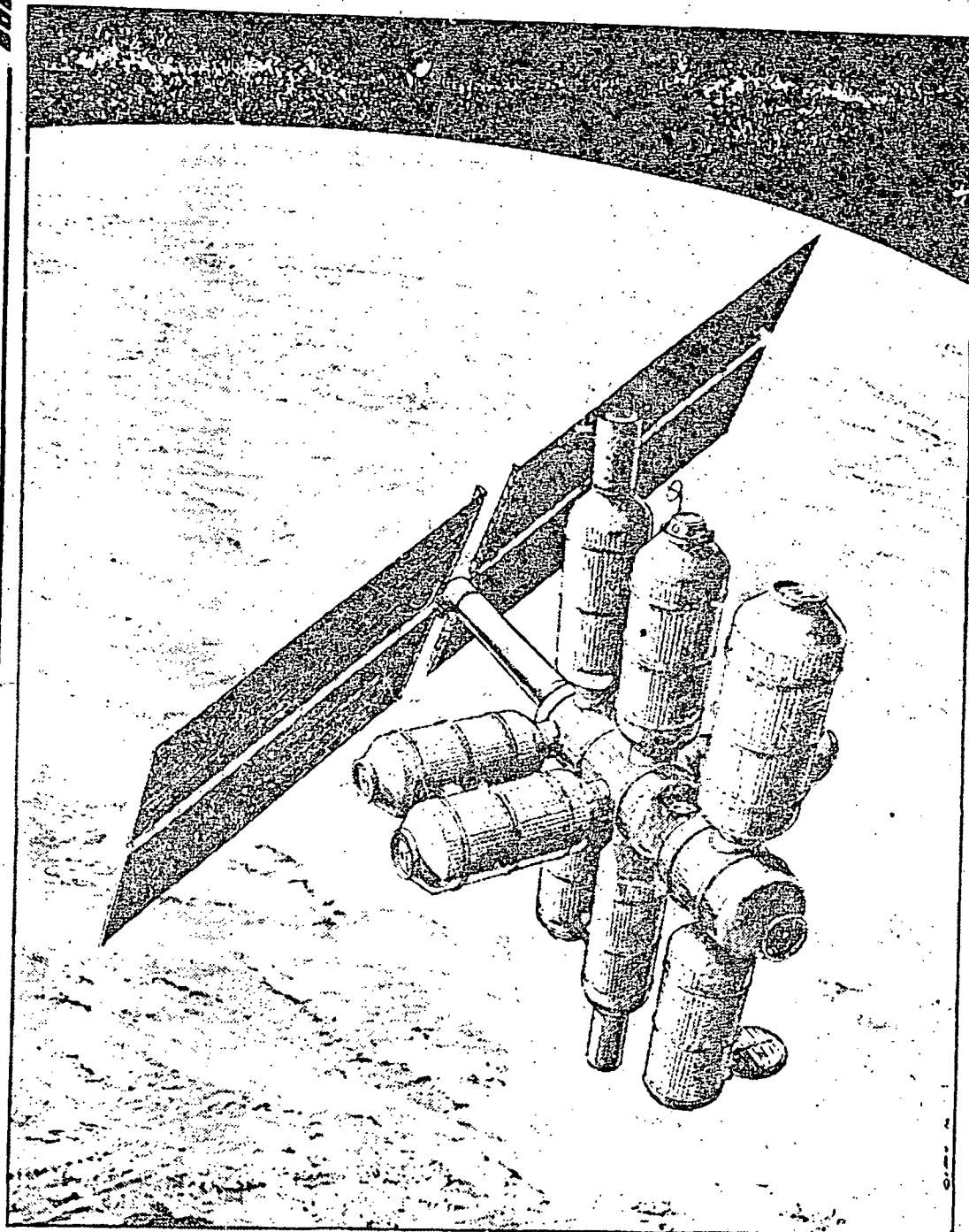
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Scenario Missions

MISSIONS	SCENARIO NO. 1	SCENARIO NO. 2	SCENARIO NO. 3	SCENARIO NO. 4
MANNED PLANET. SPACE STA.	X	X	X	X
LARGE AUTOMATED GEO. SAT.	X	X	X	
GEO. SATELLITE MAINTEN. SORTIE	X	X	X	
STAGING DEPOT		X	X	X
SCIENCE LABORATORY		X	X	
MANUFACTURING FACILITY			X	
AUTOMATED LUNAR	X	X		
AUTOMATED PLANETARY	X	X	X	X
CONSTRUCTION FACILITY				X
GEOSYNCHRONOUS SPACE STA.	X	X	X	X
INDEPENDANT LUNAR SURFACE SORTIE		X		
ORBITING LUNAR STATION			X	
LUNAR SURFACE BASE			X	
MANNED PLANETARY			X	
SPS PILOTPLANT		X		X
SPS PROTOTYPE				X
SPS OPERATIONAL				X
NUCLEAR WASTE DISPOSAL			X	

Low Earth Orbit Space Stations

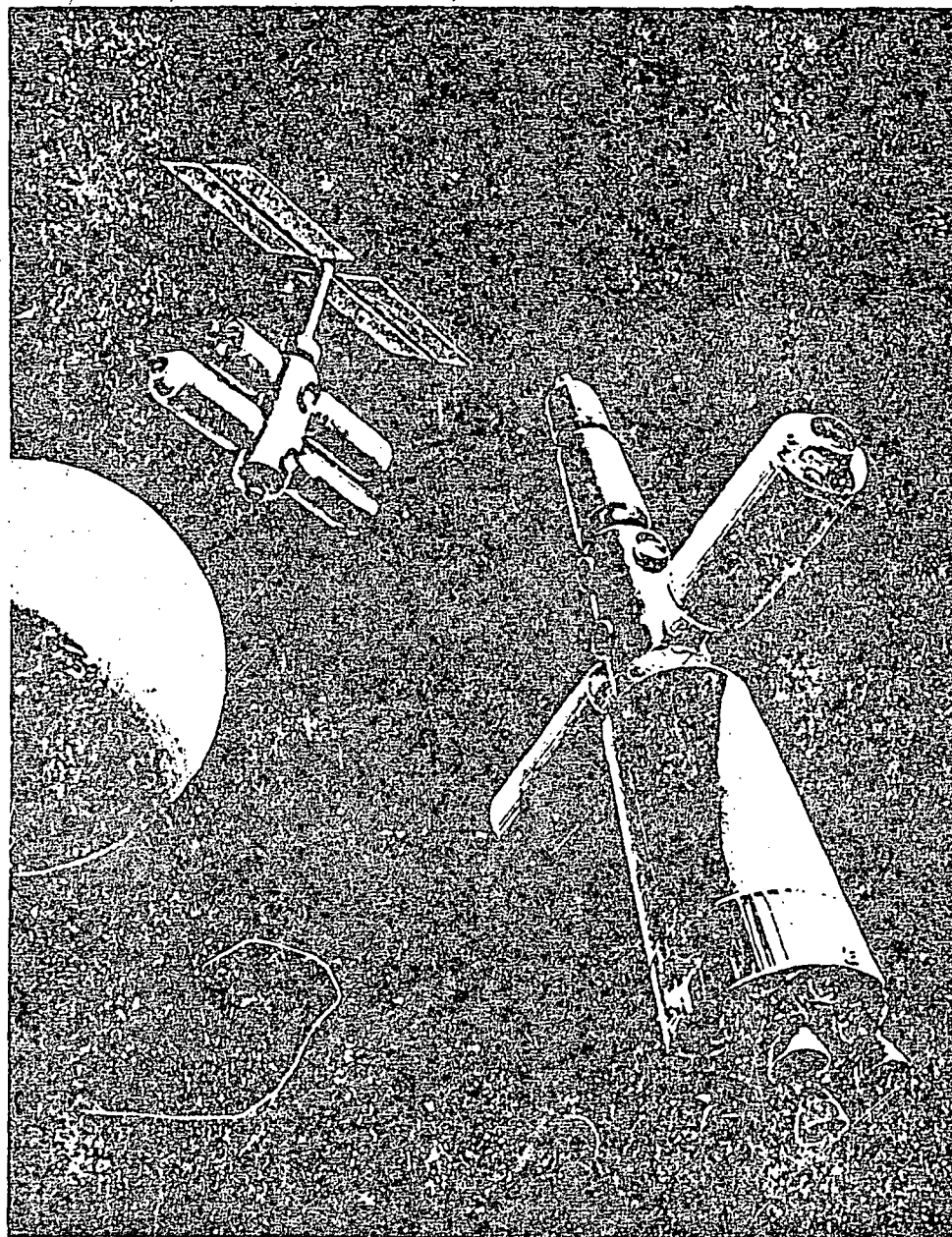
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Geosynchronous Space Stations

DOING

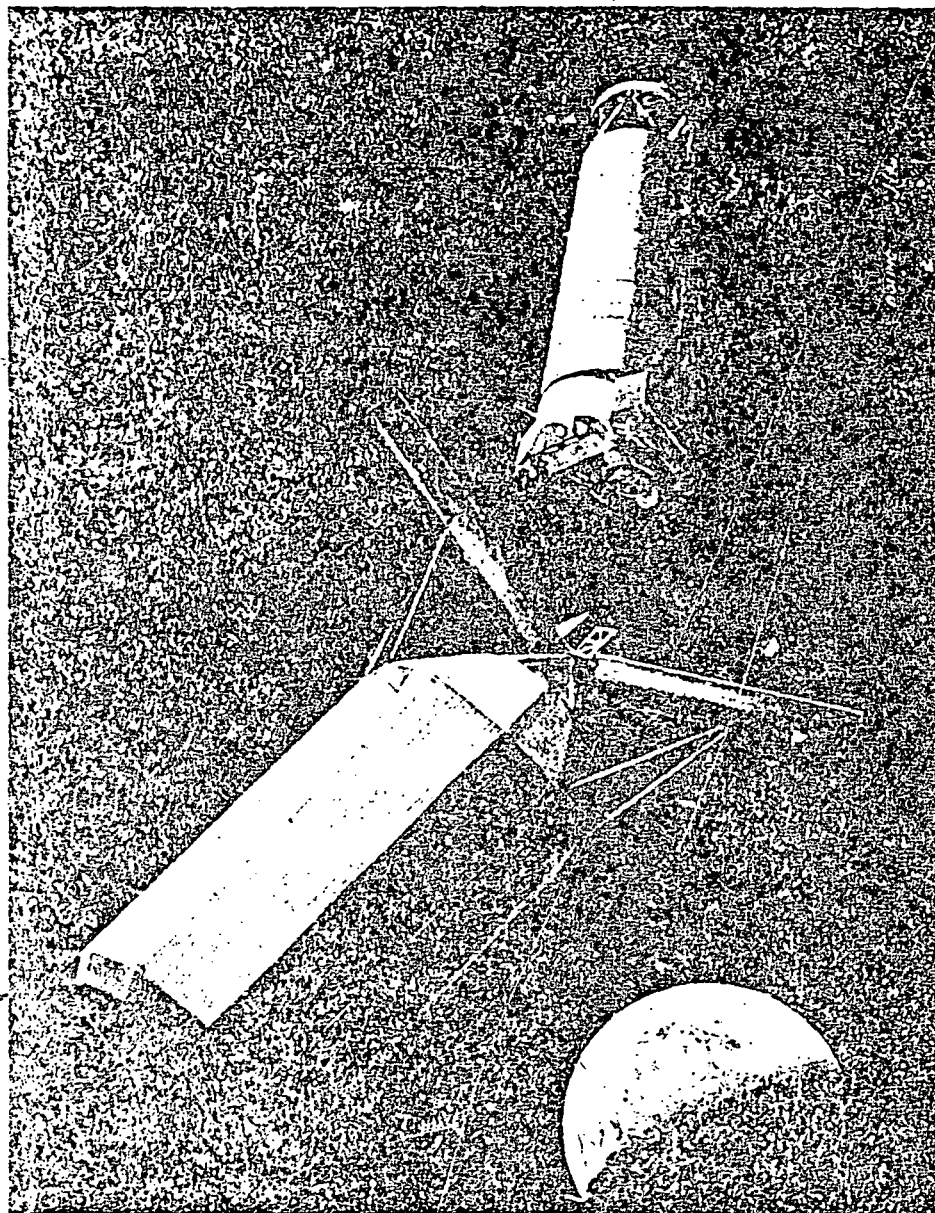


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FUTURE
SPACE
TRANSPORTATION
SYSTEMS

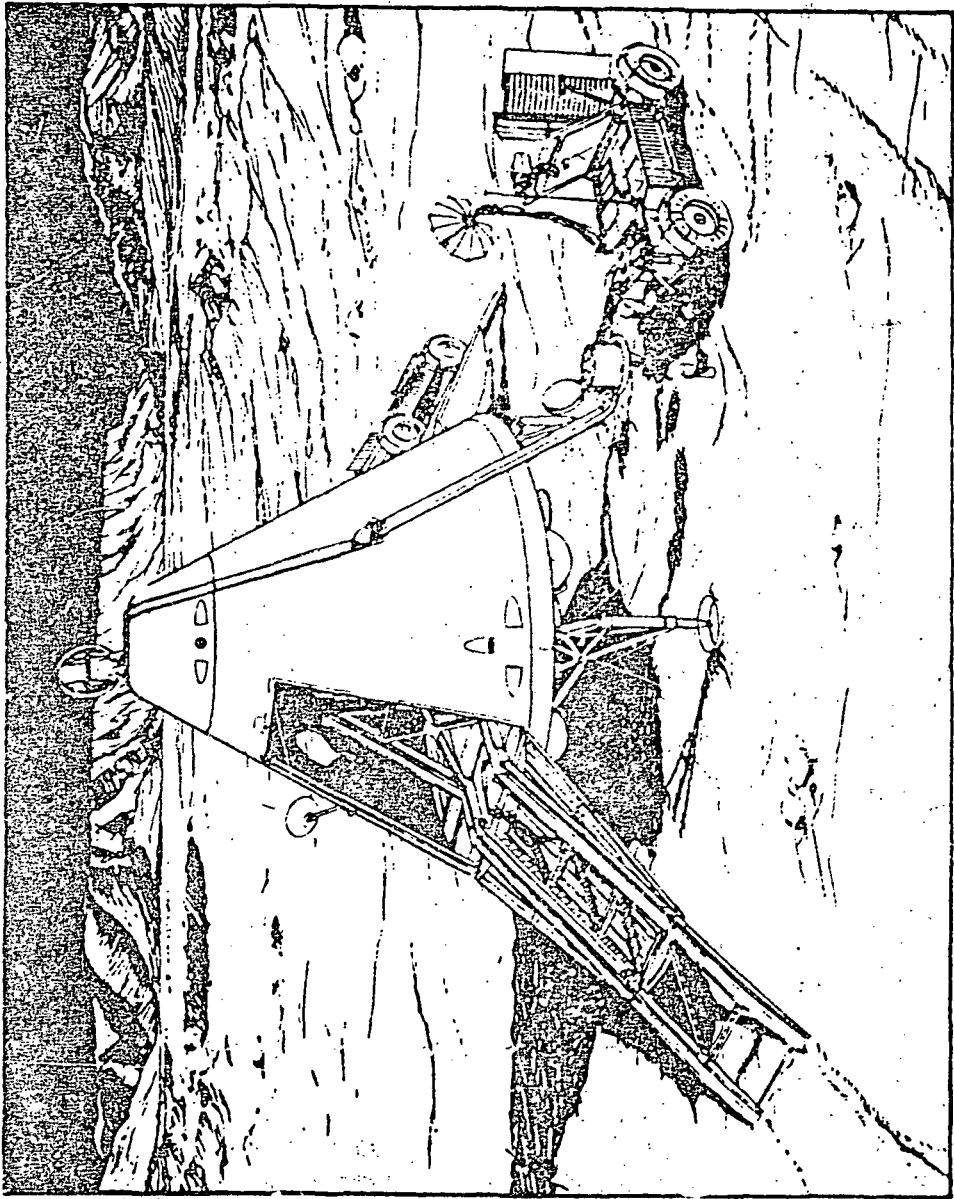
Geosynchronous Satellite Maintenance Sortie

BOEING



Mars Surface Sample Return

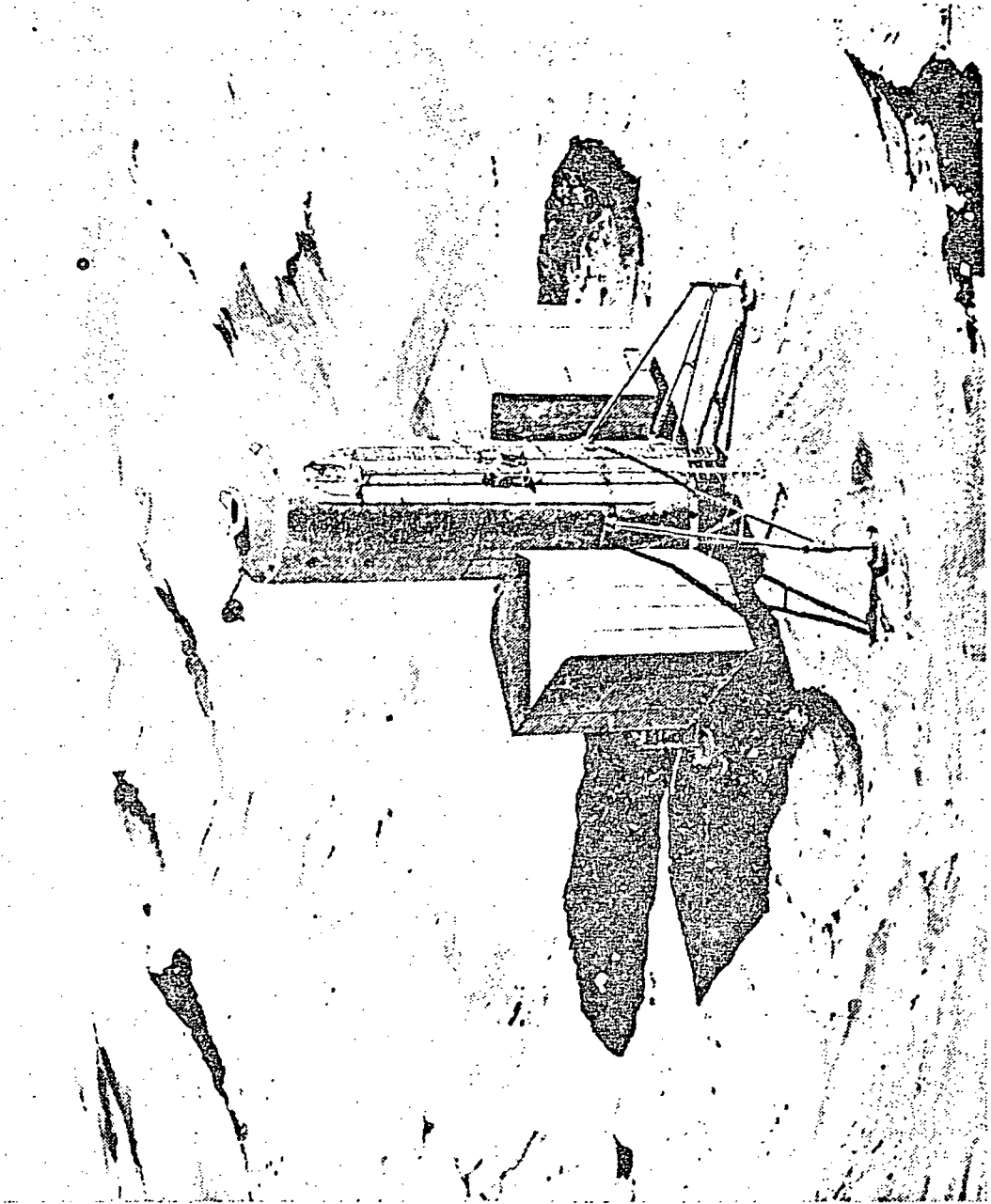
EDINA



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Independent Lunar Surface Sorties

BOEIA

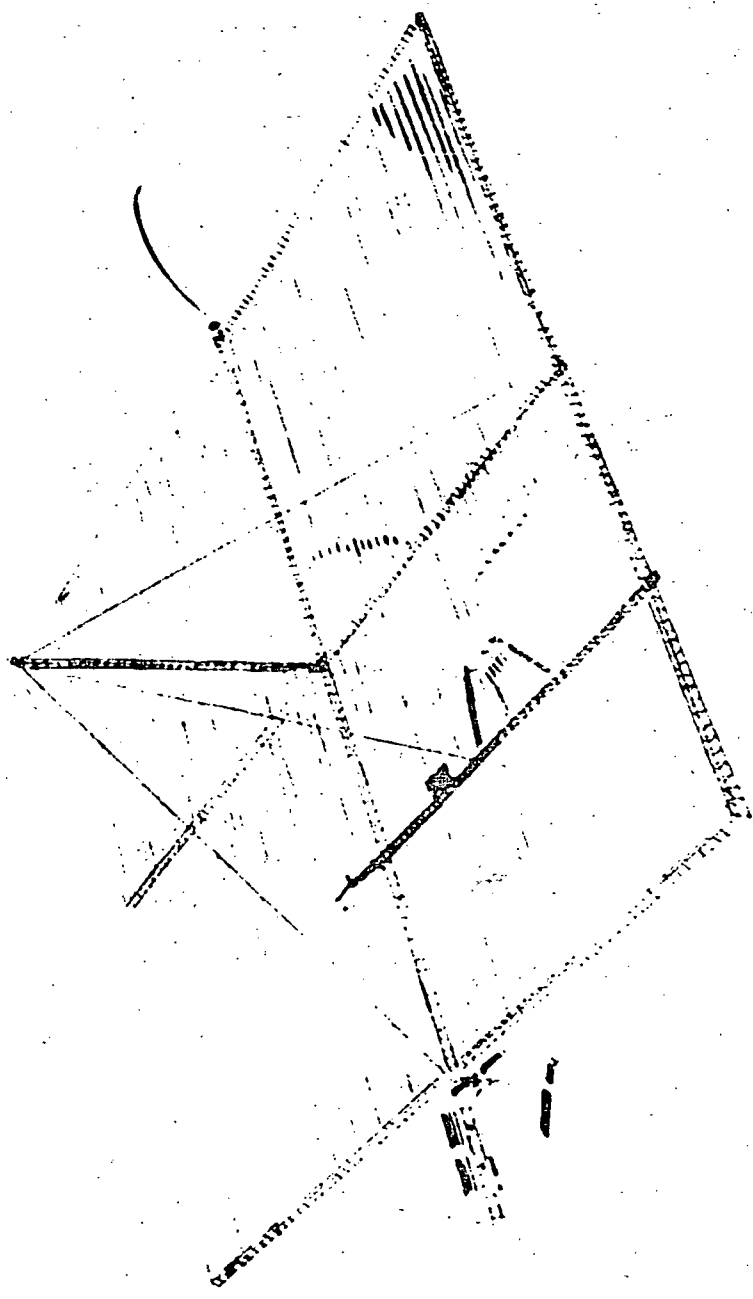


Orbiting Lunar Station Program

BOE

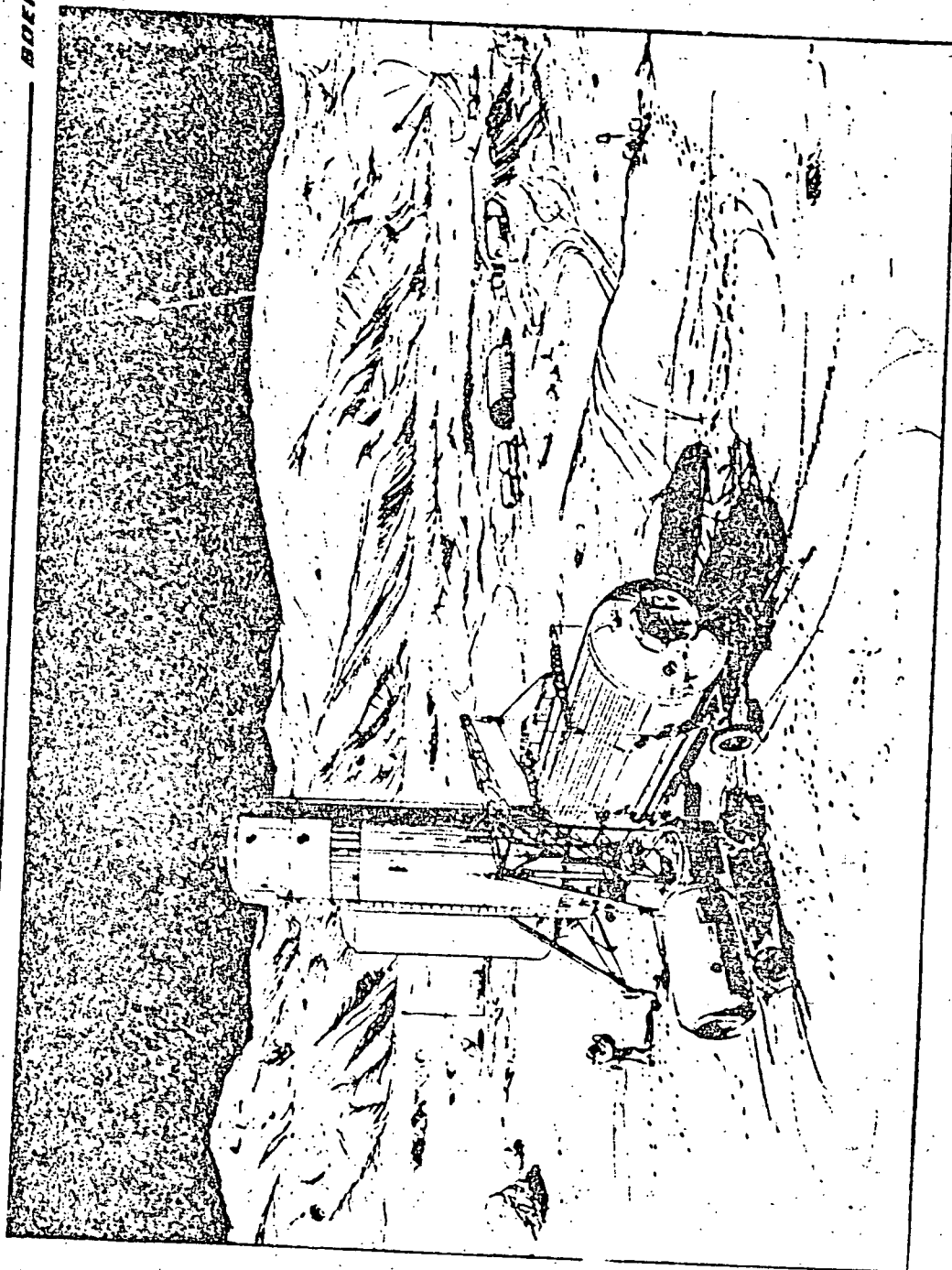


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Lunar Surface Base

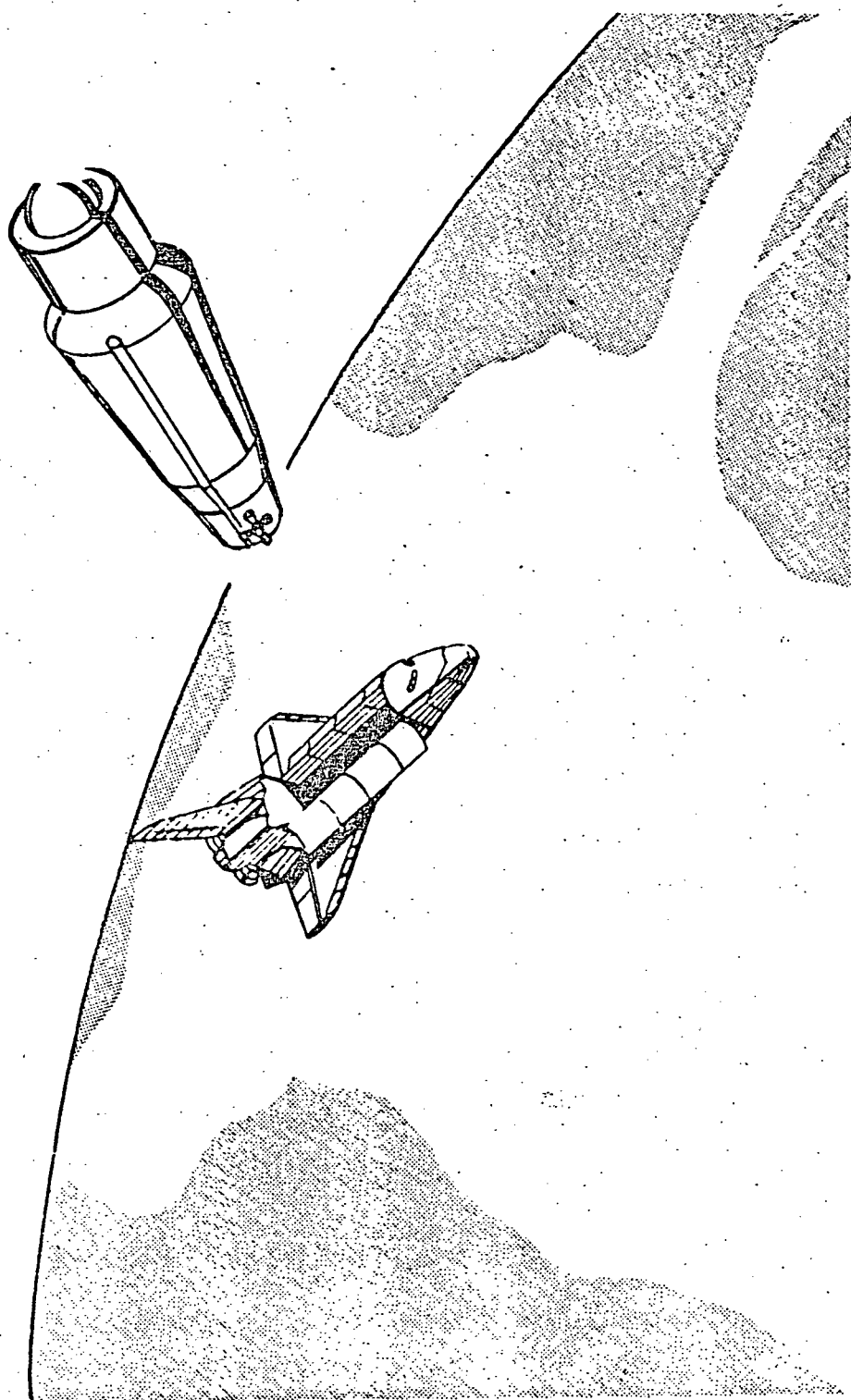
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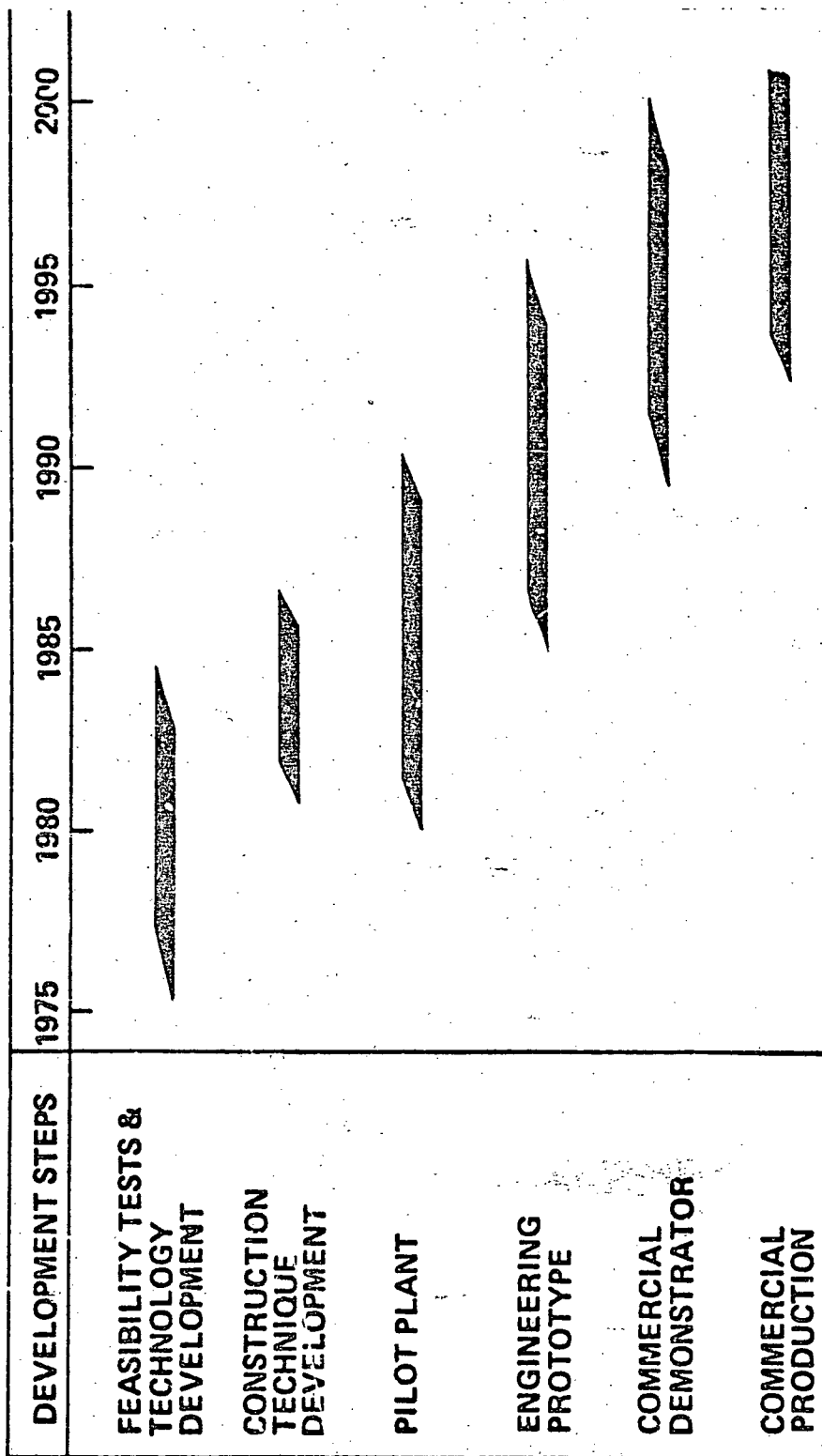
Nuclear Waste Disposal

BOEING



Power Satellite Development Phasing

BOEING



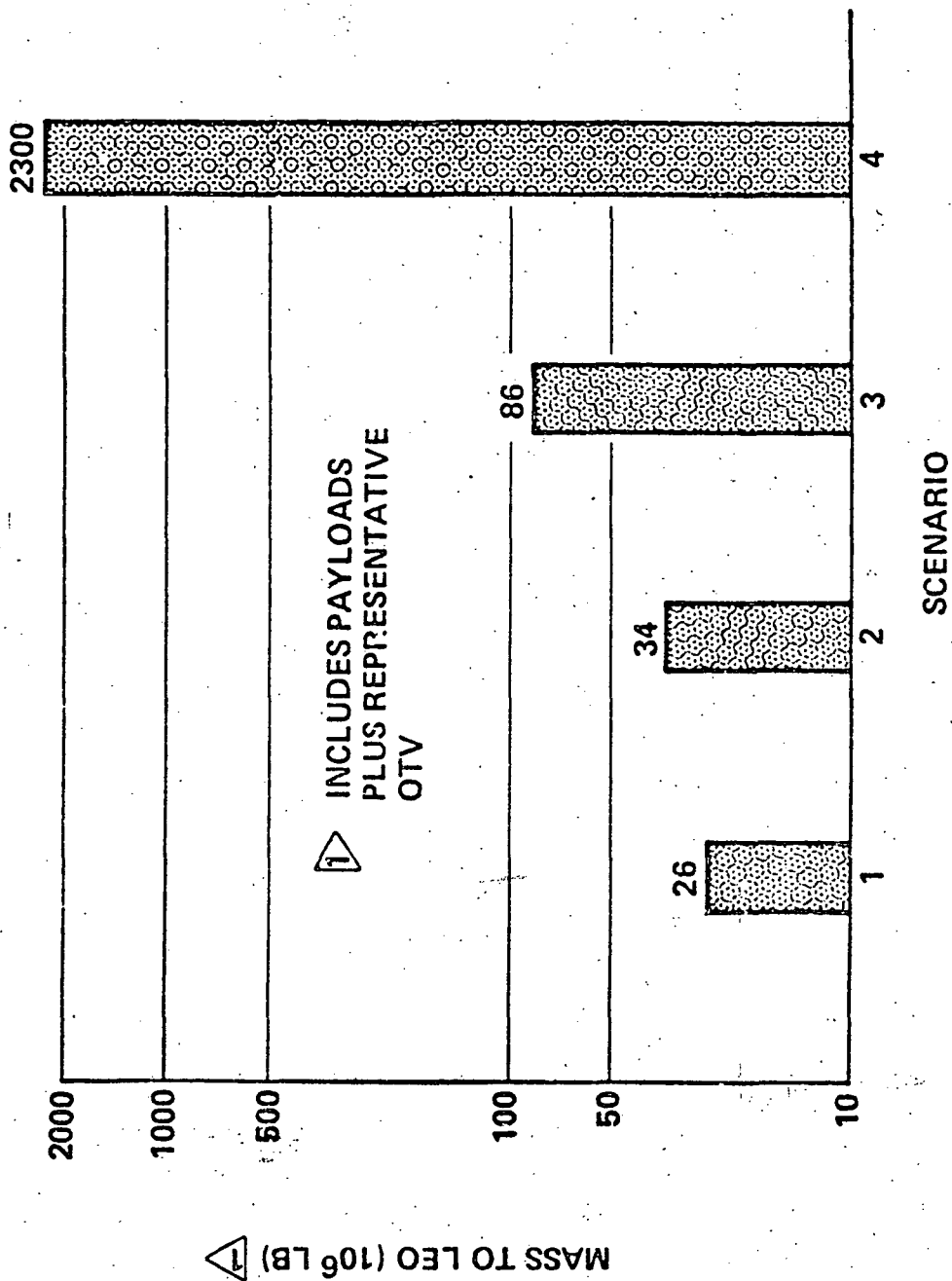
Major SPS Program End Item Objectives

BOEING

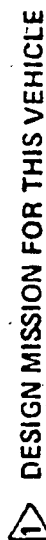
END ITEMS	ONBOARD POWER LEVEL	GROUND DELIVERED POWER LEVEL	OBJECTIVES	NUCLEAR BREEDER PROGRAM ANALOGY
• SHUTTLE SORTIES AND INTERFERO- METER	UP TO 50 KW	SIGNALS ONLY	SHOW BASIC TECHNICAL FEASIBILITY OF S/S/STEM ELEMENTS	PHYSICS EXPERIMENTS AND ENGINEERING TESTS
• SEPS TESTBED AND SPACE STATION EXPERIMENTS	UP TO 100 KW	SIGNALS ONLY	ENGINEERING FEASIBILITY AT COMPONENT LEVEL	FAST FLUX TEST FACILITY (FFTF)
• PILOT PLANT	15 MW	5-10 MW BUT NOT CONVERT- ED TO DC	ENGINEERING DEMONSTRATION OF OPERATION OF A SYSTEM	EBR's
• ENGINEERING PROTOTYPE	1200 MW	500 MW	ENGINEERING PROOF OF FEASIBILITY ON A PRACTICAL SCALE	CLINCH RIVER LMFBR
• COMMERCIAL PROTOTYPE	\$8000 MW	5000 MW	DEMONSTRATION OF COMMERCIAL FEASIBILITY	COMMERCIAL PROTOTYPE

Scenario Mass To Leo Comparison

BEING



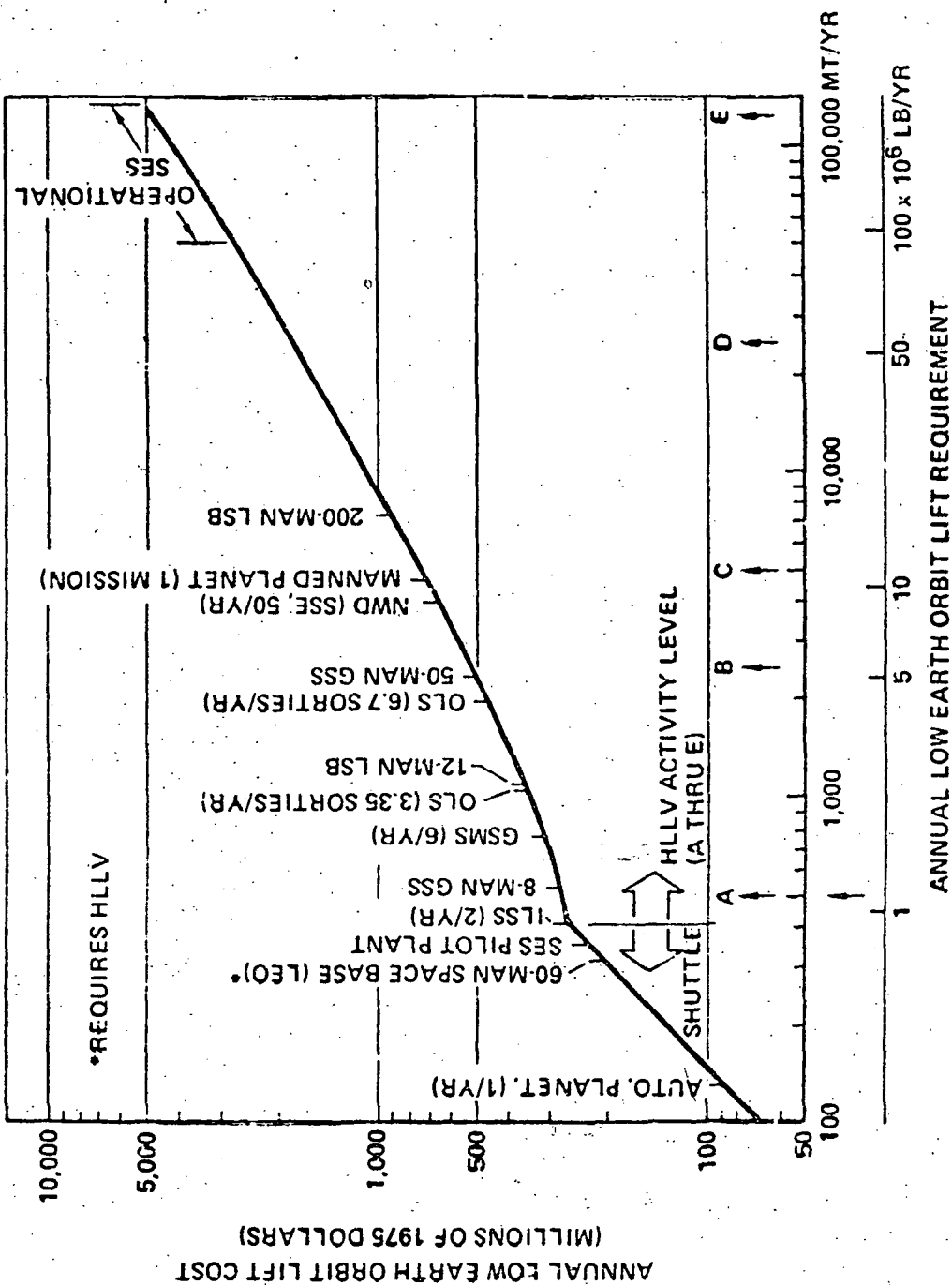
**FUTURE
SPACE
TRANSPORTATION
SYSTEMS**



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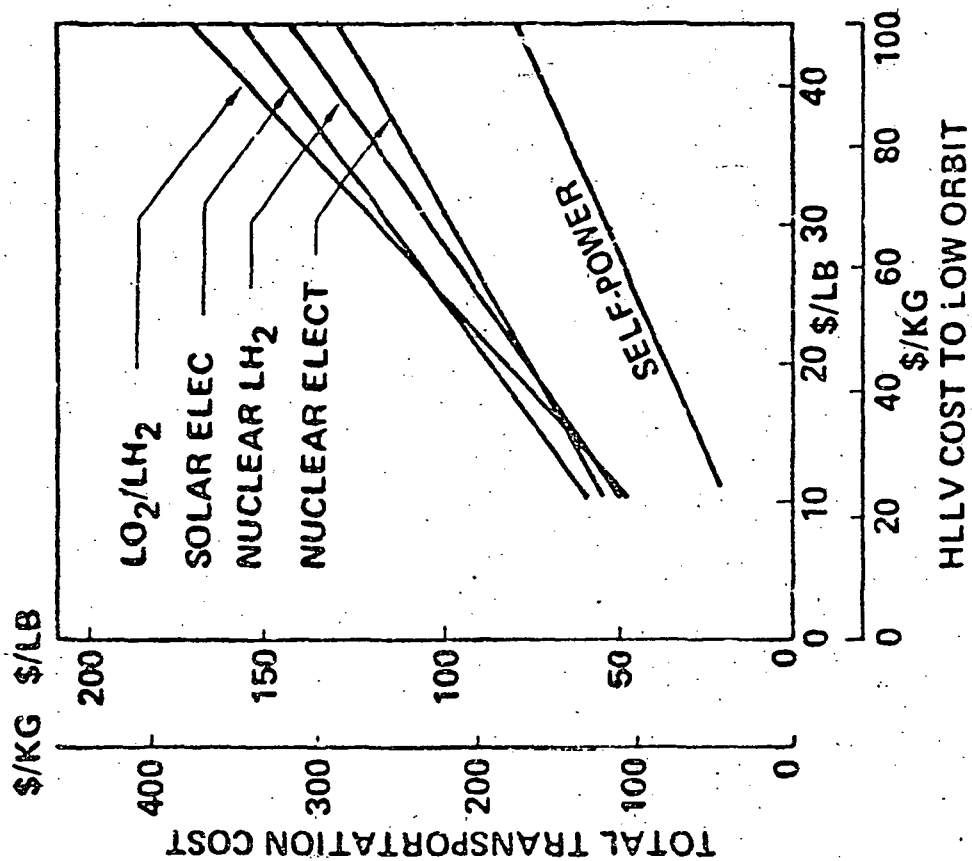
Lift Cost to Low Earth Orbit

BOEING



Power Satellite Orbit Transfer Cost Summary

BOEING



$$\text{COST} = \text{HLLV COST} (F_P + F_O + F_T) + \text{TRANSFER HARDWARE COST}$$

WHERE

F_P = PACKAGING BURDEN'
ESTIMATED 1.1

F_O = ORBITAL LOGISTICS
BURDEN, ESTIMATED 0.1

F_T = ORBIT TRANSFER
MASS BURDEN

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SPACE INDUSTRIALIZATION SYMPOSIUM
SPACE TRANSPORTATION SESSION
MAY 26, 1976
"SHUTTLE BOOSTER/PROPULSION GROWTH CONCEPTS"

L. T. SPEARS
NASA /MSFC

SUMMARY

The Space Shuttle is currently under development, to be used in a variety of space missions beginning in 1980. This paper discusses utilization of the Shuttle to support increasing future activities in Earth Orbit, with particular attention to potential for growth/improvements beyond the current Shuttle configuration. This growth/improvement can be in the form of further reductions in transportation costs, possibly in combination with increases in payload delivery capability.

The Shuttle will be employed to deliver elements of the Space Stations to orbit, along with other equipment or cargo that will be used in conjunction with the Stations. A primary and continuing role for the Shuttle will be passenger transportation to/from orbit, along with supporting logistics.

Reusability of transportation system hardware is a major means of reducing or minimizing transportation costs. The Shuttle Orbiter currently under development is to be reusable, as well as provide capability for return and reuse of payloads. However, due to budget and other constraints, the ascent propellant tankage and boosters are to be expendable or partially

reusable. The recurring costs for these elements are therefore relatively high. A logical prospect for further reductions in recurring costs is to achieve a greater degree of reusability in the propellant tankage and/or boosters.

Preliminary studies of liquid rocket, reusable booster stages have been conducted as examples of such possibilities. Boosters configured for down-range, ballistic recovery are being studied, as well as configurations employing wings for return to the launch site.

If needed for future missions, increases in payload delivery capability can be incorporated in conjunction with modifications to achieve greater reusability/lower costs. Configurations sized for approximately 100K pounds payload to orbit are being examined. In the event that future missions require much larger or heavier payloads in orbit, the Shuttle could be adapted by substituting a "one-way" payload for the Orbiter reentry vehicle. These "Shuttle derivative heavy-lift" vehicles would provide 150-200K pound payload delivery capability.

The flexibility and growth potential inherent in the Shuttle will allow effective support for activities in space in preparation for space industrialization and space power. Possibilities for future Shuttle modification to achieve reduced costs and/or increased payload capability are to continue during the next year, to develop better understanding of configuration/operation options, development requirements, and economics.

SPACE INDUSTRIALIZATION SYMPOSIUM

SPACE TRANSPORTATION SESSION

SPACE SHUTTLE

BOOSTER/PROPULSION GROWTH CONCEPTS

L. T. SPEARS

MARSHALL SPACE FLIGHT CENTER

MAY 26, 1976

SPACE TRANSPORTATION SPACE SHUTTLE

TIME

SPACE SHUTTLE/SPACELAB
INITIAL OPERATIONS

INITIAL
SPACE STATIONS

SPACE INDUSTRIALIZATION
SPACE POWER

SPACE SHUTTLE
SHUTTLE IMPROVEMENTS

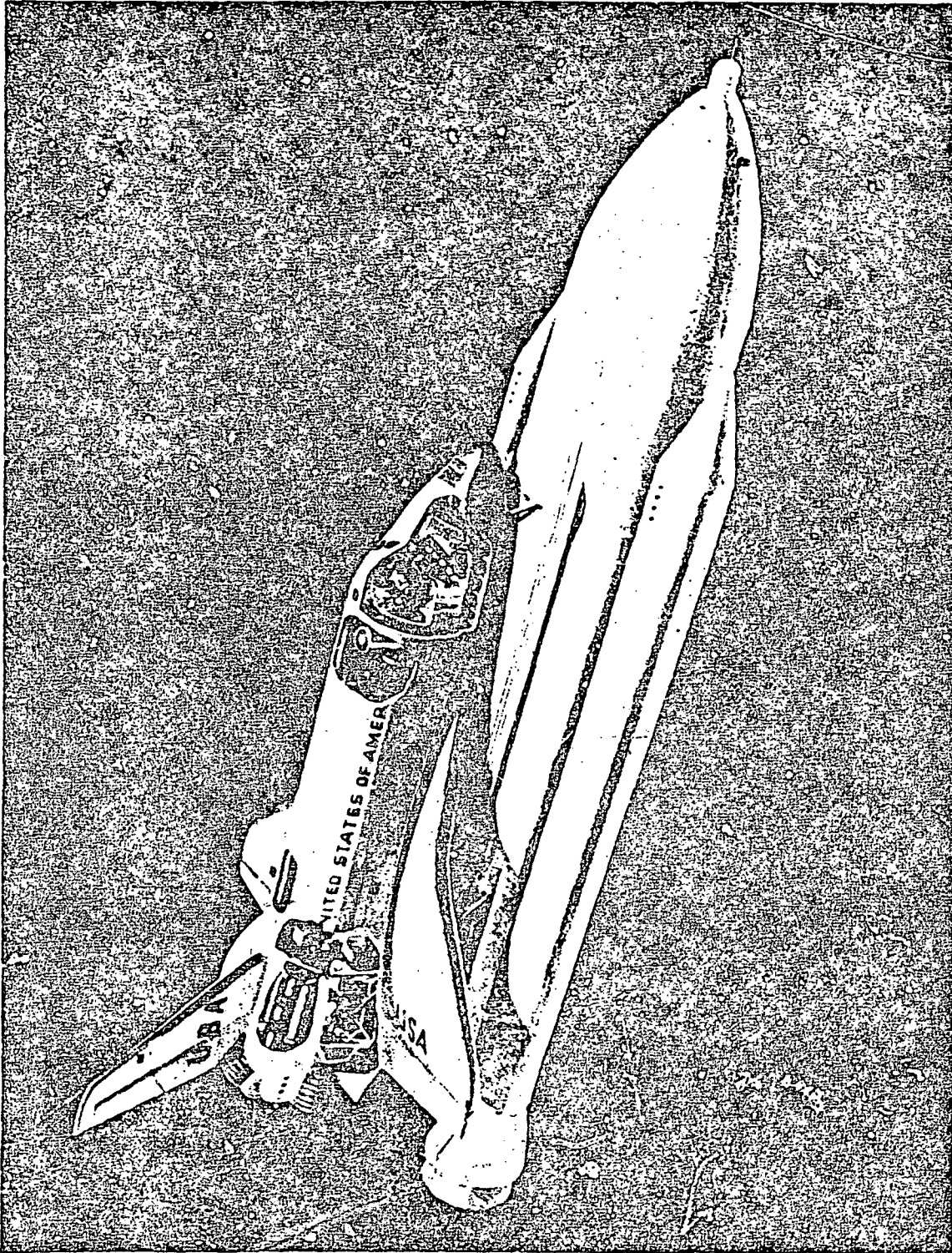
SPACELAB MISSIONS
• SATELLITE DELIVERY, RETRIEVAL, SERVICING
• PROPULSIVE UPPER STAGES

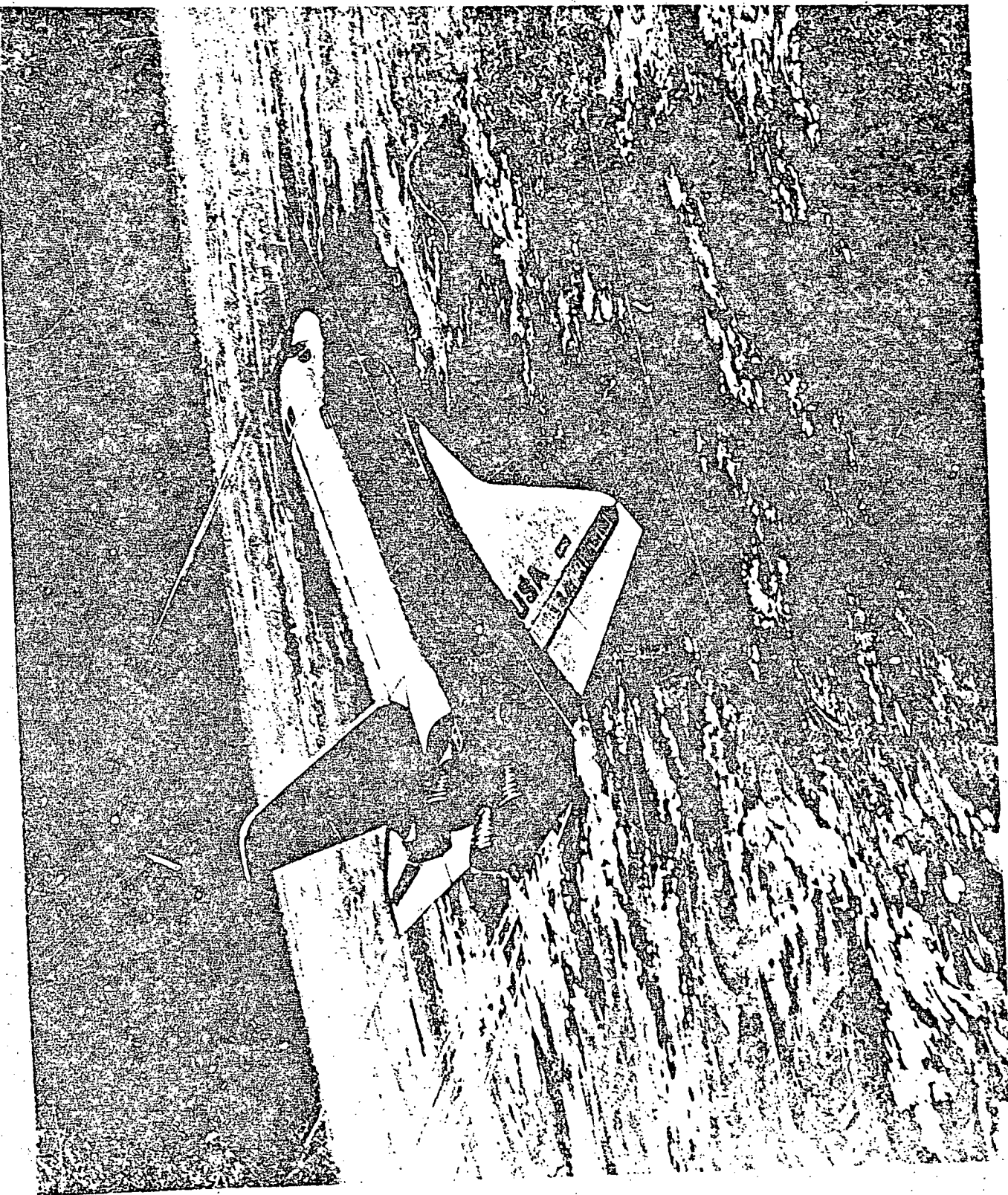
STATION DELIVERY
• CREW ROTATION, LOGISTICS
• CARGO & EQUIPMENT DELIVERY

PASSENGER TRANSPORT
• PRIORITY CARGO
• ROUND TRIP CARGO

MISSIONS/
ACTIVITIES

TRANSPORTATION



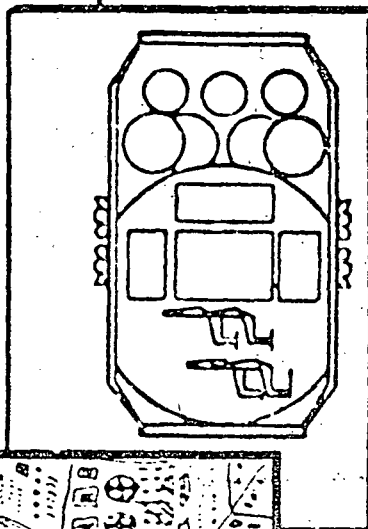


SPACE TRANSPORTATION

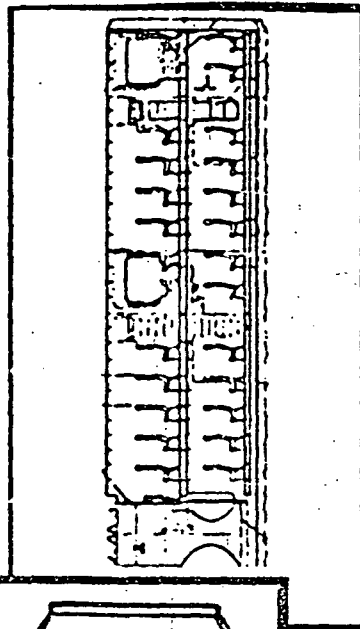
SPACE SHUTTLE
PASSENGER TRANSPORTATION/GROWTH



4 CREW
IN CABIN



CREW ROTATION/LOGISTICS
MODULE IN CARGO BAY



CONCEPT FOR LARGE-SCALE
PASSENGER TRANSPORTATION

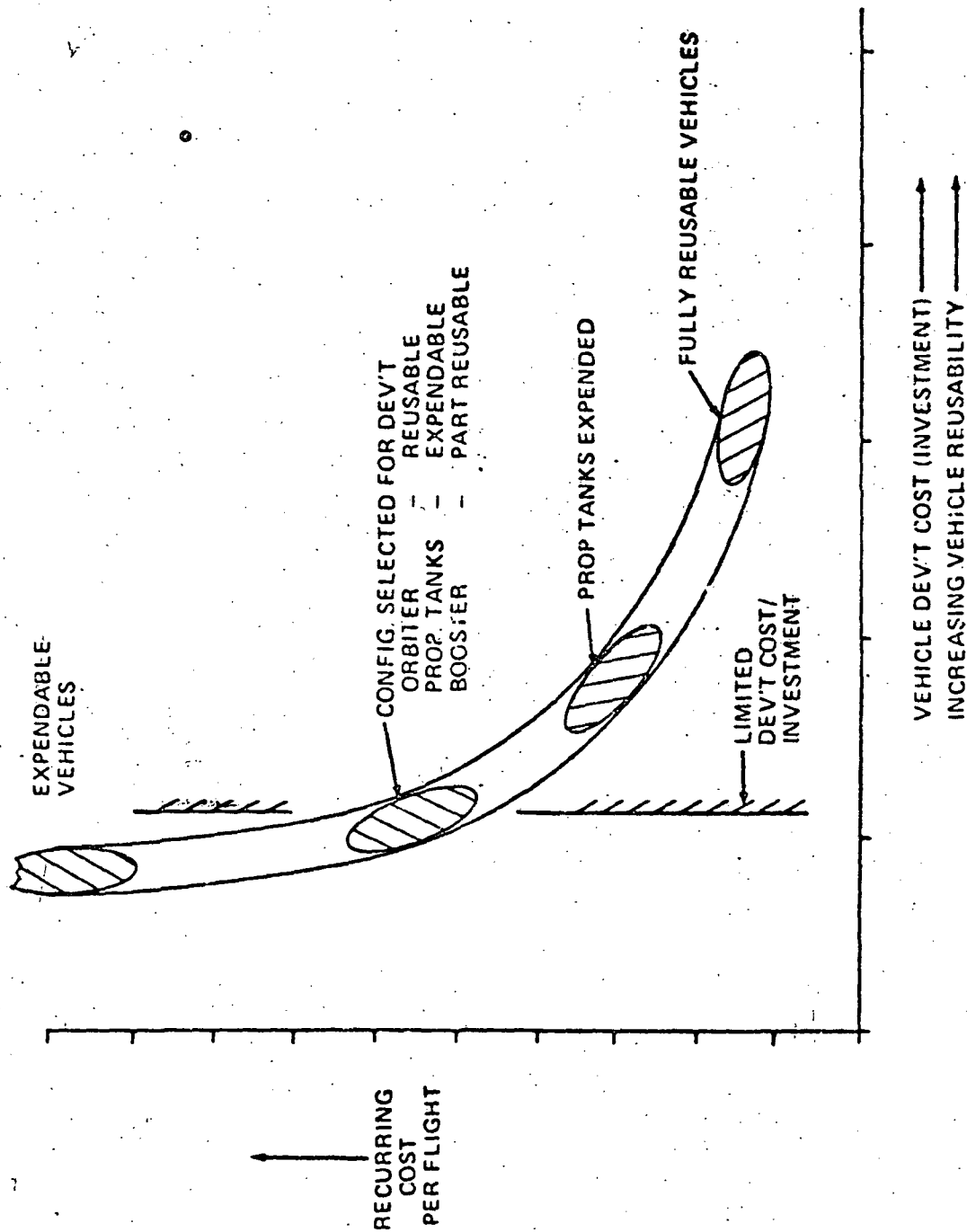
SPACE TRANSPORTATION

POTENTIAL FOR SPACE SHUTTLE GROWTH/IMPROVEMENT:

- o FURTHER REDUCTIONS IN RECURRING COSTS
- o INCREASE IN PAYLOAD CAPABILITY, AT SAME OR LOWER COSTS

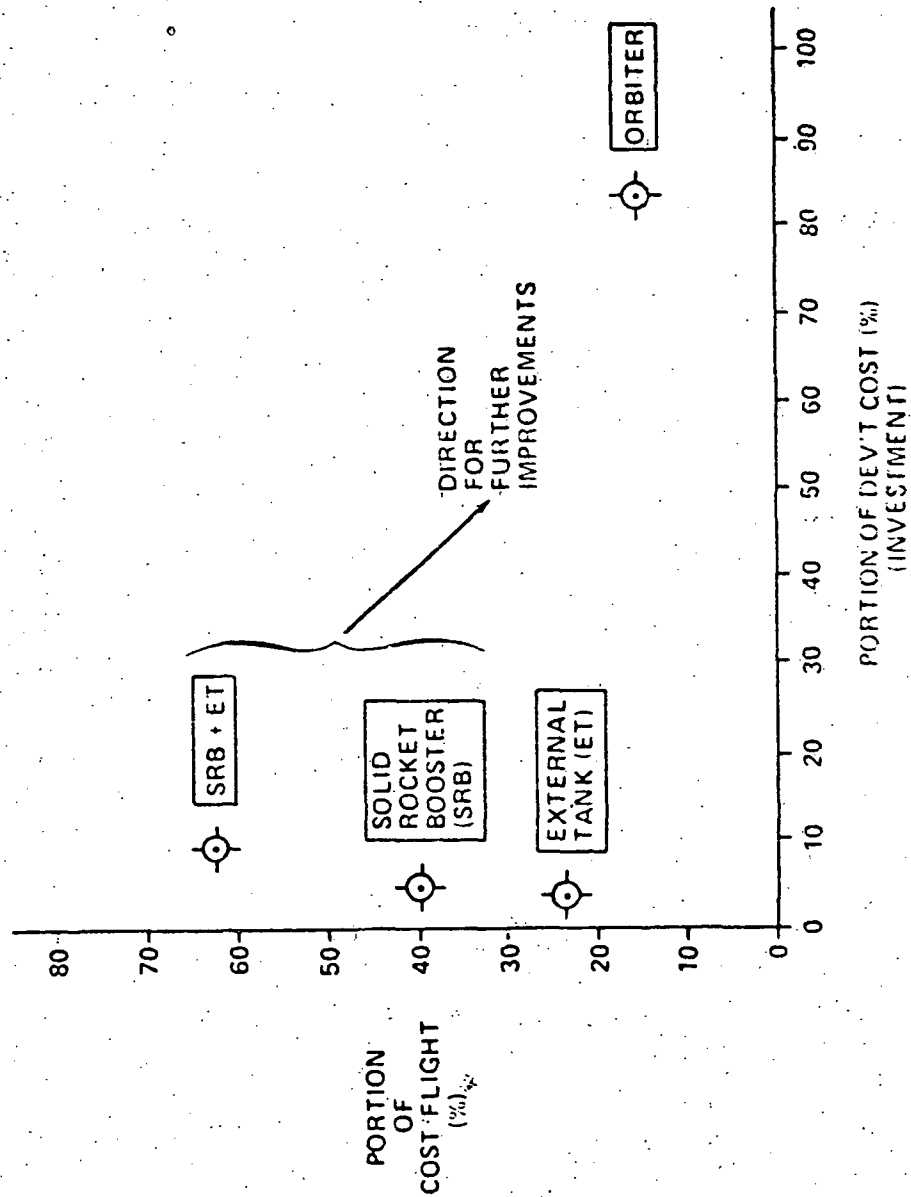
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SPACE TRANSPORTATION CANDIDATE SHUTTLE CONCEPTS



SPACE TRAINS PORTATION

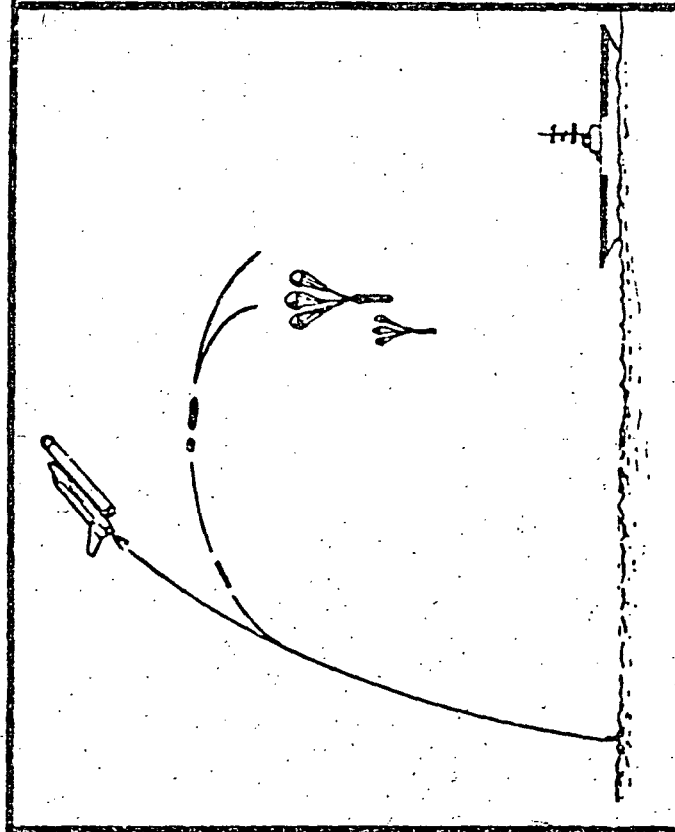
SPACE SHUTTLE



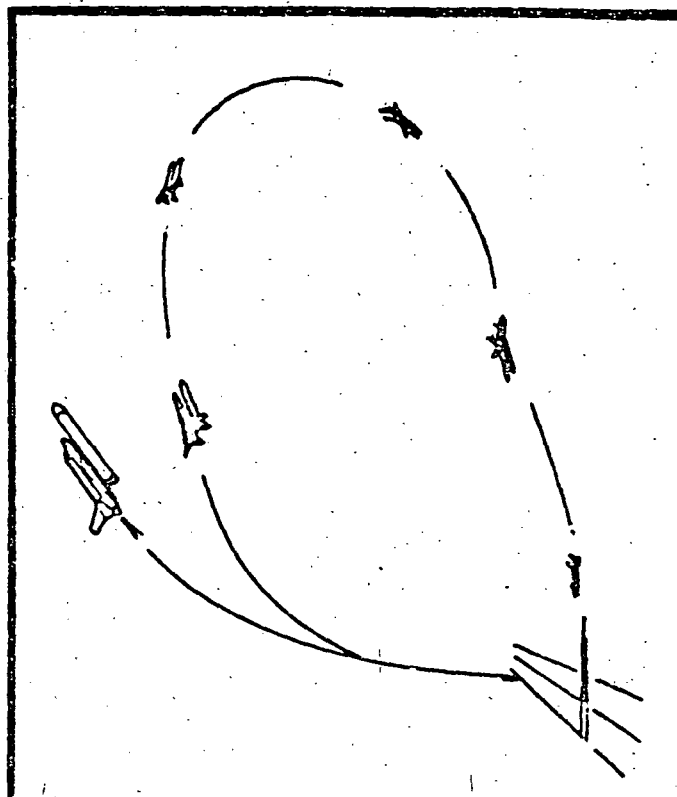
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SPACE TRANSPORTATION

SPACE SHUTTLEREUSABLE BOOSTER CONCEPTSBOOSTER RECOVERY MODES

BALLISTIC, DOWN-RANGE RECOVERY

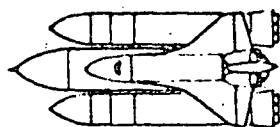
WINGED, FLY-BACK (OR GLIDE-BACK)
RECOVERY

SPACE TRANSPORTATION

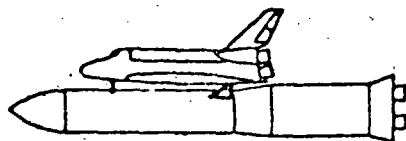
POTENTIAL SHUTTLE IMPROVEMENTS

REUSABLE BOOSTER CONCEPTS

PARALLEL
MOUNT

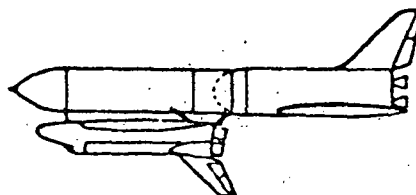
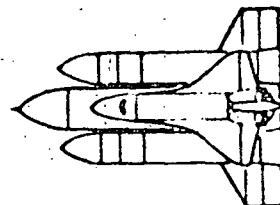


BALLISTIC
RECOVERY



TANDEM
MOUNT

WINGED
RECOVERY

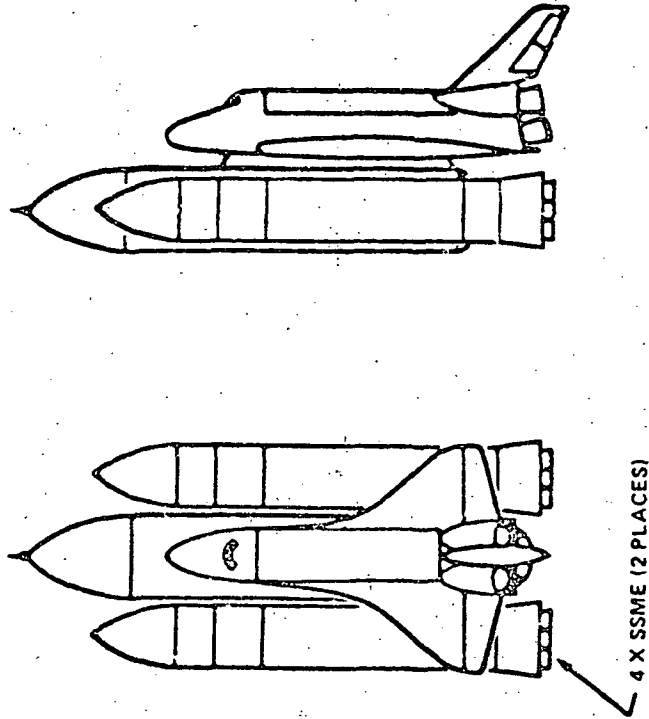


SPACE TRANSPORTATION

POTENTIAL SHUTTLE IMPROVEMENTS

REUSABLE SHUTTLE BOOSTER (BALLISTIC RECOVERY)

- LIQUID ROCKET BOOSTER
- BOOSTER WT = APPROX. 800K LBSEA.
- SIZED FOR 100K LBS. PAYLOAD TO ORBIT

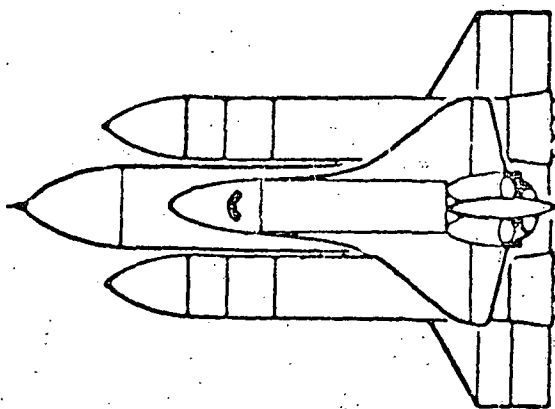


SPACE TRANSPORTATION

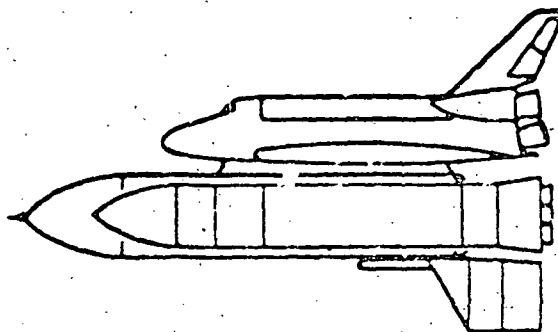
POTENTIAL SHUTTLE IMPROVEMENTS

REUSABLE SHUTTLE BOOSTER (WINGED RECOVERY)

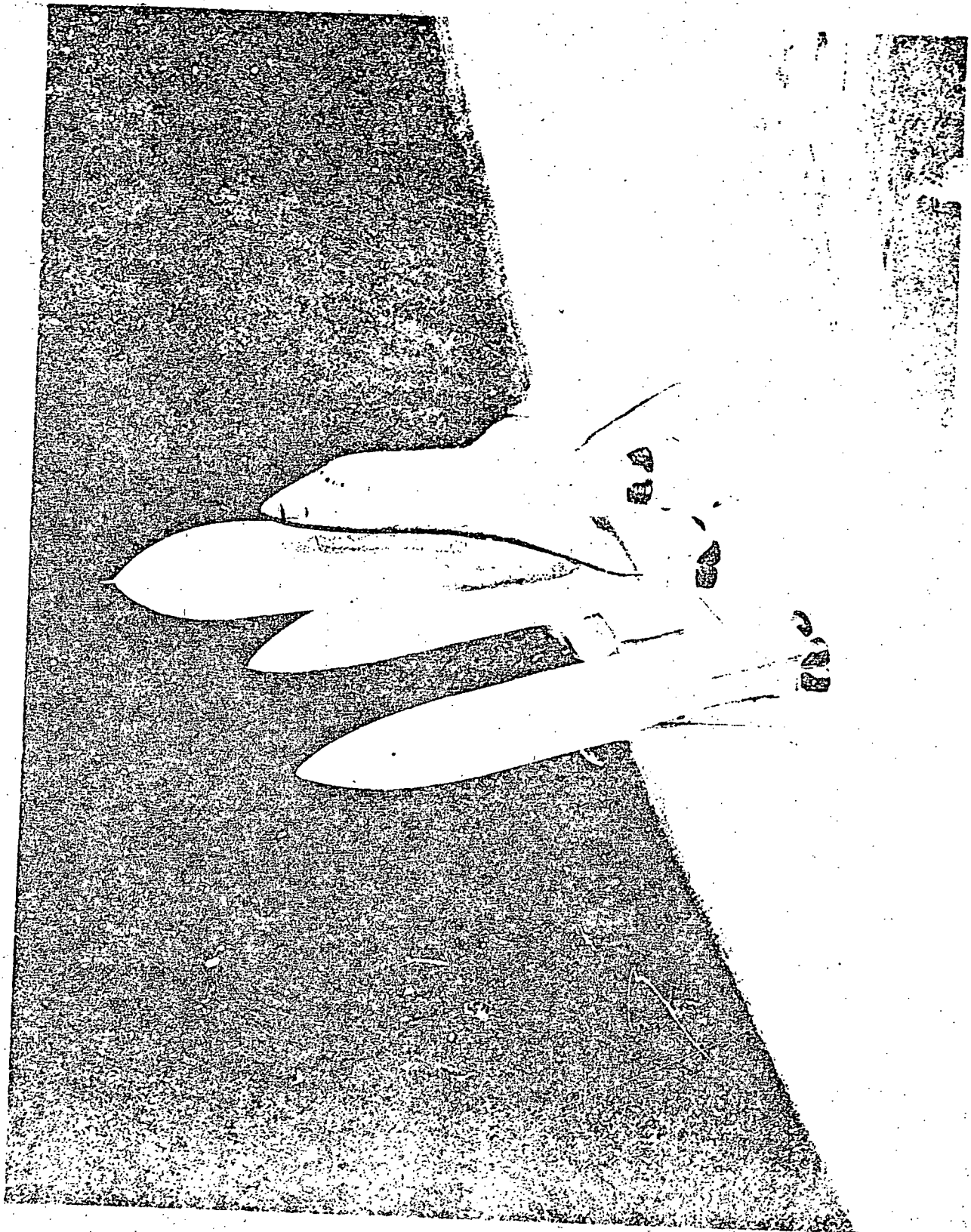
- LIQUID ROCKET BOOSTER
- BOOSTER WT. - APPROX. 1.8M LBS.
- SIZED FOR 100K LBS. PAYLOAD TO ORBIT



5XSSMC (2 PLACES)

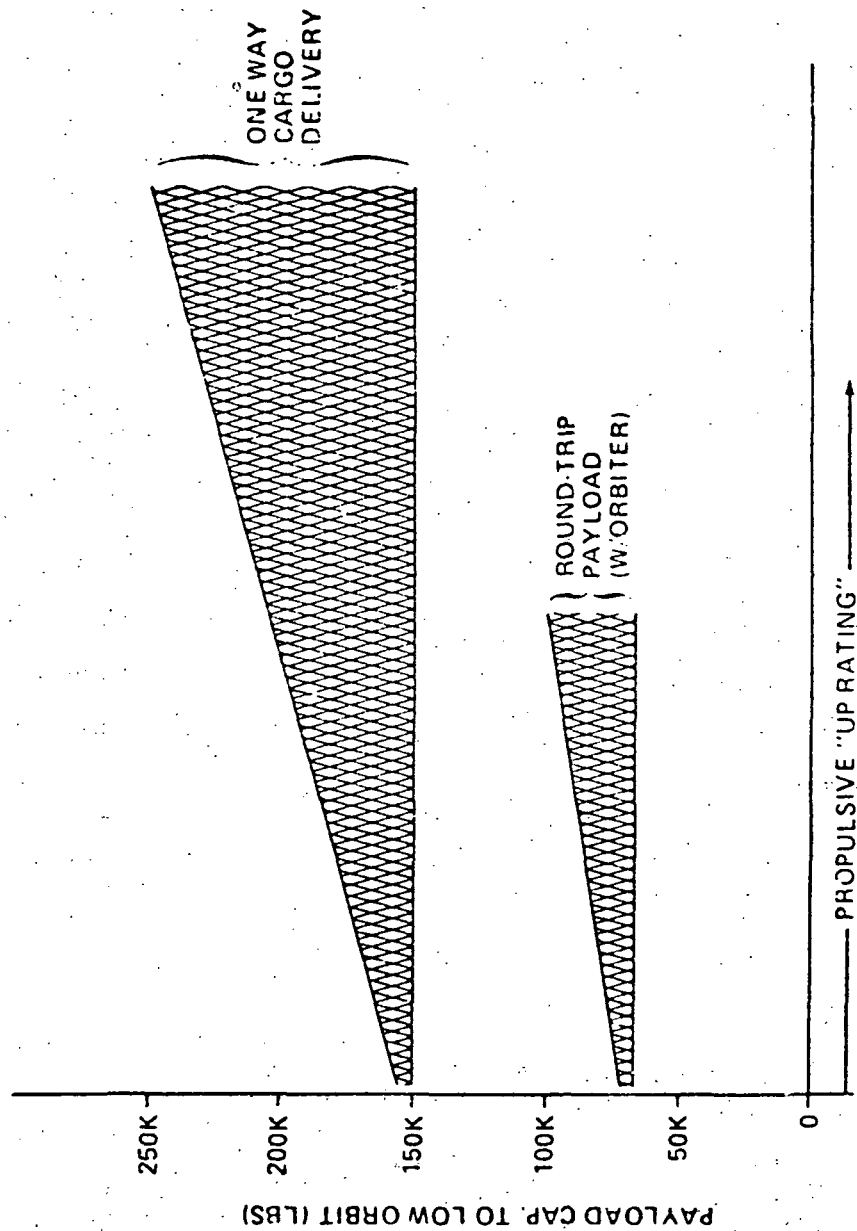


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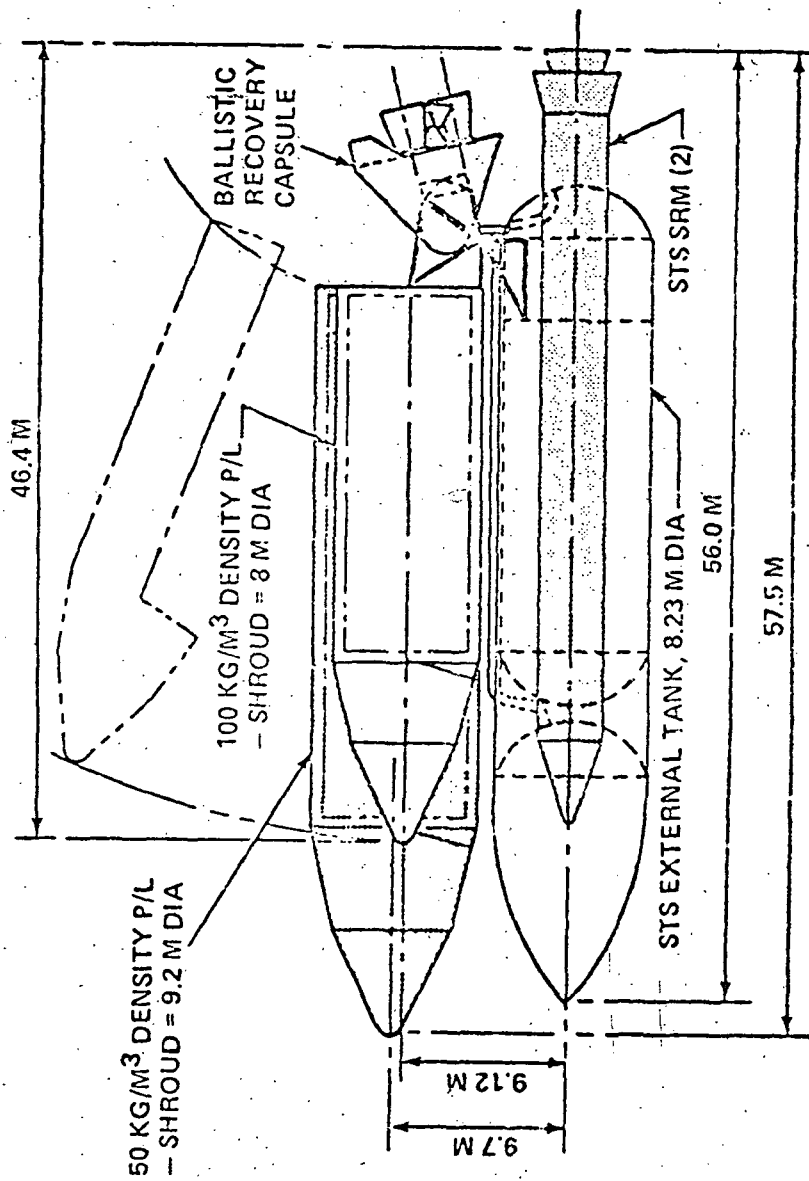
SPACE TRANSPORTATION

SPACE SHUTTLE POTENTIAL FOR INCREASED PAYLOAD CAPABILITY



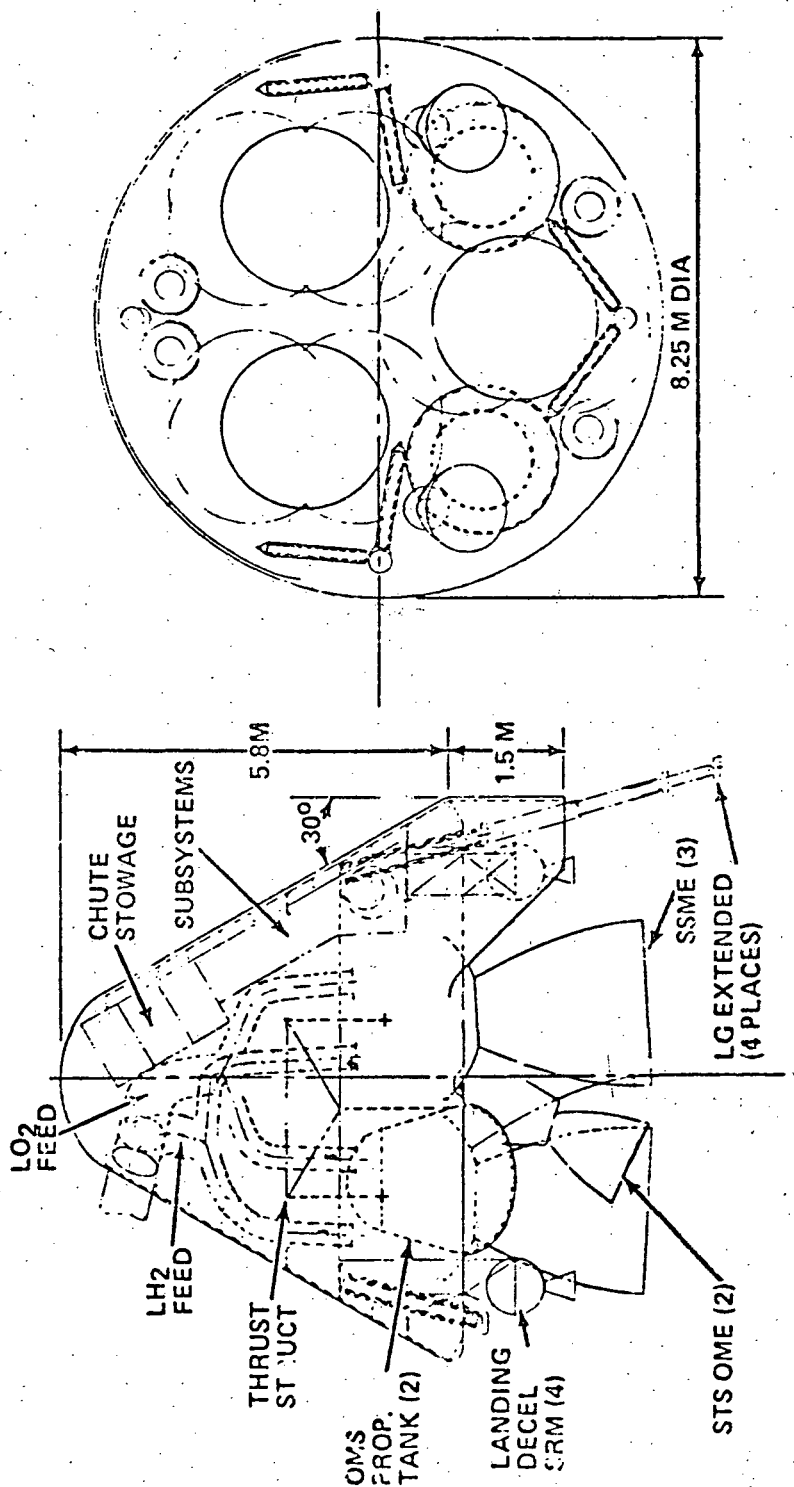
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Class 1 Stack — General Arrangement

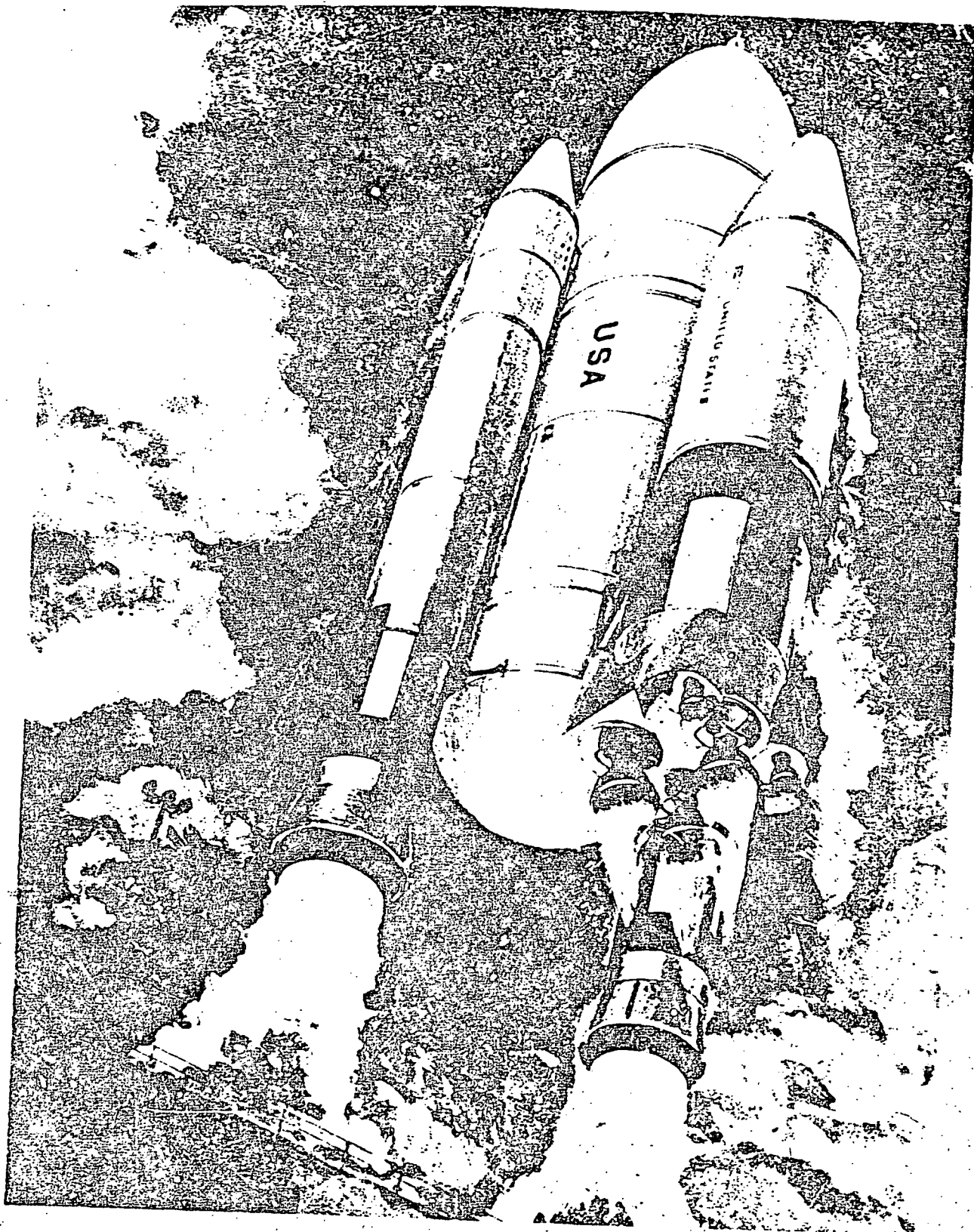


HEAVY LIFT
LAUNCH VEHICLES
BOEING/GRUMMAN

Class 1/2 Upper Stage – Ballistic Recovery Capsule General Arrangement & Inboard Profile



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SPACE TRANSPORTATION
SPACE SHUTTLE/IMPROVEMENTS

SUMMARY

SHUTTLE VERSATILITY

- o SPACELAB MISSIONS o SPACE STATIONS/EQUIPMENT
- o AUTOMATED SPACECRAFT o PASSENGER TRANSPORTATION/
LOGISTICS
- o PROPULSIVE UPPER STAGES o PRIORITY/ROUNDTRIP CARGO

SHUTTLE GROWTH/IMPROVEMENT POTENTIAL

- o INCREASE REUSABILITY, FURTHER REDUCE TRANSPORTATION COSTS.
- o INCREASE PAYLOAD DELIVERY CAPABILITY.
- INCREASE SHUTTLE/ORBITER CAPABILITY
- SHUTTLE-DERIVATIVE "HEAVY-LIFT" VEHICLE

TECHNOLOGY PLANNING FOR FUTURE EARTH ORBITAL TRANSPORTATION SYSTEMS

by

John P. Decker, B. Z. Henry, and Charles H. Eldred
NASA-Langley Research Center

ABSTRACT

The NASA is conducting continuing studies of future space transportation concepts to provide direction for long term improvements in the capability and efficiency of transporting payloads for both Earth-to-orbit launch and orbital transfer. Such improvements will greatly enhance the possibility of full utilization of space in the future. Consideration of the space shuttle-based transportation system and the possible time phasing of future systems leads to the conclusion that now is the right time to be building the technology base to meet these future needs. A broad spectrum of potentially attractive concepts is being examined in sufficient detail to determine relative merits of concepts and to determine their associated technological drivers. Goals for these future concepts include significant reductions in recurring costs, flexible operational modes, and operational simplicity. Current studies are directed toward the identification of technologies which make the most cost effective contribution to these goals and then to the establishment of programs to provide the indicated technology base.

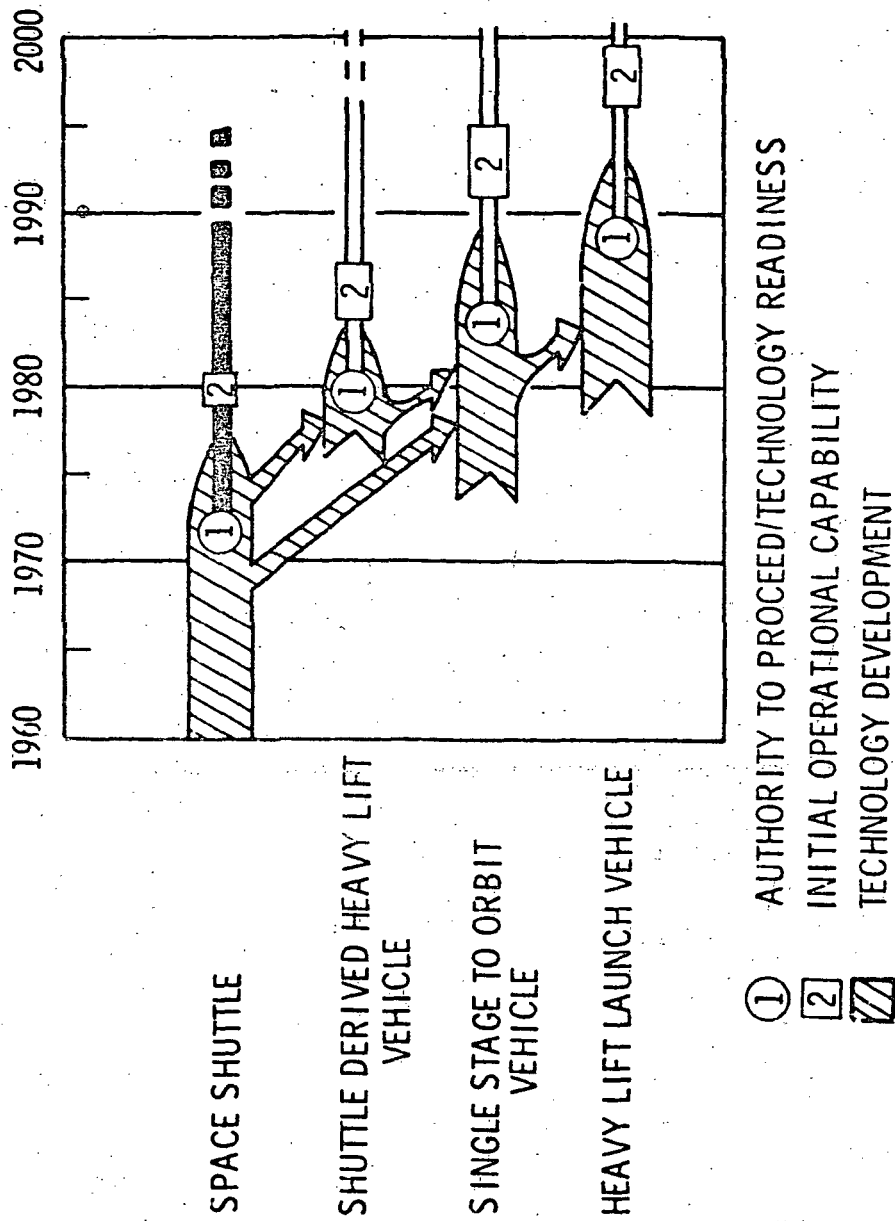
Studies to date have substantiated that, if pushed aggressively, structural weight reductions of 25% and effective propulsion system

performance improvements of 5-6% relative to current space shuttle technology are achievable in the mid-1990 time frame. With these improvements, a single-stage-to-orbit vehicle, using liquid oxygen/liquid hydrogen (LOX/LH) rocket engines would be attractive and feasible, and offer significant improvements in such areas as operational flexibility, full vehicle reuse, and reduced operating costs. Design features such as dual mode propulsion systems, modified operational approaches such as assisted horizontal takeoff, and application of control configured design principles offer additional significant improvements beyond the LOX/LH system discussed above.

This paper summarizes results from Langley Research Center studies of single-stage-to-orbit concepts including the evaluation of operational modes, thermal structural options, propulsion system optimization, cost analyses, and a current assessment of technology areas which support these vehicle systems.

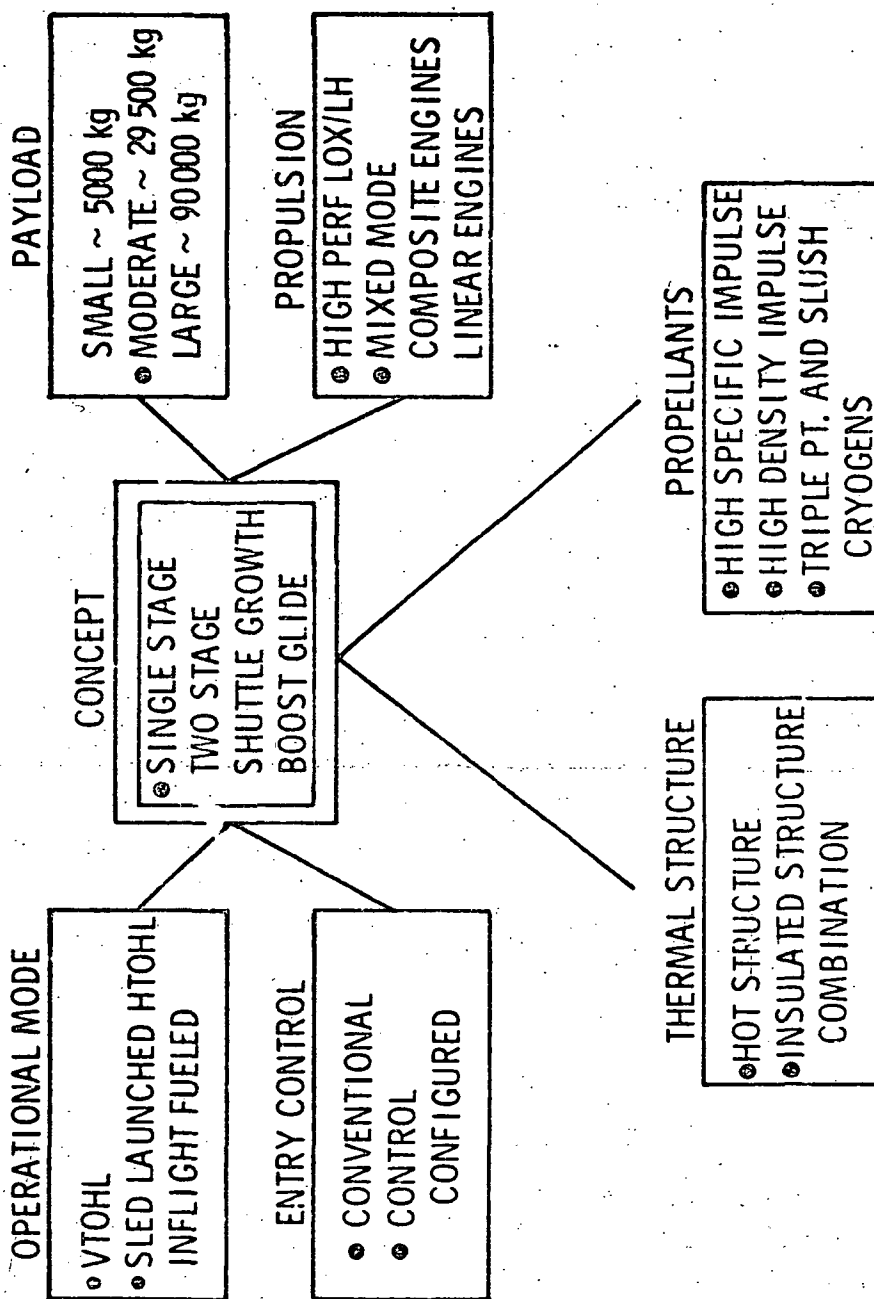
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ADVANCED VEHICLE PLANNING TIME-LINES

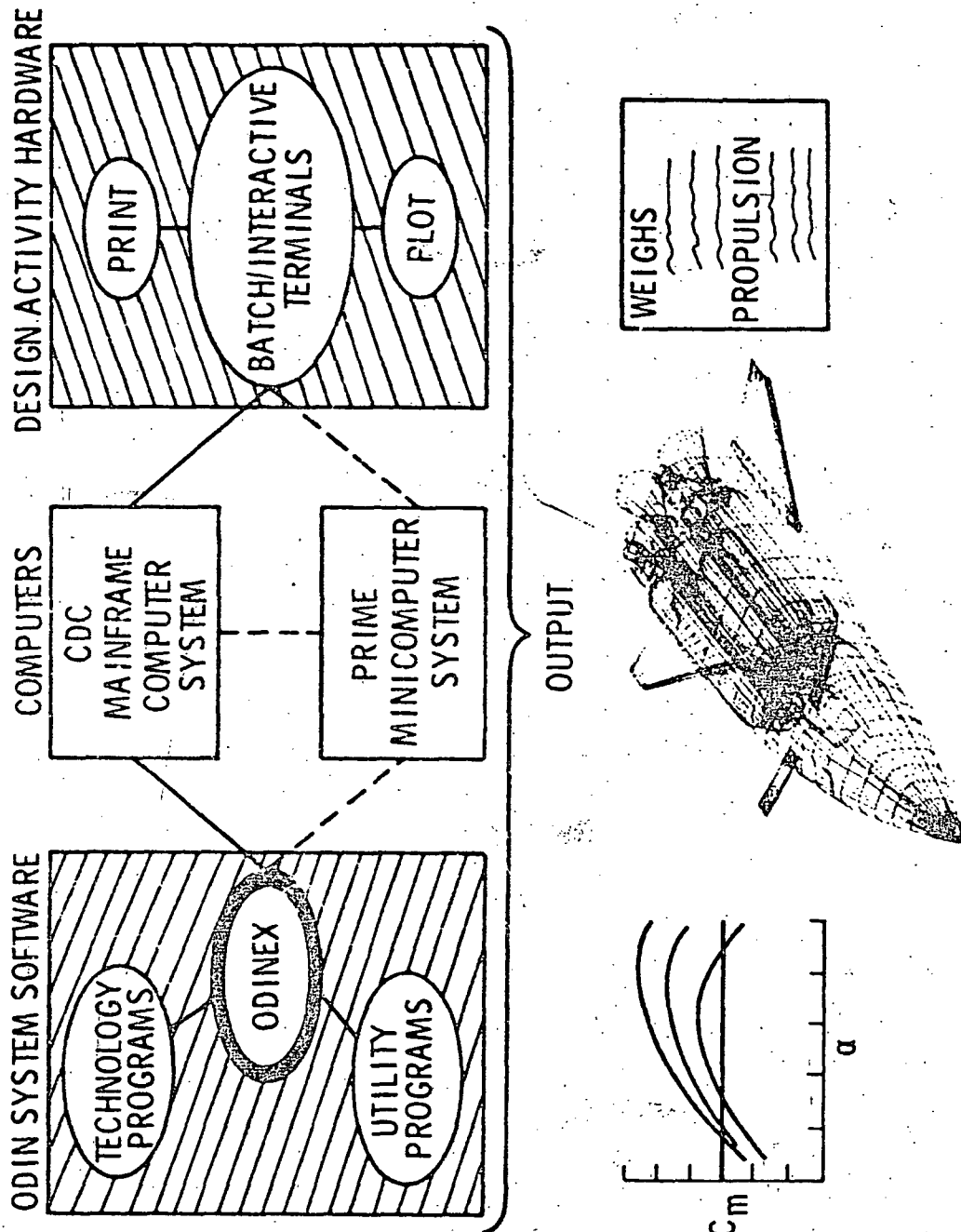


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TECHNOLOGY STUDIES

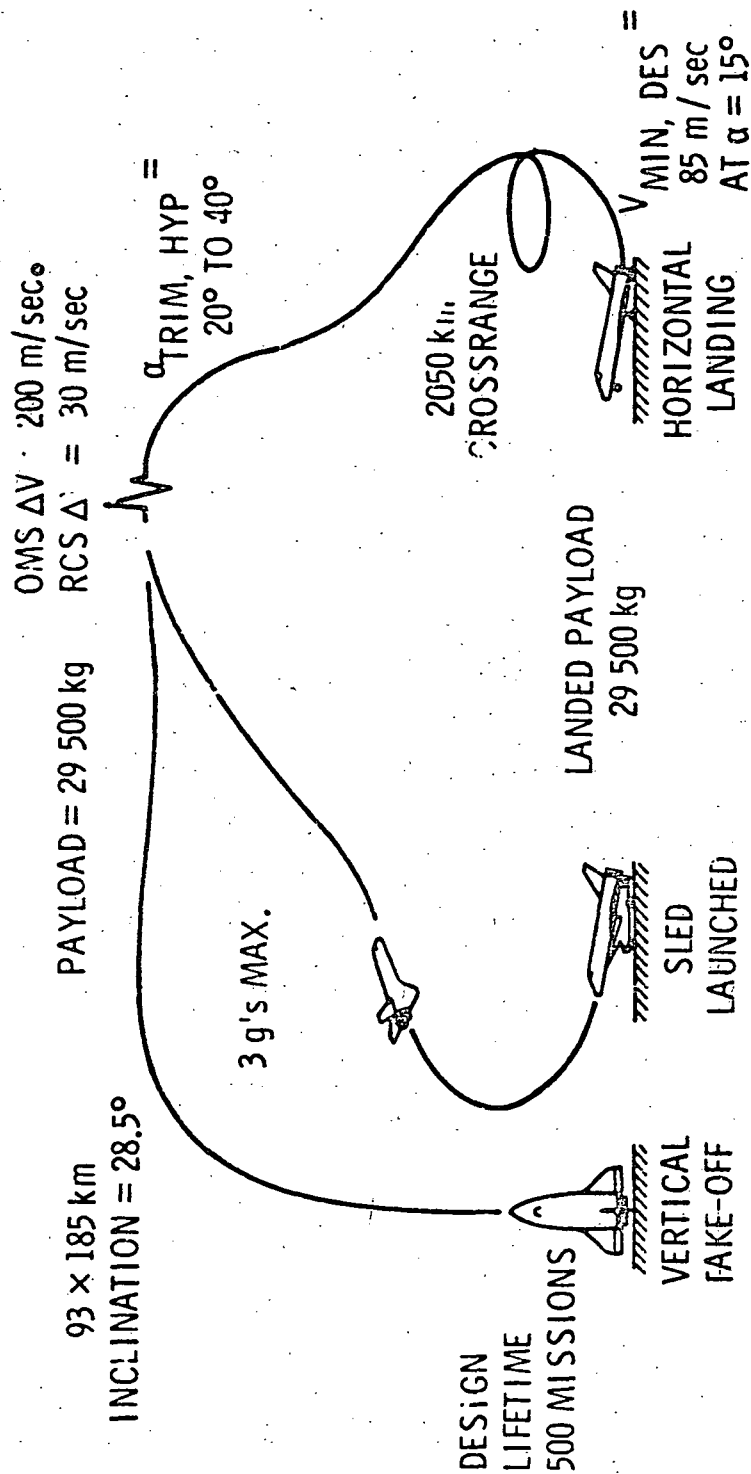


COMPUTER AIDED DESIGN



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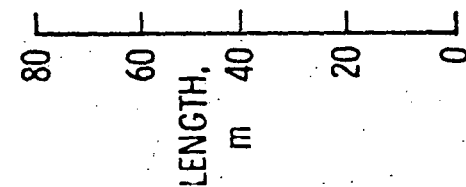
OPERATIONAL CONCEPTS



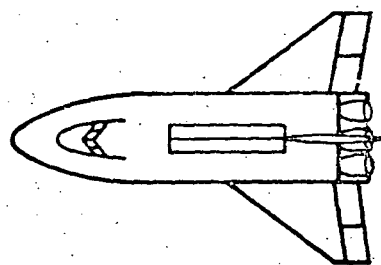
CONCEPT COMPARISON

ADVANCED TECHNOLOGY, PAYLOAD = 29 500 kg

TRIPLE PT. CRYOGENS

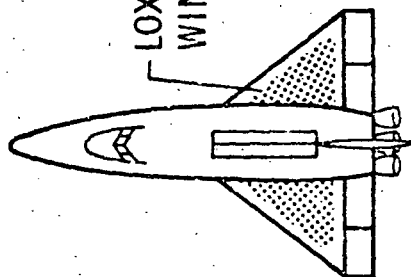


VTOHL



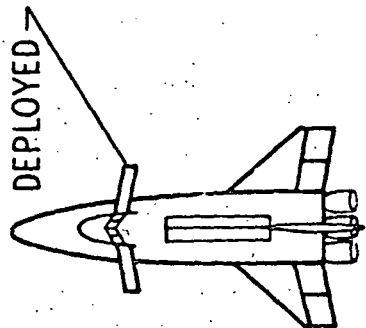
3 LOX/LH 3 LOX/LH
 $\epsilon = 50/200$ $\epsilon = 50$

HTOHL
SLED LAUNCHED



3 LOX/LH
 $\epsilon = 60/200$

VTOHL CCV
PARALLEL BURN
SUBSONICALLY
DEPLOYED



3 LOX/LH 3 LOX/RP-1
 $\epsilon = 40/200$ $\epsilon = 40$

WING AREA, m^2

DRY WEIGHT, kg

GLOW, kg

T/W

800

147400

1488000

1.30

880

118400

1152000

.77

480

104300

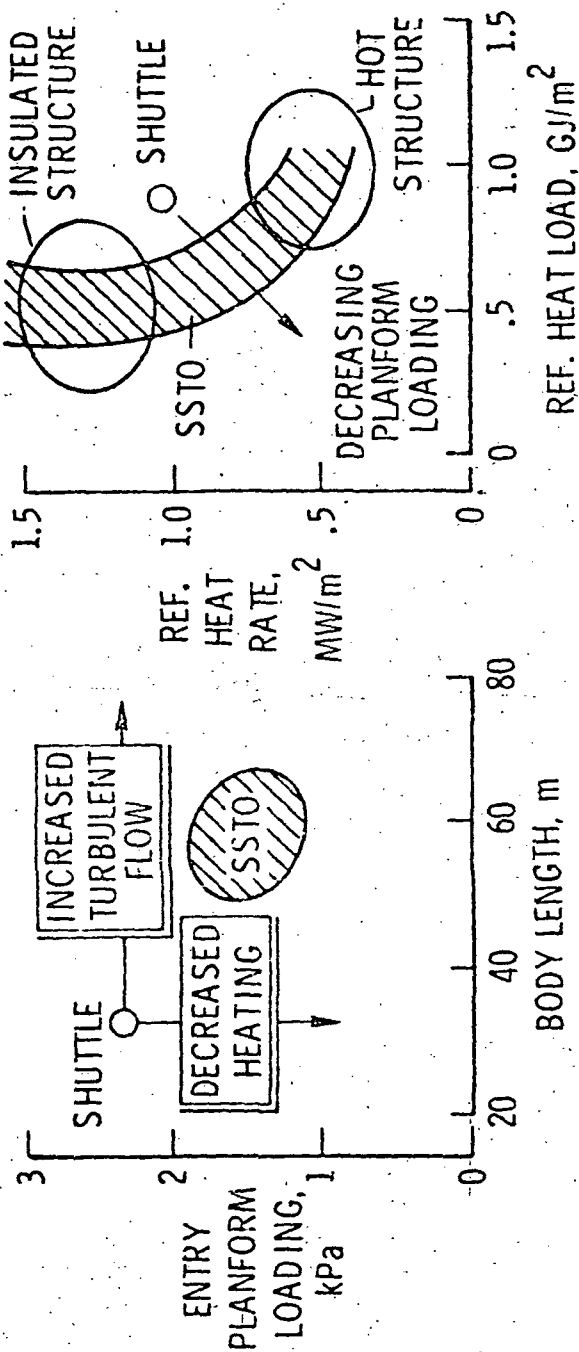
1211000

1.30

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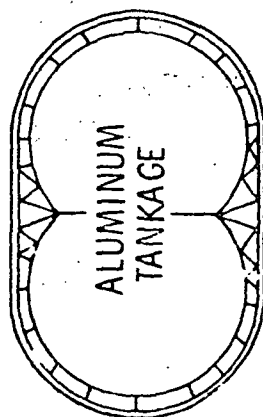
ENTRY CHARACTERISTICS

PAYLOAD = 29 500 kg



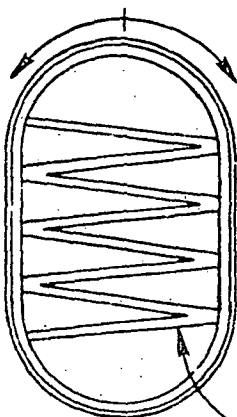
THERMAL STRUCTURE OPTIONS

INSULATED STRUCTURE



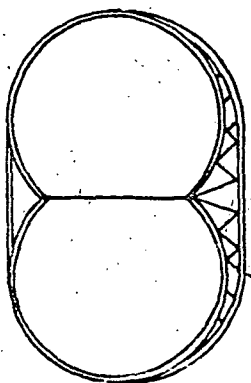
COMPOSITE CARRIER
PANELS

HOT STRUCTURE LOW TEMPERATURE HONEYCOMB MATERIAL



METAL MATRIX
COMPOSITE STRUTS

COMBINATION LOW TEMPERATURE HONEYCOMB MATERIAL



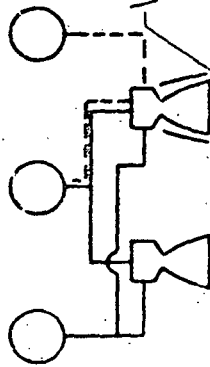
COMPOSITE CARRIER
PANELS

PROPULSION SYSTEMS

DUAL FUEL ENGINE SYSTEM

DUAL FUEL ENGINE SYSTEM

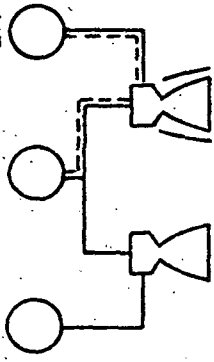
RP-1 LOX LH



— MODE 1 - LOX/RP-1
 --- MODE 2 - LOX/LH

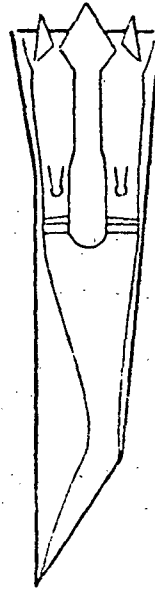
PARALLEL BURN, SEPARATE ENGINE SYSTEM

RP-1 LOX LH

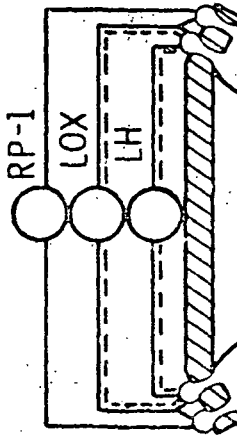


— MODE 1 - LOX/RP-1 + LOX/LH
 --- MODE 2 - LOX/LH
 LINEAR ENGINE

COMPOSITE PROPULSION
 AIRBREATHING PLUS ROCKET ENGINE



MODE 1 - AIRBREATHING/ROCKET
 MODE 2 - AIRBREATHING
 MODE 3 - ROCKET

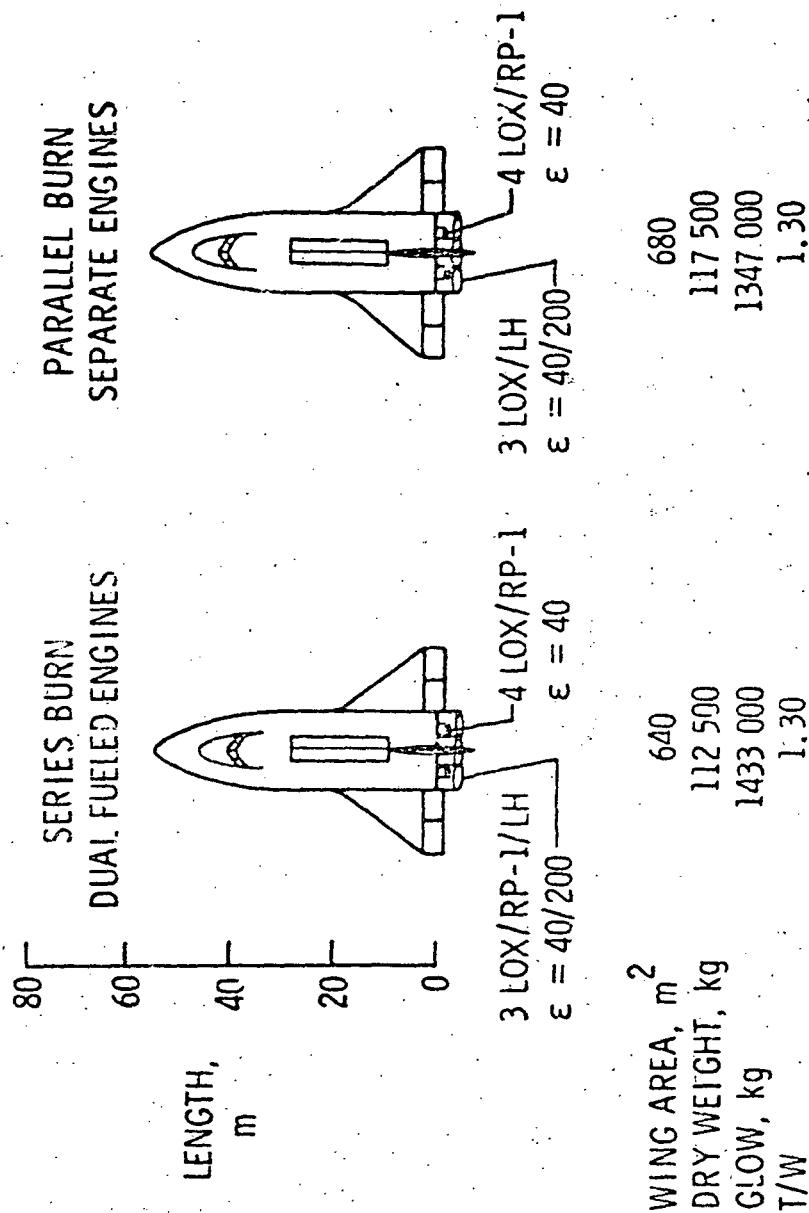


— MODE 1 - LOX/RP-1 + LOX/LH
 --- MODE 2 - LOX/LH

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DUAL MODE VTOHL SSTO CONCEPTS

ADVANCED TECHNOLOGY, TRIPLE PT. CRYOGENS, PAYLOAD = 29 500 kg



HIGH DENSITY PROPELLANT COMPARISON

PARALLEL BURN SEPARATE ENGINE CONCEPT

