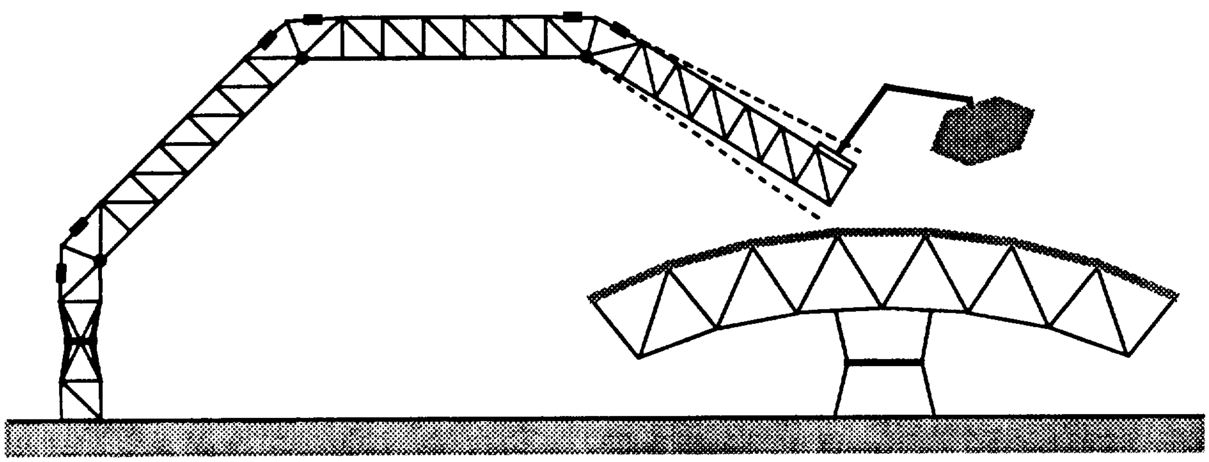
NASA Technical Memorandum 101515

An Integrated In-Space Construction Facility for the 21st Century

Martin M. Mikulas, Jr. and John T. Dorsey

(NASA-TM-101515) AN INTEGRATED IN-SPACE CONSTRUCTION FACILITY FOR THE 21ST CENTURY (NASA) 31 p
CSCL 22B
N89-13486
Unclas
G3/18 0183276



November 1988

National Aeronautics and Space Administration

Langley Research Center
Hampton, Virginia 23665

AN INTEGRATED IN-SPACE CONSTRUCTION FACILITY FOR THE 21ST CENTURY

Martin M. Mikulas, Jr. and John T. Dorsey

INTRODUCTION

Many of the proposed future space missions will require in-space construction of space systems which are both large and massive. For example, a manned sprint mission to Mars will require two large vehicles (Ref. 1); an unmanned cargo vehicle with a mass of several million pounds, and a manned sprint vehicle with a large amount of pressurized habitation volume. Similarly, establishing a manned lunar outpost will require large vehicles capable of ferrying cargo, people, and landers between Low Earth Orbit (LEO) and the Moon (Ref. 2). In addition to being large vehicles themselves, the components which make up the Lunar Transfer Vehicles and Mars vehicles, such as; Aerobrakes, Backbone trusses, Landers, and pressurized Habitation Volumes, will be large and massive. Unmanned missions, such as the Earth Observation Satellite (EOS), and Planetary Explorers, will require large precision structures (trusses, antennas, and telescopes), landers, sample return vehicles, and aerobrakes.

The systems required to accomplish these missions will be too large and massive to be placed in orbit by a single launch vehicle such as the Space Shuttle, or even a Heavy Lift Launch Vehicle (HLLV). Successfully accomplishing these missions will require the capability to construct large structures in LEO. Some on-orbit construction experience will be gained when building the Space Station Freedom in the mid 1990's and after completed, the Space Station Freedom could also serve as an operations and logistics base for constructing other large spacecraft. Such construction may, however, interfere with other research functions being carried out on the station. A free flying, large In-Space Construction Facility (ISCF) could be required to separate the dynamic operations associated with large vehicle construction from the zero-g experiments continually being conducted on the Space Station.

Major advances in several technologies will be required to successfully enable constructing large spacecraft in LEO. Currently, the automobile and manufacturing industries make regular use of automated systems which, however, require a large number of maintenance people. NASA has recently initiated the PATHFINDER program which is aimed at developing the technology required for future manned Mars and Lunar missions. An important part of the PATHFINDER program is the In-Space Assembly and Construction activity. This will develop in-space construction concepts that combine a high degree of efficiency and automation with a high degree of reliability. The automation is required since the costs associated with placing and maintaining people in orbit will clearly limit the number of persons available for system operation and maintenance.

This PATHFINDER activity will also define the infrastructure (cranes, transporters, large component assembly fixtures, storage tanks, etc.) required to construct and service a variety of large space vehicles. The types of operations which may be performed at the facility include; vehicle construction, vehicle repair and refurbishment, refueling, and vehicle checkout and testing. The infrastructure required to accomplish all of these operations must have a high degree of flexibility, adaptability, and commonality to minimize long term costs.

A major area for research and technology development in the In-Space Assembly and Construction activity, will be to advance the area of large space vehicle design-for-construction. Design-for-construction will emphasize integrating construction and assembly operations into the spacecraft design and layout. This activity will also concentrate on developing concepts for constructing large generic spacecraft components which will serve as building blocks for assembling a wide variety of space vehicles. The construction process will affect the component design, and the component design will affect the construction process, leading to an integrated approach for in-space vehicle construction.

The Pathfinder In-Space Assembly and Construction activity will:

1) Develop structural concepts and methodologies for constructing large vehicles in space, while emphasizing design-for-construction;

2) Develop the construction aids and techniques necessary to construct vehicles in-space; and

3) Define the ISCF layout and infrastructure requirements to support constructing a wide variety of vehicles in space.

Technology and process development will be continuously demonstrated throughout the Pathfinder program at a ground based test-bed. Hardware fabrication will be emphasized to prove construction concepts and methods and a set of technology focus problems, which encompass a variety of potential vehicle construction tasks, will be defined and demonstrated at the test-bed. Concepts and methodologies for constructing a number of generic spacecraft components, as well as assembling complete vehicles, will be developed in this program. Computer simulations will be developed to demonstrate and validate construction methods.

CONSTRUCTION APPROACHES

Future NASA missions to Mars and the Moon will require spacecraft of such complexity and size that they will have to be constructed on orbit. An artist's drawing of a spacecraft for a manned mission to Mars is shown in Figure 1. Such a spacecraft will consist of aerobrakes, surface rovers, fuel tanks, and pressurized manned modules. For the spacecraft shown in Figure

1, the backbone framework, to which all components are attached, has been built from the 5-meter strut-length erectable truss developed for Space Station Freedom. Constructing, outfitting, and checking-out such a large and complex spacecraft on orbit represents a major challenge which must be met before such missions are feasible.

Several approaches for constructing spacecraft on-orbit are shown in Figure 2. Most current spacecraft are of the first type indicated, that is, they are completely self contained in a single launch package and may have a few simple antennas or arms that deploy once in orbit. When feasible, this approach is very desirable, since all vehicle systems can be completely integrated and checked out on the ground prior to launch. The major limitation, however, is that the size and mass of the spacecraft is constrained by the size of the largest available launch vehicle. A second approach to achieving a large spacecraft on-orbit is to launch individual modules and mate these modules once in orbit. The Apollo/Soyuz mission is an example of such an approach. This modular approach is also very attractive, since each individual module would be completely integrated and checked out on the ground prior to launch, thus, minimizing the number of on-orbit interfaces required. A third approach for achieving a large spacecraft is to completely assemble it. This approach offers the advantage that the spacecraft is constructed from individual elements once on-orbit, thus its geometry is not limited by launch vehicle size constraints. Although each of these three approaches for achieving a spacecraft on-orbit has desirable features, constructing of a very large spacecraft will require a hybrid approach which incorporates the best features of each. A large spacecraft, as indicated by item 4 in Figure 2, will consist of major elements such as large integrated components, pressure vessels, and manned modules, all attached to a skeletal framework formed of erectable or deployable trusses. An example of such a spacecraft is the Mars vehicle shown in Figure 1.

The primary design drivers for very large space structures are shown in Figure 3. Technology development for large space structures has been underway within NASA for the past 15 years. Many structural concepts have been investigated and the first three items listed in Figure 3 have been the subject of considerable research. Although all of these items require further development, the last one, on-orbit construction, represents the major current challenge for enabling spacecraft construction on orbit.

Two of the main on-orbit construction issues, which have a direct impact on cost, are construction time and reliability. To reduce the amount of EVA time required for construction, considerable attention is being given to automated construction. The issue of automated system reliability then becomes a major concern. One way to reduce construction costs is to make as much use as possible of commonality in both hardware and construction approaches. Because designing new hardware and developing new construction procedures for every new spacecraft will be an extremely expensive approach, it is advantageous to develop a set of generic spacecraft components which can be used to construct many different vehicles. The other main element that will affect on-orbit construction costs is an on-orbit construction facility. The optimum on-orbit construction facility will achieve a good balance between the number of astronauts and robots needed for construction. Although automated equipment will reduce the number of EVA hours required to perform a construction task, the best approach for assuring reliability in the construction task is to have man involved in a supervisory role.

Structures technology within NASA has developed considerably over the past 15 years and some of these developments are highlighted in Figure 4. A number of trusses and quick-attachment joints have been developed and demonstrated both operationally and structurally in extensive ground test programs. The results of these studies are reported in References 3 through 10. A major direct benefit of this technology has been the development of the erectable truss structure for Space Station Freedom. The erectable truss selection criteria, design constraints and design process is discussed in Reference 11.

NASA will spend a considerable amount of money developing the truss structure and its associated construction approach for Space Station Freedom. In subsequent sections of this paper, applications of the space station truss to other missions, to take advantage of commonality, will be discussed.

WHY TRUSSES?

Trusses composed of triangulated members represent the most efficient structural form. In many earth bound applications, structural forms other than trusses are used but for reasons other than efficiency. For example, houses require siding for protection from the elements and aircraft structures need skin covering for aerodynamic purposes. In other applications, structures are required to act as containers and in some cases, the form is chosen for purely aesthetic reasons. The main design requirements for large space structures are shown in Figure 5. The first two requirements, low weight and high stiffness, are met extremely well by truss structures because trusses are specifically designed to have members which carry all loads in either tension or compression. A truss structure can either be folded (deployable truss) or taken apart (erectable truss) to be packaged very tightly for launch vehicle stowage. Linear structural behavior of erectable truss joints has been demonstrated with tests, making the truss structure performance, after construction, very predictable. Structural predictability is extremely important because it will not be possible to assemble and test large spacecraft on the ground prior to launch. Truss nodes and joints for erectable trusses have been designed to permit a wide variety of spacecraft shapes to be constructed, which provides a great deal of construction versatility. Finally, modern trusses have been in use for over a 100 years in civil engineering structures and accordingly, a considerable amount of verified truss analysis and design capability exists.

Trusses can be used to build a wide variety of structural shapes as is shown in Figure 6. Platforms and beams can be used as a skeletal framework to which other components or modules can be attached, forming a large integrated spacecraft. These same truss can be shaped into boxes or cylinders and covered to produce shelters or sunshields for various applications. Trusses can be built very accurately and covered with modular reflectors to form large very precise antennas or reflective surfaces. Trusses can also be built to carry very large loads and covered with modular heat shields to form large high energy absorbing aero-assist decelerators (aerobrakes) as shown in the lower right of Figure 6.

AFFORDABLE MISSIONS ARE POSSIBLE

A major impediment to pursuing bold new missions is the perceived ultra high cost of constructing and operating large spacecraft in space. Due to their novel and one-of-a-kind nature, design and development costs dominate the total cost of current spacecraft. This is contrasted with civil engineering structures, where design and development represent less than 10 percent of the cost of large new structures. The major differences between these two approaches lies in the amount of off-of-the-shelf hardware used and the cost associated with construction. To make large spacecraft "affordable" the two technology items identified in Figure 7 must be provided. First, generic "off-of-the-shelf" building blocks, which can be used for many different large space structural systems, must be developed. As these basic building blocks are developed and mature through demonstrations, the verification costs of missions using these building block structures will decrease substantially. Second, an integrated in-space construction system, where the basic facility structural framework also serves as construction scaffolding as well as a roadbed for construction aids, must also be developed. The integrated construction system will provide an optimum balance of automated construction and EVA tasks to maximize reliability.

IN-SPACE CONSTRUCTION FACILITIES

Space Station Freedom has all of the basic features required to be converted into a completely integrated construction facility for very large spacecraft (Fig. 8). The 5-meter erectable space station backbone truss was designed specifically to be used for such large scale construction. The truss is not only expandable to meet all construction needs, it can also serve as construction scaffolding and as a vehicle hangar, as shown in Figure 9. Additional truss scaffolding can be erected for a specific construction job and then taken down or reconfigured for a different construction task. The large truss size was specifically chosen to increase its stiffness, thereby minimizing disturbances to other activities during the construction process. The erectable truss is very versatile and can be used to build protective shelters as well as serve as the roadbed for the Mobile Transporter (which is a major construction aid). The truss size was also selected to be compatible with shuttle cargo bay size payloads, allowing the payloads to be placed in or on the side of the truss with no overhang to interfere with operations.

A Mobile Transporter will be an integral component of the Space Station Freedom system. This transporter is used for the constructing, maintaining, and repairing the station and is shown in operation in Figure 10. This Mobile Transporter can also be used to add erectable space station truss for scaffolding purposes as well as for controlled transporting and positioning of payloads which may be required for the construction process (Ref. 12). The transporter eliminates the need for delicate "free flying" maneuvers of the Shuttle or other systems in the vicinity of the station. The mobile transporter in conjunction with a build-as-needed scaffolding approach, provides a basic general purpose construction aid for other spacecraft. By outfitting the mobile transporter with automated end effectors, this combination would provide a complete capability for fully automated construction operations.

Although the Space Station would provide an excellent construction facility for other very large spacecraft, the dynamic disturbances introduced during the construction process may not be tolerable. The Space Station will also be a experimental facility for a large number of continuous zero-g and observation experiments. If the disturbances are not acceptable for Space Station Freedom, a separate special purpose construction facility could be built using common space station hardware. Such a facility is shown in Figure 11. This facility is built from the same 5-meter erectable truss hardware as Space Station Freedom and would co-orbit with the space station to permit regular transfer of astronauts and equipment. The particular system shown in Figure 11 was configured specifically for a large manned Mars vehicle. The truss shown in Figure 11 is composed of 1800 individual struts and weighs about 20,000 pounds. EVA construction time for the truss alone would be on the order of 30 hours. The relatively short time required to construct the truss (disassembly time would be about the same) means that this facility could easily be reconfigured for other missions.

PATHFINDER ON-ORBIT CONSTRUCTION PROGRAM

The PATHFINDER on-orbit assembly and construction program is aimed at providing the enabling technology to permit efficient, reliable in-space construction of very large spacecraft as indicated in Figure 12. Since there are numerous future missions being considered, a decision was made to select a representative in-space construction focus problem that has most of the elements required to drive technology development. One goal of this program is to define and develop methodologies for constructing generic spacecraft components (such as aerobrakes, backbone trusses, pressurized modules, etc.) that can be applied to many different missions. This will lead to spacecraft which have assembly and construction requirements integrally incorporated into their design. The second goal is to develop the processes (welding, bonding, and mechanically attaching) required to join components in space. Accomplishing this objective will require that concepts for specialized holding fixtures and robot end effectors be developed. Methods for testing and verifying joint integrity must be developed in concert. The third goal is to develop the ability to manipulate and precisely position large massive vehicle components so that they can be permanently joined. Concepts, such as transporters, space cranes and large component assembly fixtures, will be fabricated and demonstrated to achieve this objective. The fourth and final goal is to define the Facility layout and infrastructure which is required to support construction of large spacecraft in space. Envisioned is a blueprint for a facility having a high degree of construction flexibility, adaptability, autonomy, and commonality.

To achieve these goals, a large reentry spacecraft was chosen as the primary focus problem and is shown schematically in Figure 13. The specific aerobrake concept chosen for study is 120 feet in diameter, supports a 1,000,000 lbm payload and is subjected to a 3-g deceleration loading during reentry. The resulting support truss for such an aerobrake would have 14 foot long struts which would carry an average load of approximately 150,000 lbf. This large reentry spacecraft is encompassing enough to allow the four objectives listed in the preceding paragraph to be accomplished and can be directly applied to several advanced missions currently being studied by NASA. The first part of the focus problem, construction of an aerobrake, involves a very large area structure and applies to Manned Moon, Manned Mars, and unmanned Planetary Exploration missions. This part of the problem will demonstrate; heavily loaded truss construction, precision structure (heat shield) construction and installation, and large area bonding or welding to make an impermeable surface (heat shield). Concepts for deployable utilities will also be developed and integrated into the aerobrake. The second part of the focus problem will demonstrate large component assembly. A large and massive component will be attached to the aerobrake using a transition truss. An artist's drawing of an aerobrake structure with large masses attached is shown in Figure 14. This particular drawing is a space based orbital transfer vehicle being studied by General Dynamics. Although this aerobrake is not as large as the one being chosen for the current study, the aerobrake backup truss and the transition truss are both similar to those being considered.

A preliminary study of the large 120 diameter aerobrake indicated the individual struts will be quite large as is shown in Figure 15. The study also showed that there are about 800 individual struts in the aerobrake and that the total truss weight would be about 60,000 pounds. The aerobrake strut is compared with struts being considered for precision reflectors and for Space Station in Figure 15. The two major differences for the aerobrake strut are; that it is very highly loaded, and that it has a large diameter. The high load capacity required of the struts means that current joint concepts are not applicable. Special purpose, quick-attachment joints, designed for loads in the 200,000 pounds class will have to be developed to make such structures feasible. The large diameter of the struts means that astronauts will have a difficult time handling each strut. The previous struts for precision reflectors and for Space Station have been limited in diameter to 2 inches or less to be compatible with an astronauts pressurized glove, permitting an astronaut to easily handle each strut with one hand for positioning and inserting into the truss. The larger diameter struts would require special handling aids if they are to be handled by astronauts, or perhaps it implies that some type of a machine (perhaps automated) may be needed for truss construction. This larger, more heavily loaded truss is an example of the new structural and construction issues that are being addressed in this focus problem. These and other technology challenges being addressed in this program are shown on Figure 16. In each area, concepts will be developed and taken to the point of building test hardware for verification.

An important new concept being developed in this program, a large space crane, could be of value in positioning large spacecraft components for in-space attachment. The goal of this portion of the program is to develop a space crane concept to the point that its use can be realistically traded off against other construction approaches.

The space crane concept initially selected for study is shown in Figure 17. In this schematic the space crane is shown attached to the construction facility truss of Figure 11. As with the construction facility truss, the space crane is constructed from the Space Station 5-meter struts. The rotary joint at the base is the same as the alpha rotary joint used on Space Station Freedom's transverse boom to track the Sun. A mobile transporter is used to build the space crane in the same fashion that the space station truss was built. The mobile transporter is parked at the end of the crane and its 60-foot-long manipulator arm is used as an end effector. In this portion of the program, the space crane articulating joints and computer driven control system will be developed. A one-fifth scale model of the crane will be built and installed in a test-bed for construction verification studies, as indicated in Figure 18.

The final major portion of the PATHFINDER program will define an in-space construction facility. As part of this effort, methods for constructing a variety of generic structures which can be used to build many different vehicles, will be developed. Construction requirements, such as; amount and type of infrastructure, sequence of operations to be performed, and the degree of autonomy in the construction process will be identified and defined. A database, which will contain computer models of the components to be constructed, payload positioning devices, facility infrastructure, etc., will be established and maintained. The database will provide a common set of information and will enable a variety of simulations to be performed such as; crane motion/reach, construction sequence planning, and component/system dynamics and control. The size, layout, and supporting infrastructure required by an In-Space Facility will be defined and continuously updated in the database as construction concepts are defined and verified. The interaction (information exchange, formats, protocols, etc.) between various automated systems in the Facility will also be defined in this activity.

CONCLUDING REMARKS

In this paper, the various types of structures and equipment that will be required to construct very large spacecraft in space are discussed. Although considerable research has been conducted on developing various structures for space, very little effort has been applied to the development of on-orbit construction methods. One of the basic issues that must be resolved is the appropriate mix of humans and robots in the construction process. While using robots offers the potential for reducing the number of EVA hours required for a particular construction task, the availability of humans greatly increases the reliability of complex construction tasks.

Space Station Freedom has incorporated all of the basic design characteristics to permit its growth into an in-space construction facility for constructing very large spacecraft. However, since numerous zero-g and precision pointing experiments are onboard the station, a dedicated, co-orbiting construction facility may be required. Such a facility could be easily built using truss hardware and systems previously developed for the Space Station Freedom program.

A PATHFINDER research effort, which addresses on-orbit construction, has been initiated by NASA to address the technology challenges of constructing very large spacecraft. This will be a highly focused effort and will concentrate on constructing a large spacecraft attached to a large aerobrake. This particular focus problem was chosen to significantly advance the range of structural and construction parameters currently being considered. A 100-meter-long space crane will be developed as a major part of this new effort. This will bring the space crane to the level of maturity where its use can be realistically traded off against other construction approaches.

REFERENCES

1. Cirillo, William M.; Kaszubowski, Martin J.; Ayers, J. Kirk; Llewellyn, Charles P.; Weidman, Deene J.; and Meredith, Barry D.: Manned Mars Mission Accommodation - Sprint Mission. NASA TM-100598, April 1988.

2. Weidman, Deene J.; Cirillo, William M.; Llewellyn, Charles P.; Kaszubowski, Martin J.; and Kienlen, E. Michael, Jr.: Space Station Accommodations for Lunar Base Elements - A Study. NASA TM-100501, October 1987.

3. Heard, Walter L., Jr.; Bush, Harold G.; Wallsom,Richard E.; and Jensen, J. Kermit: A Mobile Work Station Concept for Mechanically Aided Astronaut Assembly of Large Space Trusses. NASA TP-2108, 1983.

4. Mikulas, Martin M., Jr.; Bush, Harold G.; Wallsom,Richard E.; Dorsey, John T.; and Rhodes, Marvin D.: A Manned-Machine Space Station Construction Concept. NASA TM-85762, 1984.

5. Bush, Harold G.; Mikulas, Martin M., Jr.; Wallsom,Richard E.; and Jensen, J. Kermit: Conceptual Design of a Mobile Remote Manipulator System. NASA TM-86262, 1984.

6. Mikulas, Martin M., Jr., et al: Space Station Truss Structures and Construction Considerations. NASA TM-86338, 1985.

7. Mikulas, Martin M., Jr., et al: Deployable/Erectable Trade Study for Space Station Truss Structures. NASA TM-87573, 1985.

8. Young, John W.; Lallman, Frederick J.; Cooper, Paul A.; and Giesy, Daniel P.: Control/Structures Interaction Study of Two 300 KW Dual-Keel Space Station Concepts. NASA TM-87679, 1986.

9. Heard, Walter L., Jr., and Watson, Judith J.: Results of the ACCESS Space Construction Shuttle Flight Experiment. AIAA Paper No. 86-1186-CP. Presented at the AIAA Space Systems Technology Conference, San Diego, California, June 9-12, 1986.

10. Card, Michael F.; Heard, Walter L., Jr.; and Akin, David L.: Construction and Control of Large Space Structures. NASA TM-87689, 1986.

11. Mikulas, Martin M., Jr. and Bush, Harold G.: Design, Construction and Utilization of a Space Station Assembled from 5-Meter Erectable Struts. NASA TM-89043, October 1986.

12. Bush, Harold G.; Lake, Mark S.; Watson, Judith J.; and Heard, Walter L., Jr.: The Versatility of a Truss Mounted Mobile Transporter for In-Space Construction. NASA TM-101514, November 1988.

Figure 1

POTENTIAL ON-ORBIT CONSTRUCTION APPROACHES

1 - COMPLETELY DEPLOYABLE SPACECRAFT

2 - MODULAR SPACECRAFT

3 - COMPLETELY ASSEMBLED SPACECRAFT

4 - HYBRID SPACECRAFT

- Large Integrated Components
- Pressure Vessels
- Modules
- Erectable And/Or Deployable Trusses

NASA — Mikulas 10/15/88

Figure 2

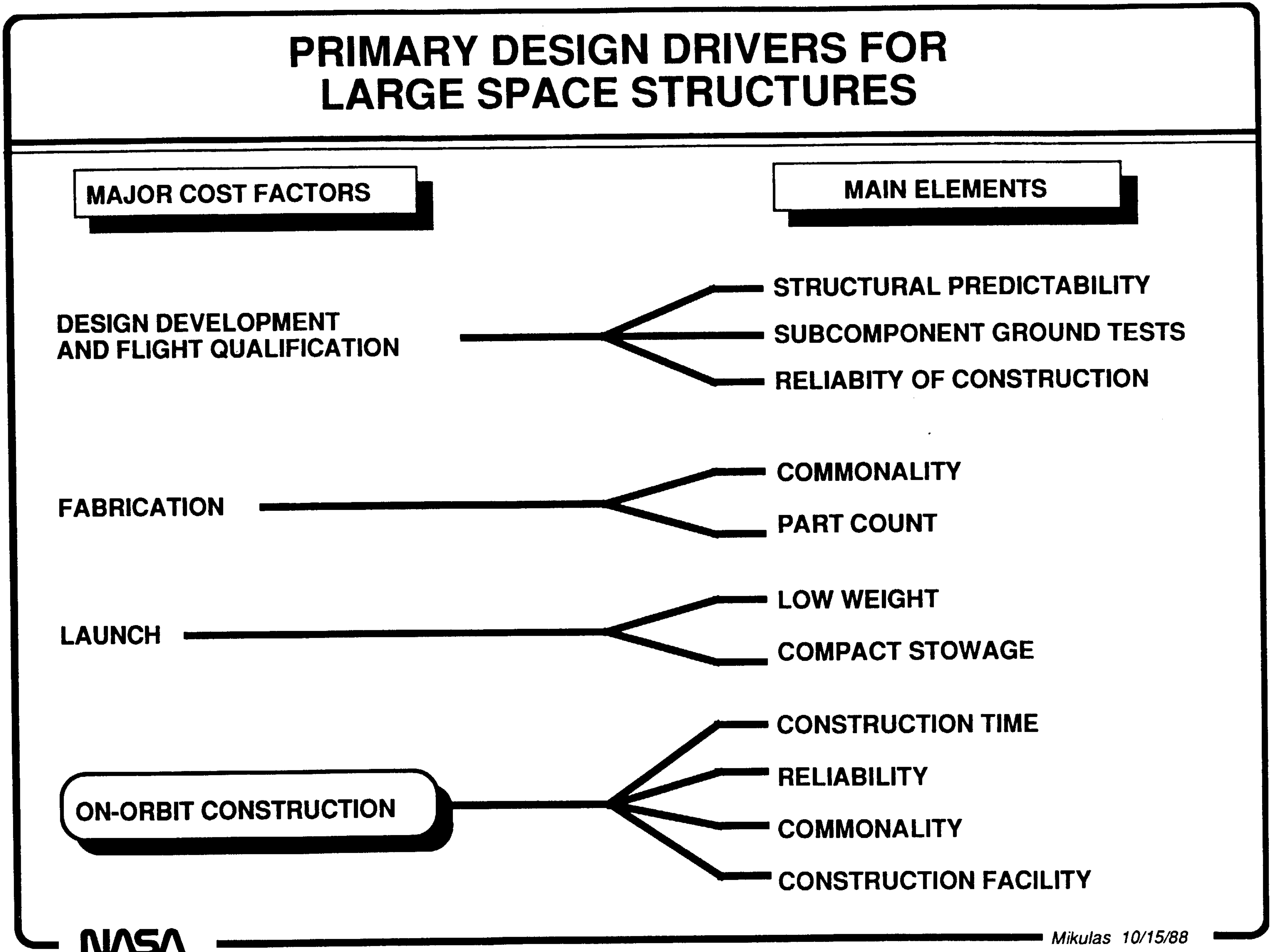

PRIMARY DESIGN DRIVERS FOR
LARGE SPACE STRUCTURES
MAJOR COST FACTORS
MAIN ELEMENTS
DESIGN DEVELOPMENT AND FLIGHT QUALIFICATION
STRUCTURAL PREDICTABILITY
SUBCOMPONENT GROUND TESTS
RELIABITY OF CONSTRUCTION
FABRICATION
COMMONALITY
PART COUNT
LAUNCH
LOW WEIGHT
COMPACT STOWAGE
ON-ORBIT CONSTRUCTION
CONSTRUCTION TIME
RELIABILITY
COMMONALITY
CONSTRUCTION FACILITY
NASA
Mikulas 10/15/88

Figure 3

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 4

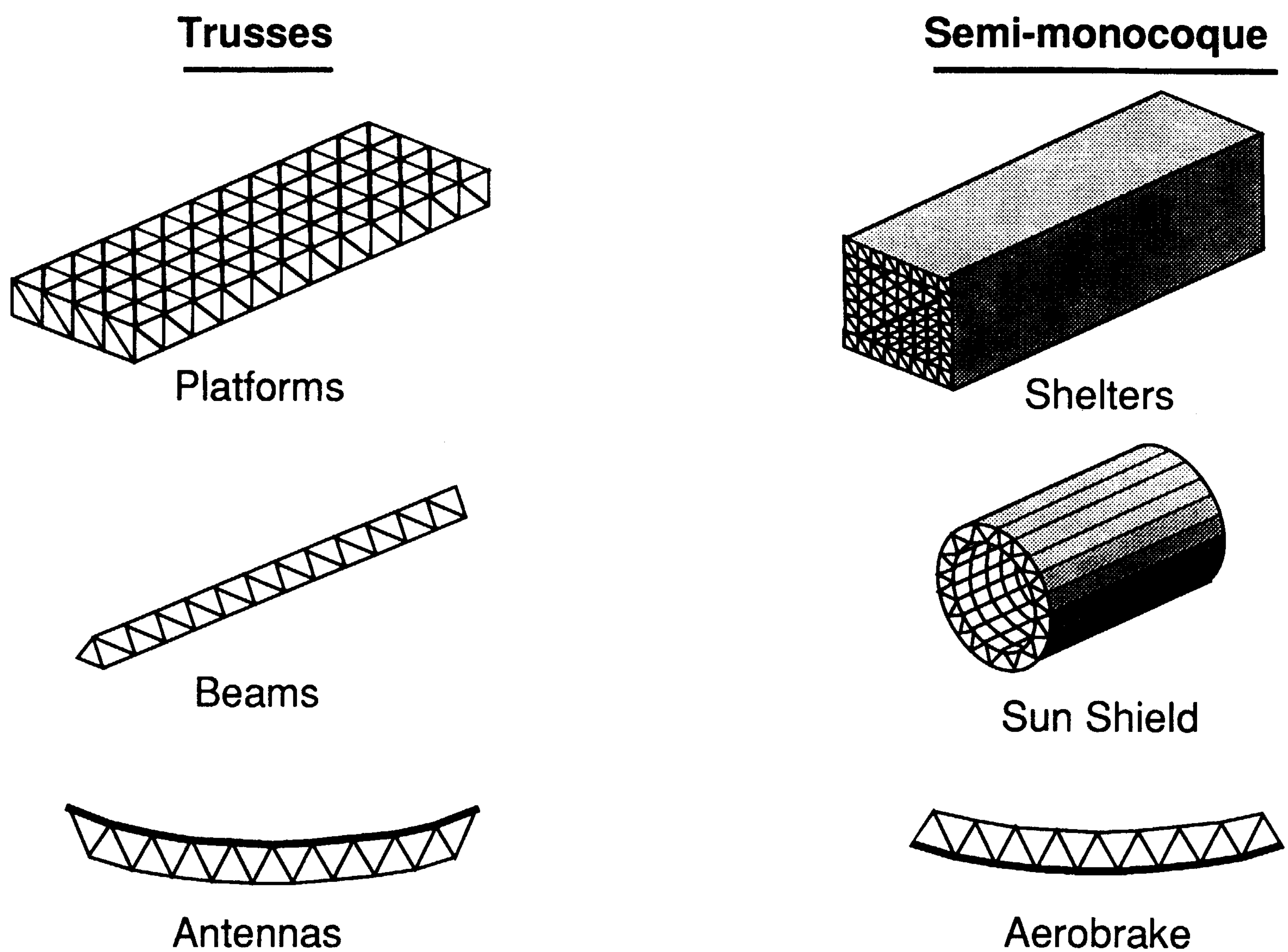
TRUSSES ARE IDEAL BASIC ELEMENTS FOR IN-SPACE CONSTRUCTION

- Low Weight
- High Stiffness
- Compact Stowage
- Predictable
- Versatile
- Considerable Experience

Mikulas 10/15/88

Figure 5

TRUSSES PROVIDE BASIC BUILDING BLOCKS FOR A VARIETY OF SPACE APPLICATIONS



NASA Mikulas 10/15/88

Figure 6

AFFORDABLE MISSIONS ARE POSSIBLE

- o Need To Develop Common "Off-Of-The-Shelf" Building Blocks
  - Erectable And Deployable Area Trusses (1 Meter To 10 Meter Struts)
  - Erectable And Deployable Beams (1 Meter To 10 Meter Struts)
- o Need An Integrated In-Space Construction System
  - Multi Purpose Construction Aid
  - Automated Construction Capability

NASA Mikulas 10/15/88

Figure 7

CURRENT SPACE STATION IS BASIS FOR AN INTEGRATED CONSTRUCTION SYSTEM

o 5 METER ERECTABLE SPACE STATION

- Expandable To Meet Construction Needs
  (Truss Is Construction Scaffolding)
- Stiff Truss To Minimize Disturbances
- Truss Can Be Used To Build Protective Shelters
- Truss Is Roadbed For Transporter

o MOBILE TRANSPORTER

- Used In Constructing The Station
- Used For Station Maintenance And Repair
- Provides Controlled Transport And Positioning Of Payloads
- Shuttle "Free-Flying" Not Required
- Basic Construction Aid For Other Spacecraft
- Enabling Capability For Automated Construction Operations

NASA Mikulas 10/15/88

Figure 8

SPACE STATION EXPANDED INTO A CONSTRUCTION FACILITY

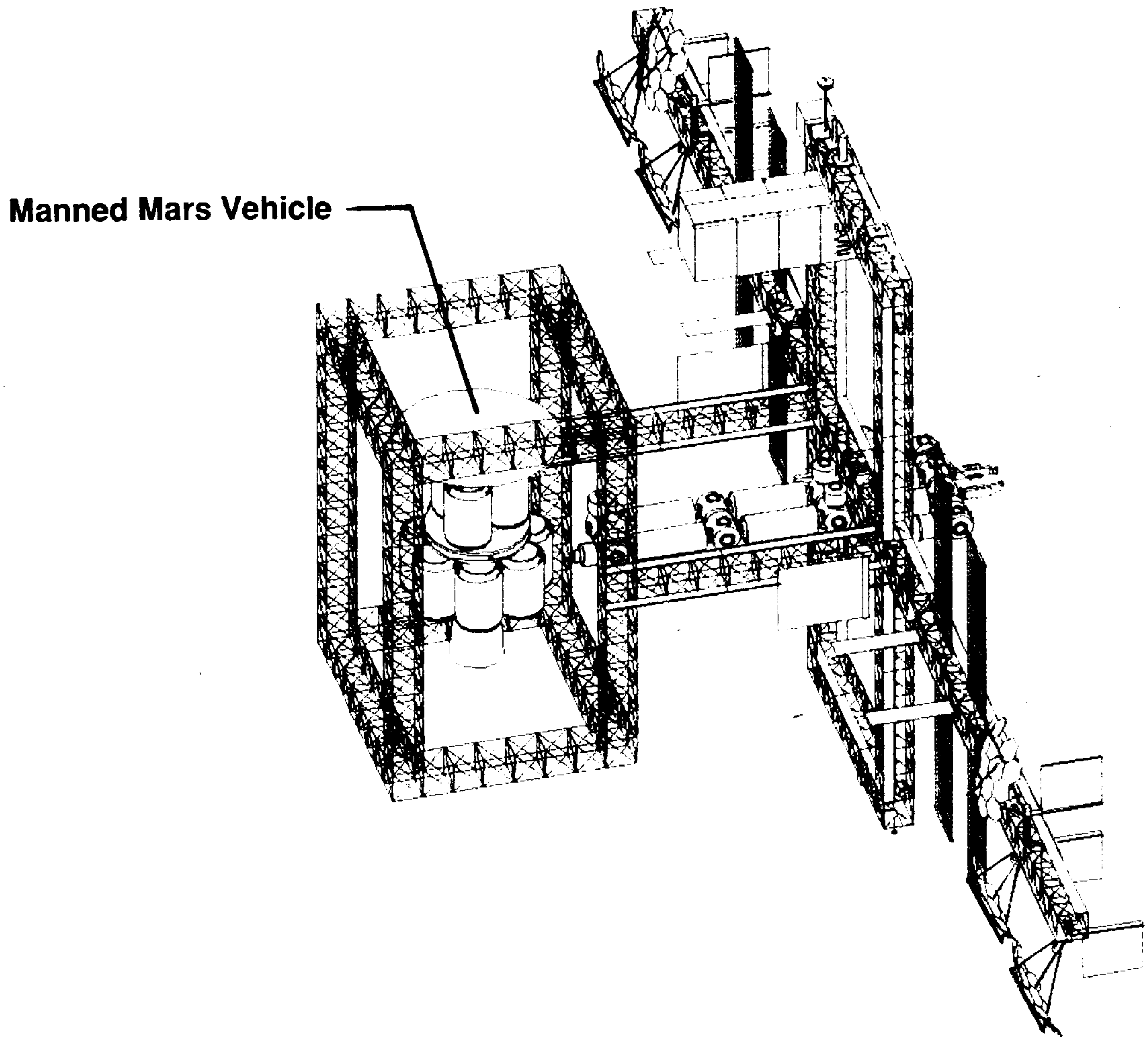
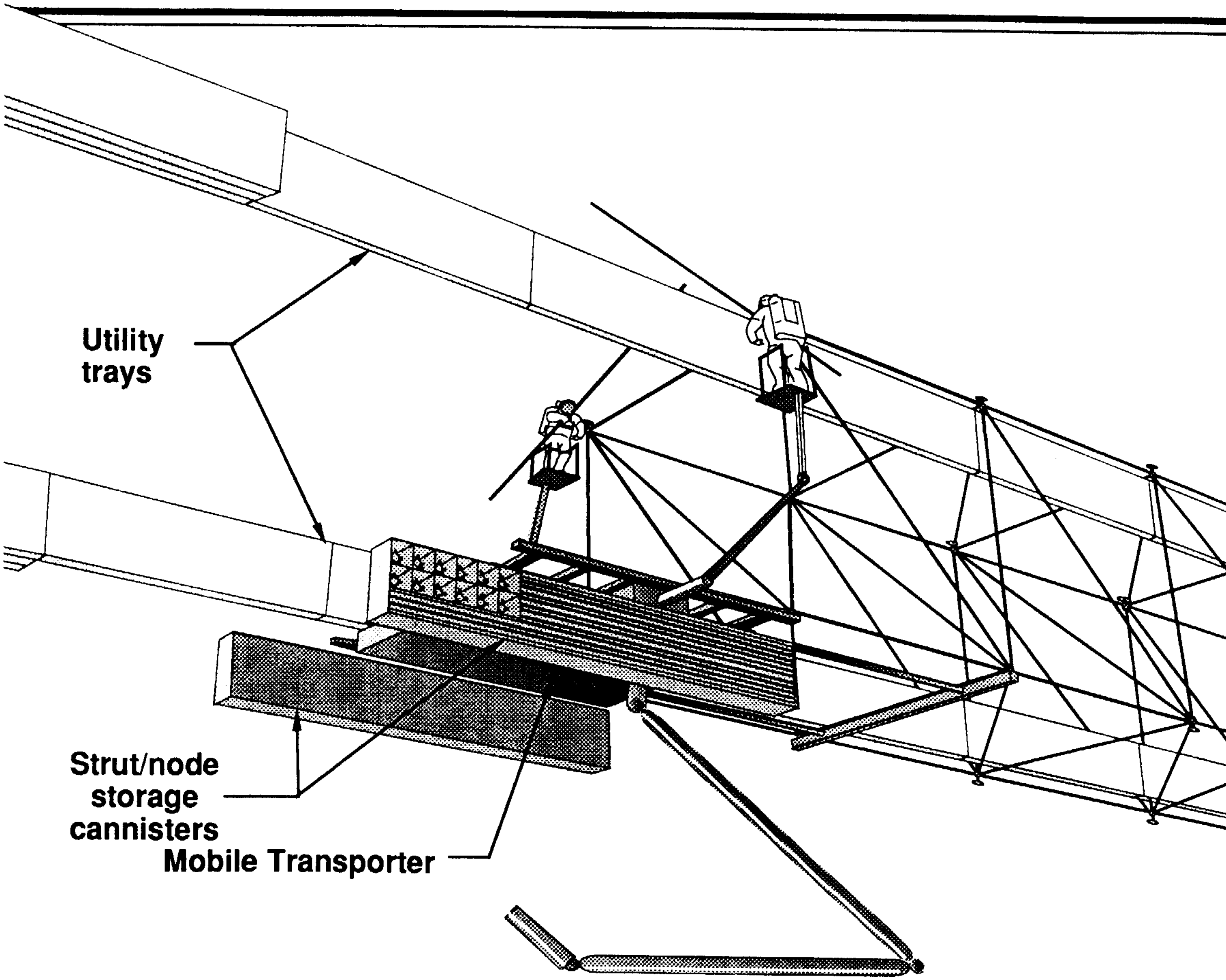


Figure 9

MOBILE TRANSPORTER CONFIGURED FOR SPACE STATION TRUSS CONSTRUCTION



NASA Mikulas 10/15/88

Figure 10

MAN TENDED CO-ORBITING CONSTRUCTION FACILITY

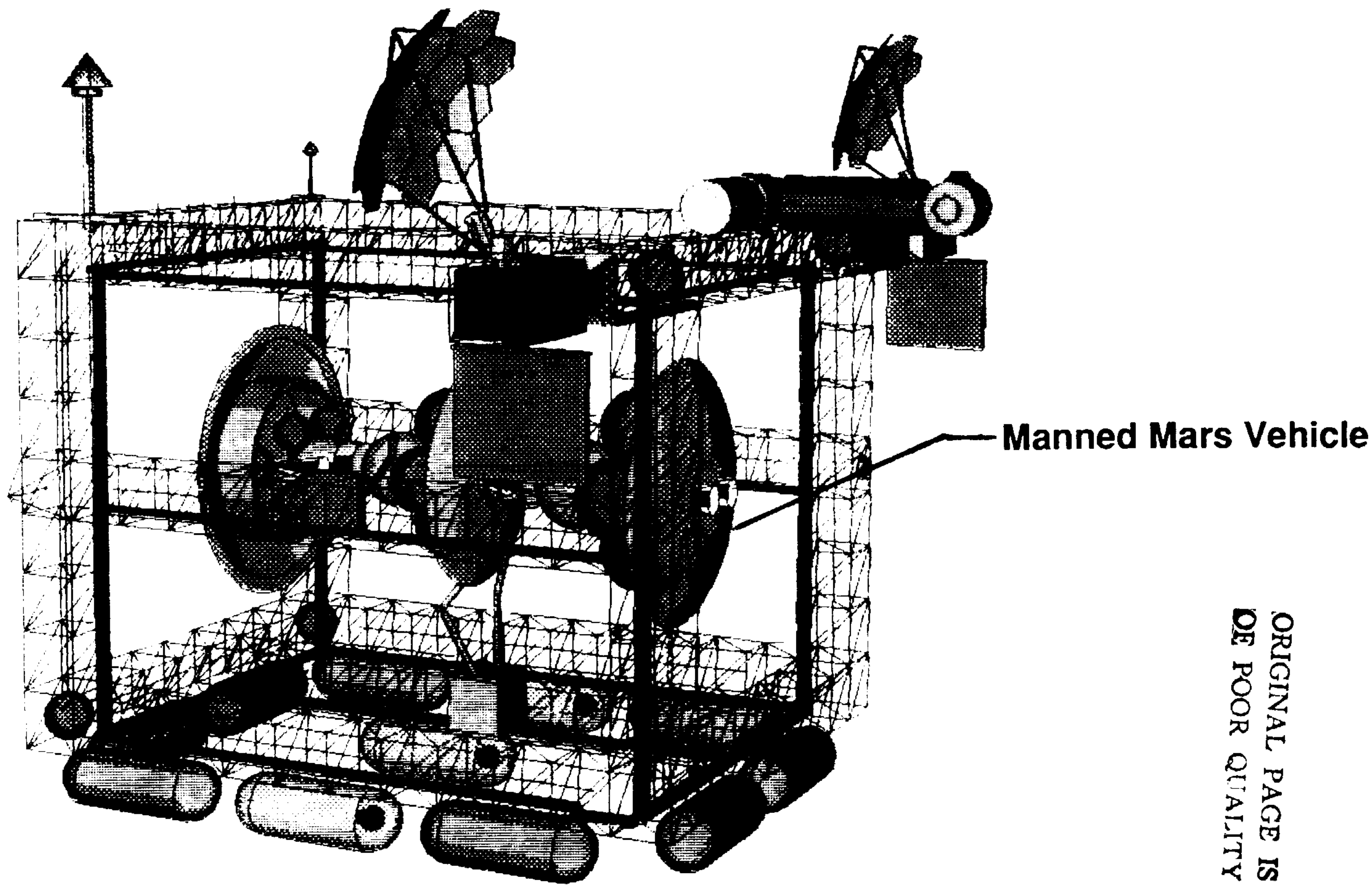


Figure 11

PATHFINDER ON-ORBIT CONSTRUCTION PROGRAM

OBJECTIVE

Provide Enabling Technology to Permit Efficient, Reliable In-Space Construction of Very Large Spacecraft

APPROACH

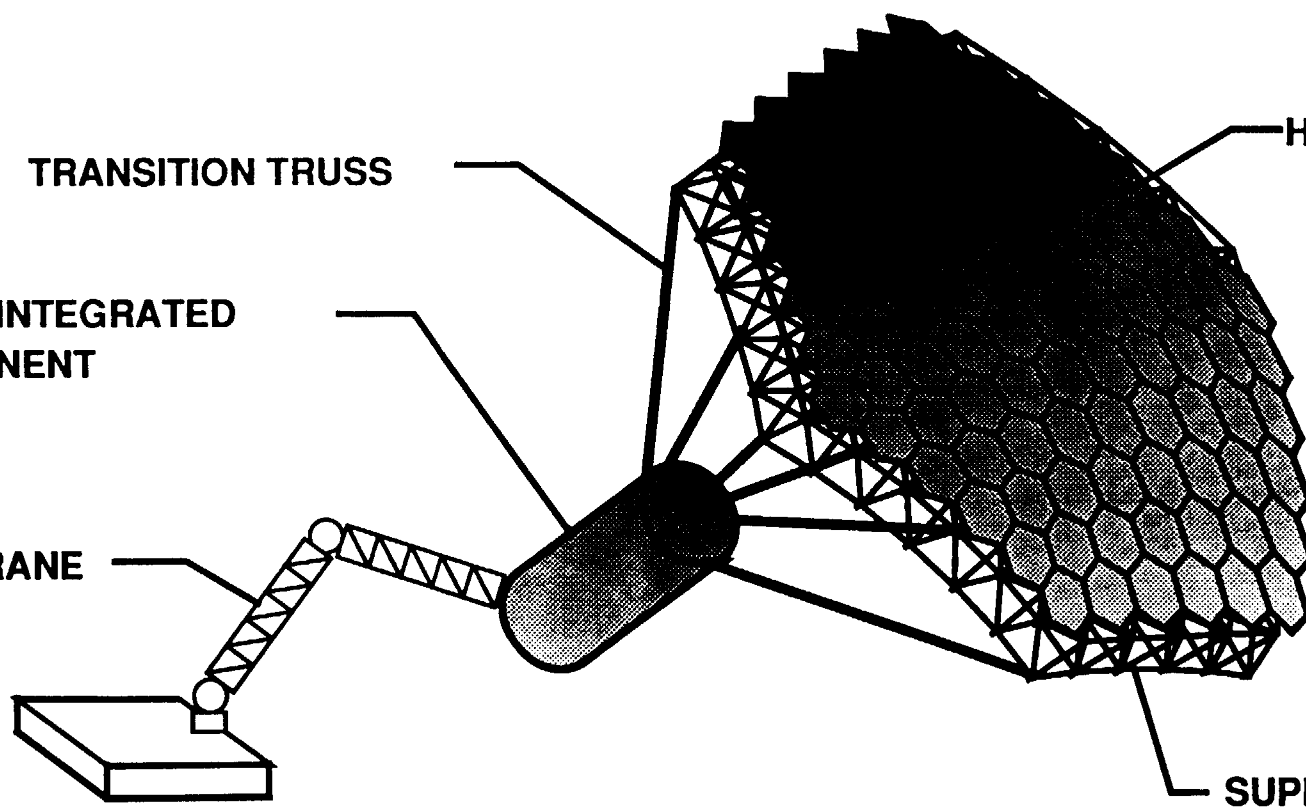
Select a Focused Problem With a Completely New Range of Structural Parameters and Construction Parameters

NASA

Mikulas 10/15/88

Figure 12

PATHFINDER FOCUS PROBLEM



NASA Mikulas 10/15/88

Figure 13

ORIGINAL PAGE IS
OF POOR QUALITY

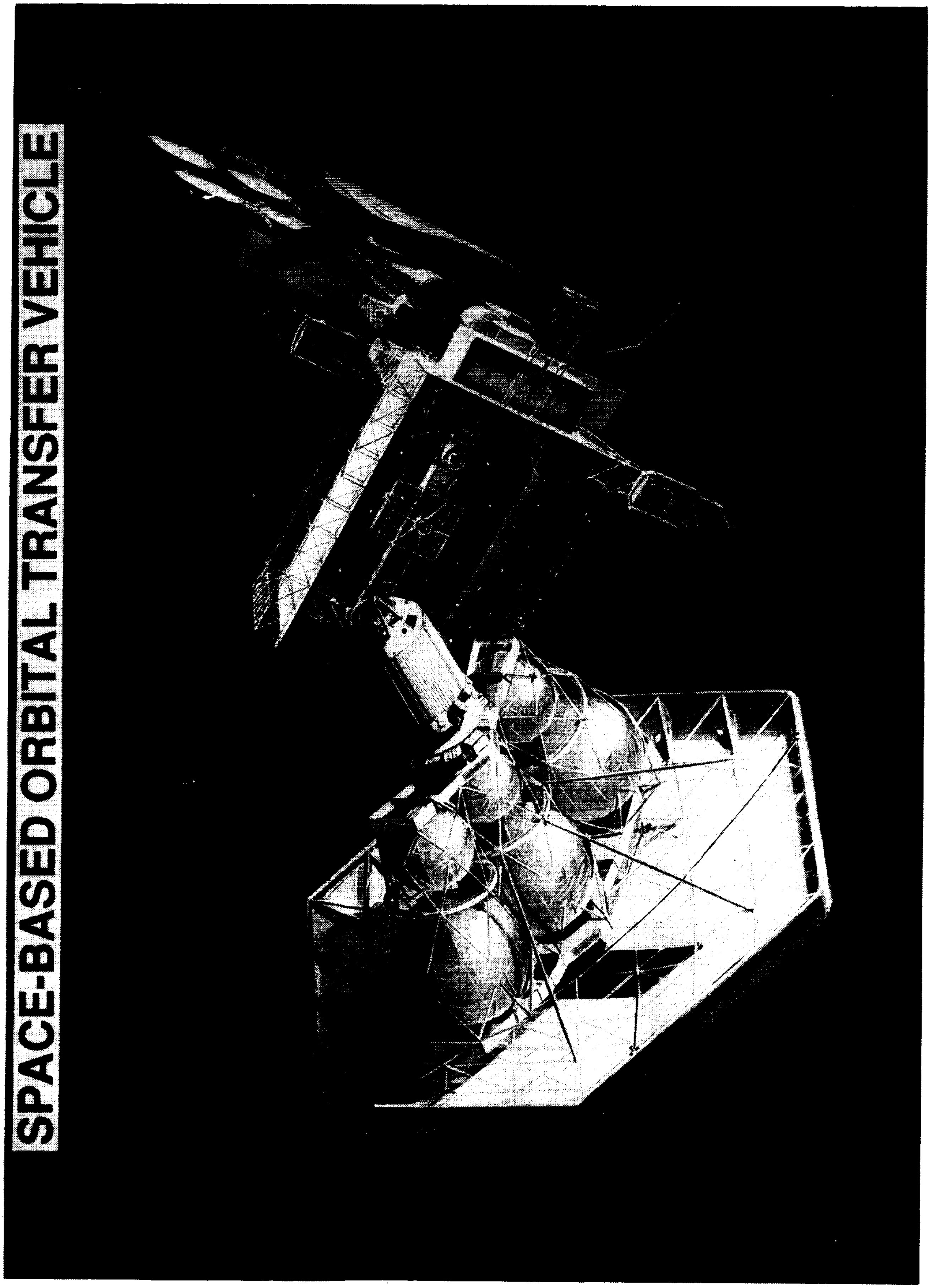
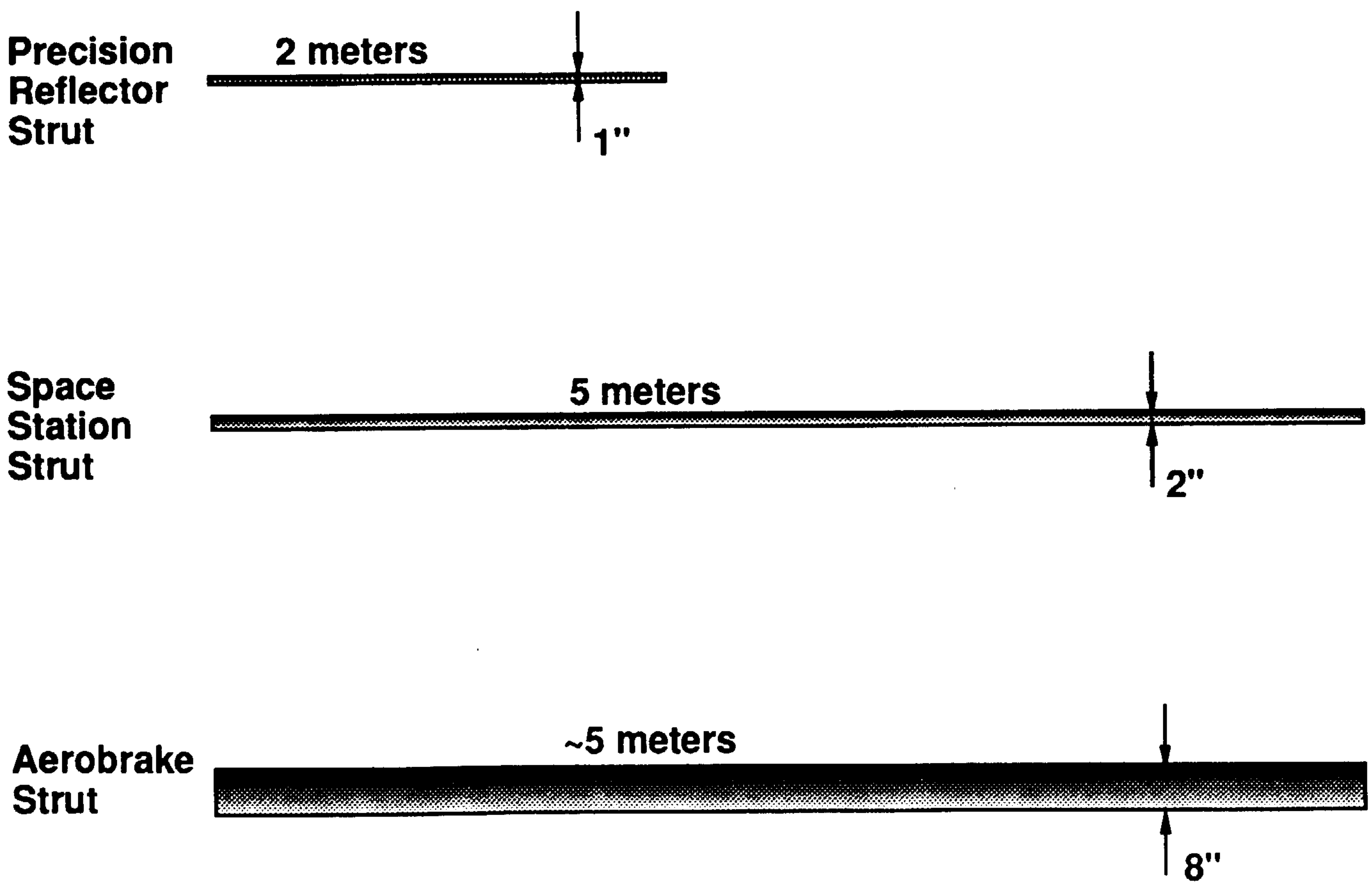


Figure 14

AEROBRAKE TRUSS PARAMETERS GREATLY EXTENDS STRUCTURES DESIGN RANGE



LOAD (Stress)	MAIN ISSUES
1000 lb (4,000 psi)	Accuracy
2000 lb (4,000 psi)	Stiffness
200,000 lb 40,000 psi	-Strength -Packaging

NASA

Mikulas 10/15/88

Figure 15

MAJOR PATHFINDER TECHNOLOGY CHALLENGES

AEROBRAKE TRUSS

- o Concept
- o Joints
- o Construction

AEROBRAKE HEATSHIELD

- o Concept
- o Construction
- o Sealing
- o Attachment

TRANSITION TRUSS

- o Concept
- o Construction
- o Joints

SPACE CRANE

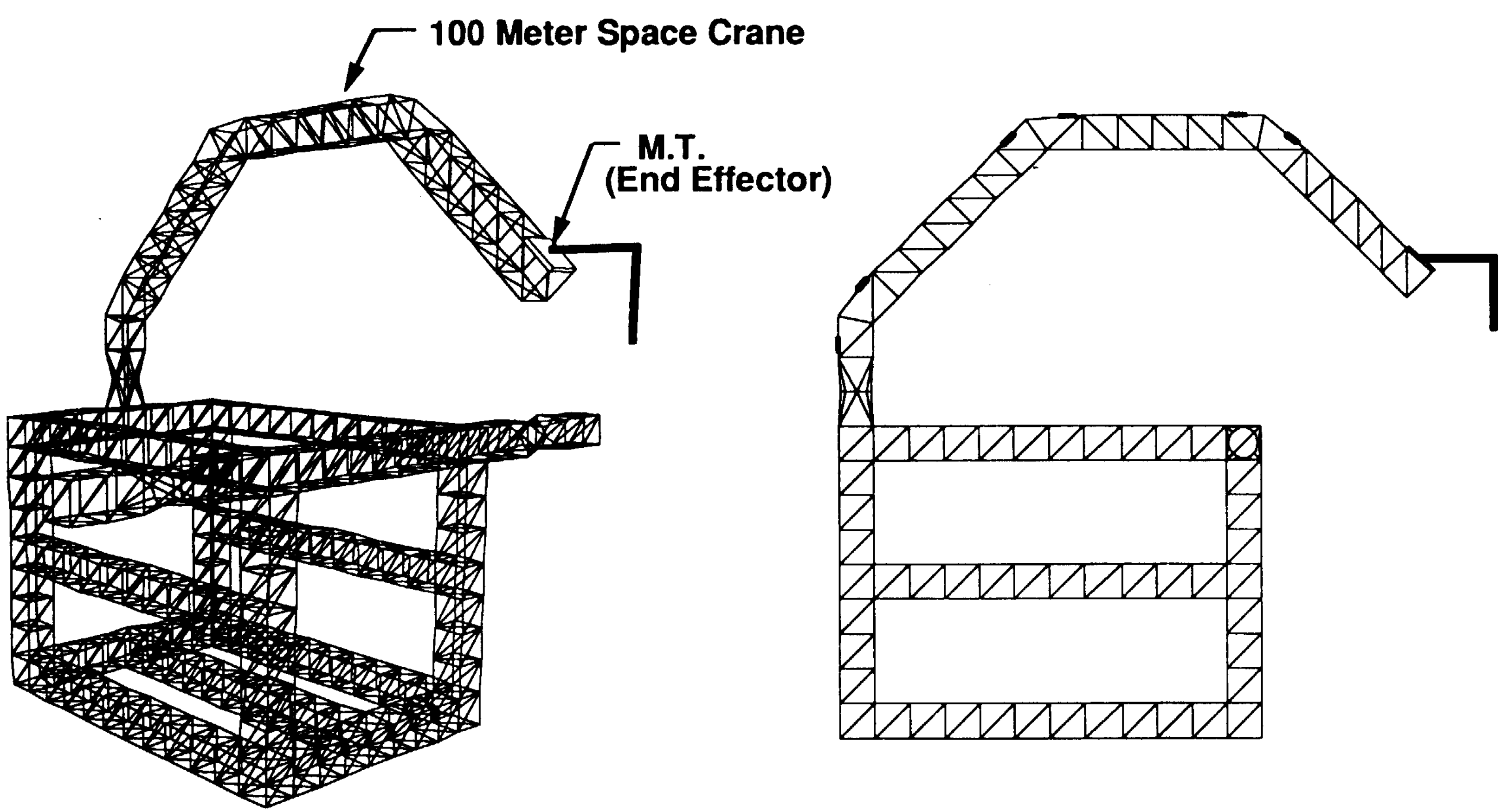
- o Concept
- o Actuators
- o Dynamic Control

SPACECRAFT CONSTRUCTION

- o Joints
- o Construction

Figure 16

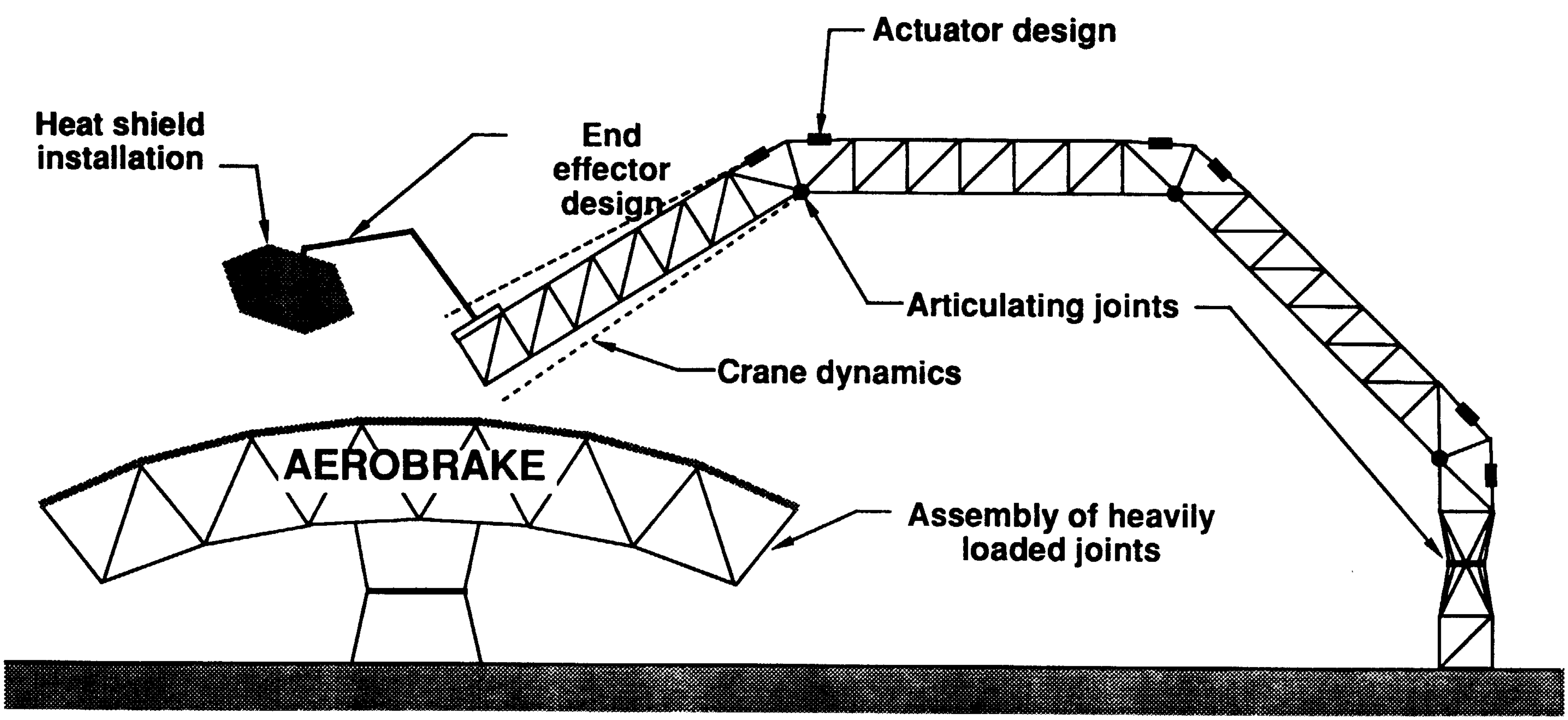
SPACE CRANE ON ASSEMBLY DEPOT



MIKULAS 10/17/88

Figure 17

60 FOOT SPACE CRANE PROVIDES TEST BED FOR WIDE RANGE OF IN-SPACE CONSTRUCTION STUDIES



NASA Mikulas 10/15/88

Figure 18

CONCLUDING REMARKS

- Commonality Of Hardware Needed To Make Large Spacecraft Affordable
- Space Station Can Be Expandeded To accommodate Large Spacecraft Construction
- A Co-Orbiting Construction Facility Could Be Built Using Space Station Hardware
- PATHFINDER Program In Place To Develop Enabling Technology For Large Scale Construction

NASA Mikulas 10/15/88

Figure 19

ORIGINAL PAGE IS
OF POOR QUALITY

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-101515		

4. Title and Subtitle	5. Report Date
An Integrated In-Space Construction Facility for the 21st Century	November 1988
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Martin M. Mikulas, Jr. and John T. Dorsey	
	10. Work Unit No. 506-43-41-02
9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, VA 23665-5225	
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Washington, DC 20546-0001	

15. Supplementary Notes

16. Abstract

This paper presents preliminary results of studies currently being conducted by NASA on the construction of very large spacecraft. The paper discusses the various approaches for constructing spacecraft and their relative merits. It is observed that the Space Station Freedom has all of the basic design characteristics to permit its growth into an in-space construction facility for very large spacecraft. Also it is noted that if disturbances from construction operations are intolerable to other Space Station experiments, a co-orbiting construction facility could be built using previously developed Space Station truss hardware and systems. A discussion is also presented of a new PATHFINDER research initiative on on-orbit construction. This research effort is aimed at developing construction methods for very large spacecraft and includes the development of a 100-meter-long space crane.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
In-Space Construction Space Crane EVA Robotics	Unclassified - Unlimited Subject Category 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	30	A03

NASA FORM 1626 OCT 86