

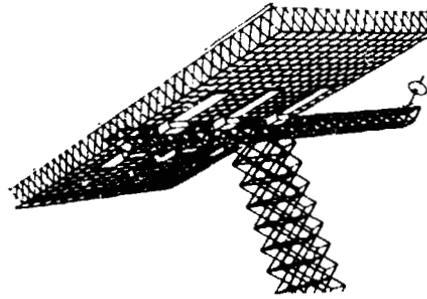
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# Conceptual Design and Evaluation of Selected Space Station Concepts

## Executive Summary

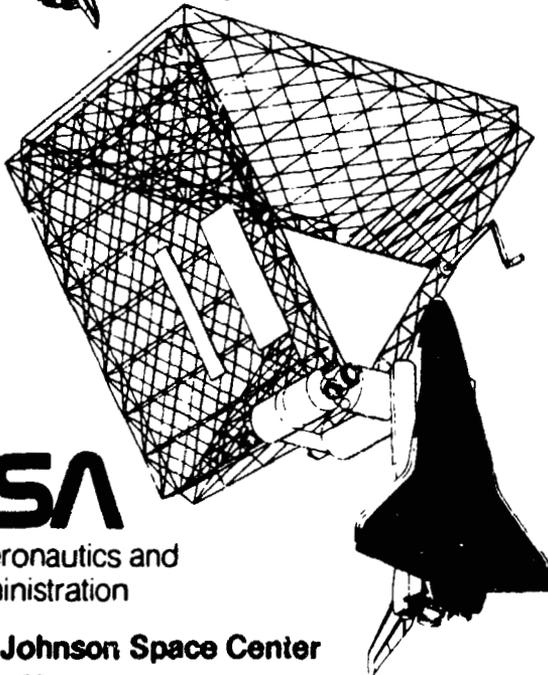
December 1983



N85-11128

(NASA-TM-87382) CONCEPTUAL DESIGN AND  
EVALUATION OF SELECTED SPACE STATION  
CONCEPTS: EXECUTIVE SUMMARY (NASA) 64 p  
HC A04/BF A01 CSCL 22B

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# NASA

National Aeronautics and  
Space Administration

Lyndon B. Johnson Space Center  
Houston, Texas

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# Conceptual Design and Evaluation of Selected Space Station Concepts

## Executive Summary

December 1983



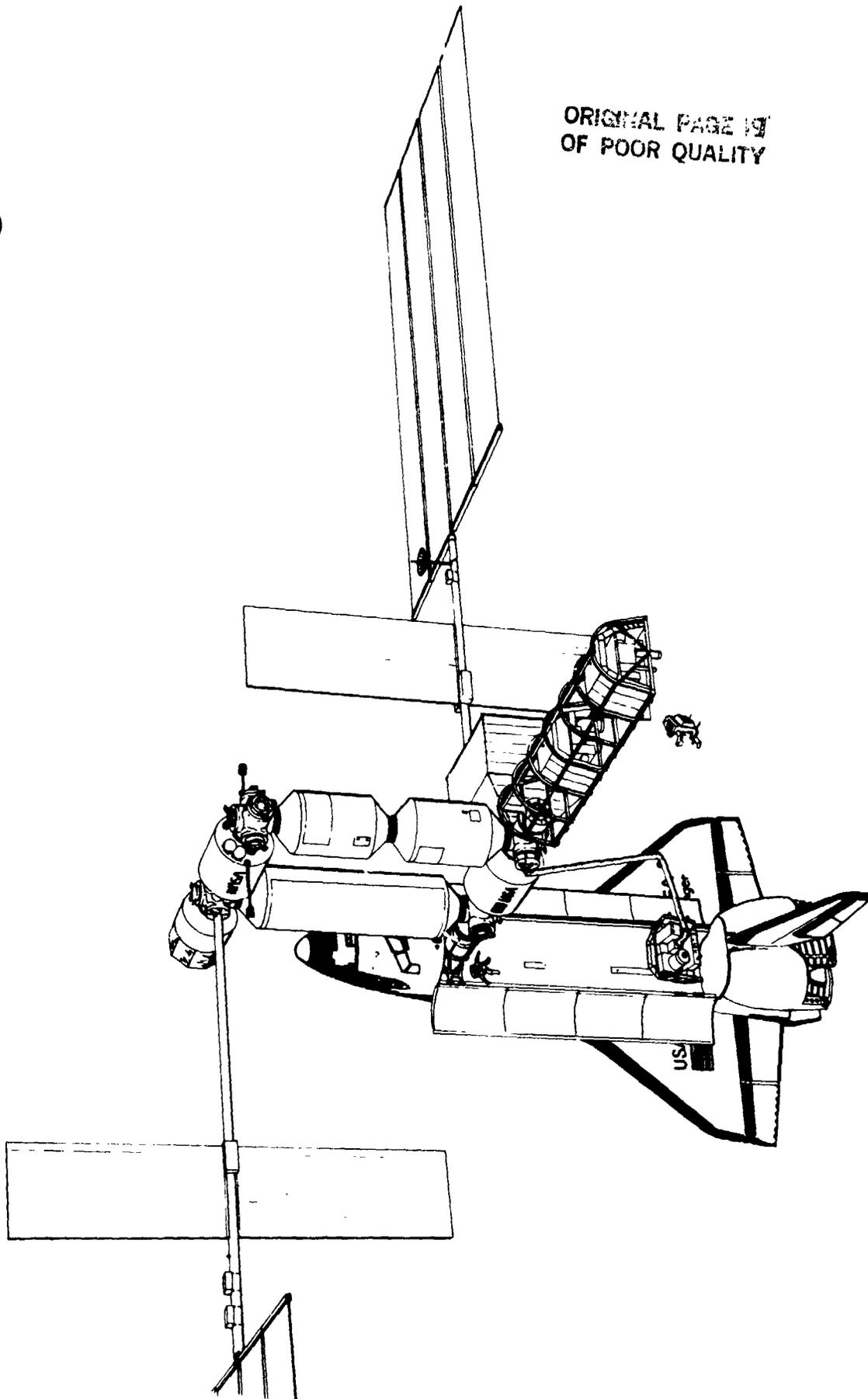
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Houston, Texas

**NASA**

**IOC**

# **Building Block Configuration**



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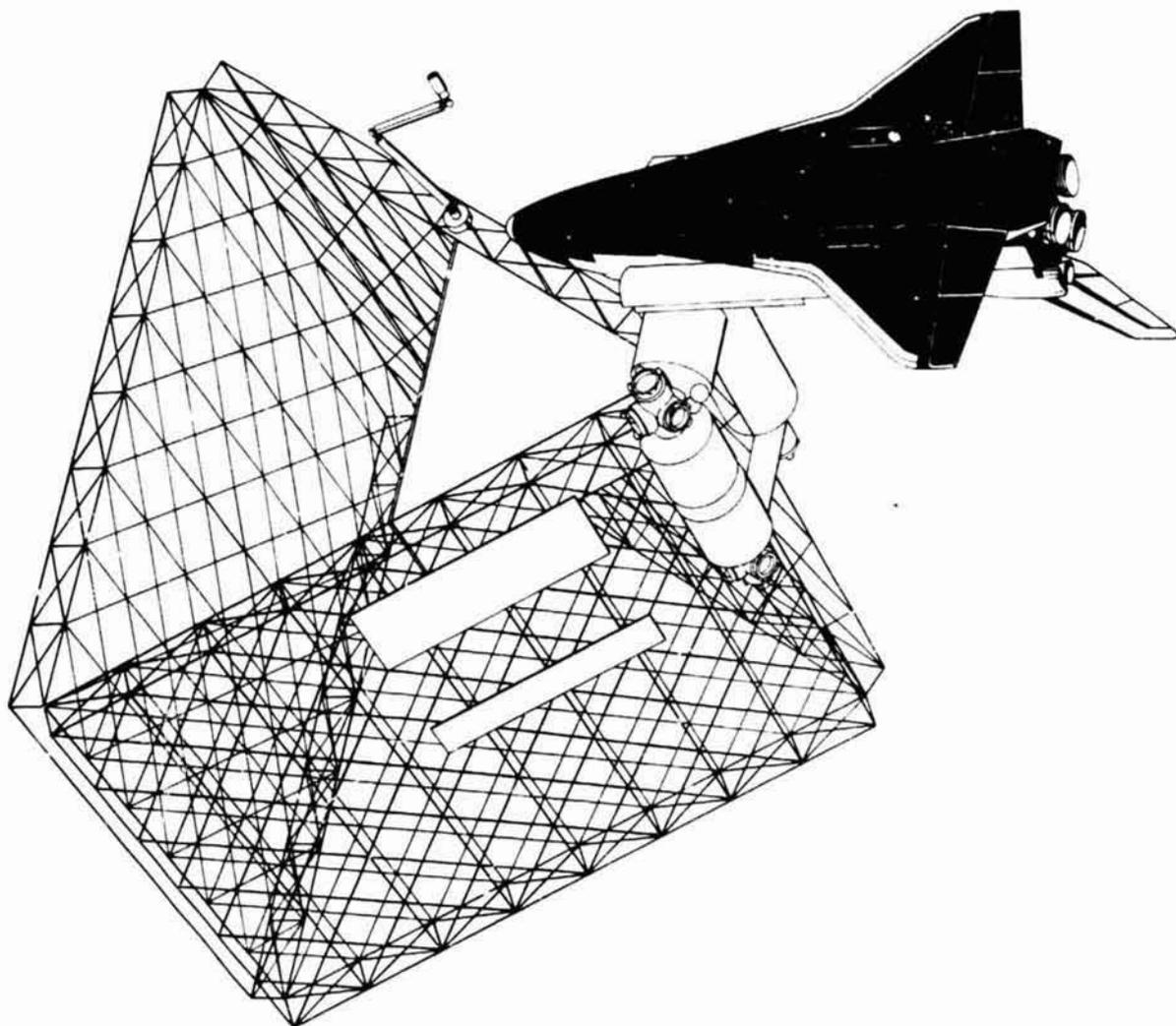


**NASA**

**IOC**

**Delta Configuration**

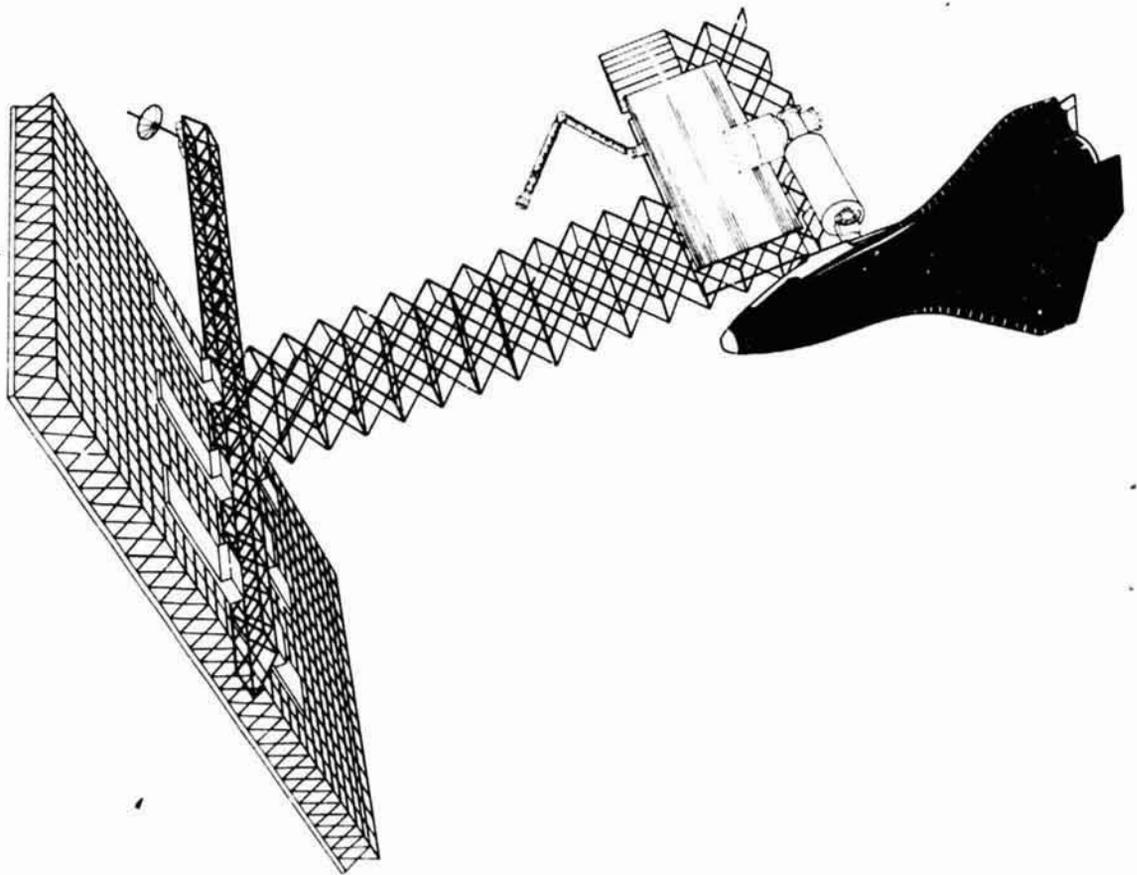
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**NASA**

**IOC**

**“T” Configuration**



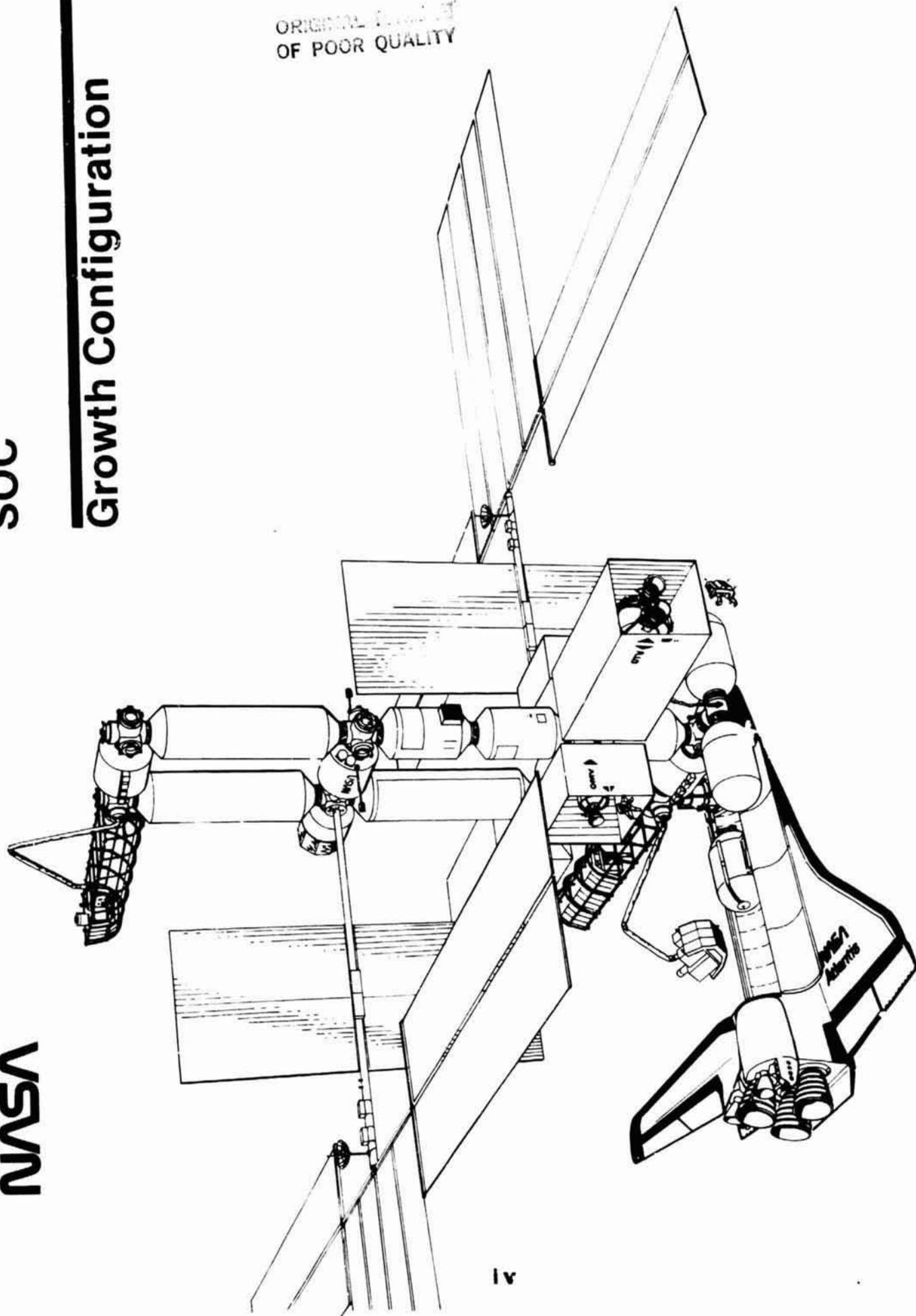
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NASA

SOC

# Growth Configuration

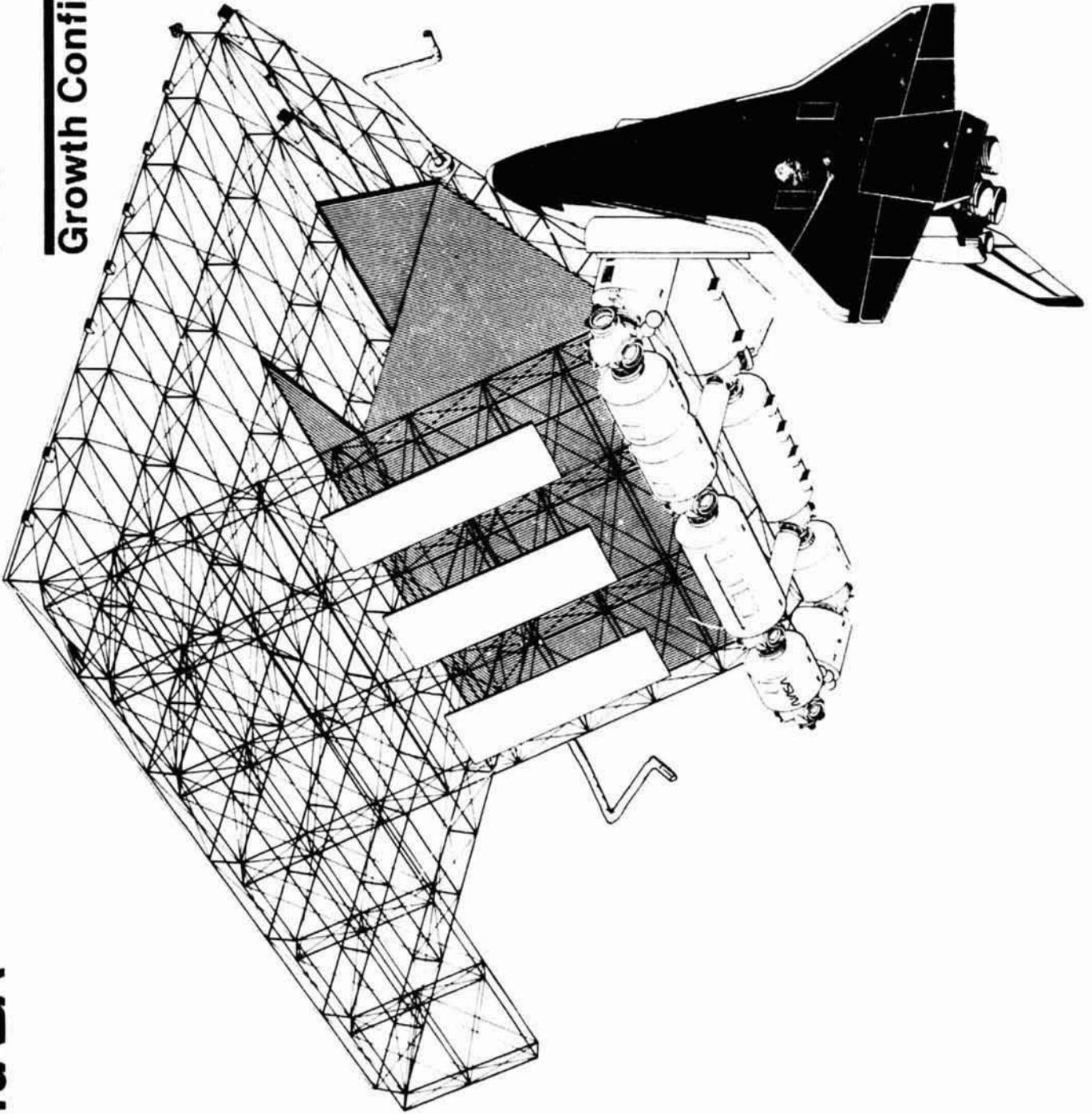
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Delta

**Growth Configuration**

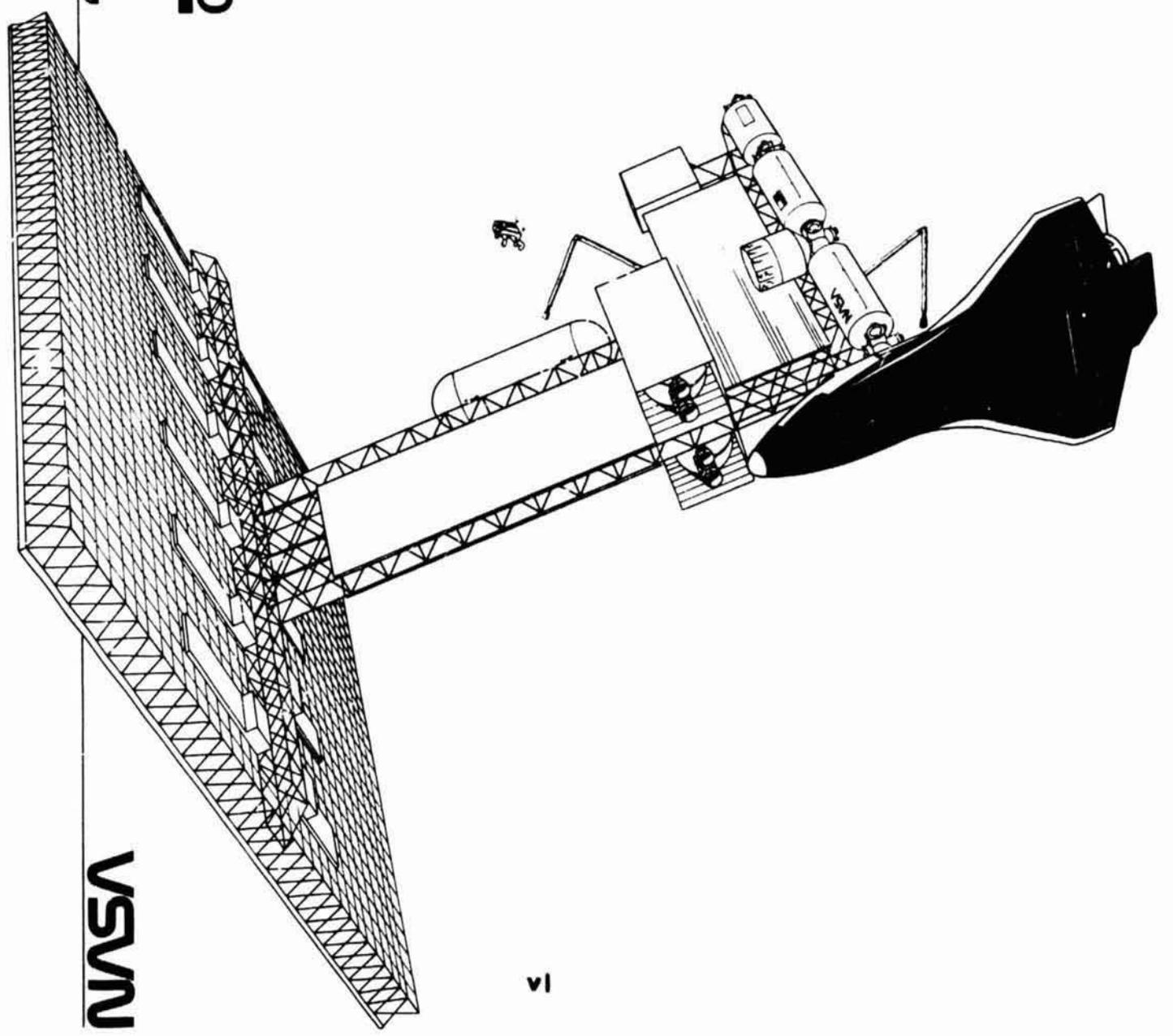


**NASA**

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“T”

# Growth Configuration



NASA

## FOREWORD

This document summarizes the results of a space station conceptual design and evaluation study conducted at the Johnson Space Center during November 2 through December 16, 1983. The study represented a temporary focusing and acceleration of a longer term in-house space station study, which was initiated at JSC in early 1983 and is scheduled for completion in April 1984. The need for temporary focusing was prompted by necessity for developing a greater depth of understanding of candidate configurations which existed at the time in support of space station program and technical planning activities.

The conceptual space station design study was performed by an interdisciplinary team of engineers, designers, and scientists. The approach utilized to document the study results was to first develop an outline of the report contents and then assign an individual primary responsibility for preparing a specific section of the report. The assigned individuals were supported by a team of contributors representing the disciplines involved in the particular report section.

This report series includes three documents:

- Executive Summary
- Volume I - Conceptual Design and Evaluation of Selected Space Station Concepts (Concept Overview and Evaluation).
- Volume II - Conceptual Design and Evaluation of Selected Space Station Concepts (System/Subsystem Definition and Issues)

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## LIST OF ACRONYMS AND ABBREVIATIONS

BB	Building Block
C/CM	Command/Control Module
CDG	Concept Development Group
CMG	Control Moment Gyro
DDT&E	Design, Develop, Test, and Evaluation
ESS	Energy Storage Subsystem
ET	External Tank
EVA	Extra Vehicular Activity
FF	Free Flyer
HM	Habitation Module
HZ	Hertz (Cycles per second)
IM	Interconnect Module
IOC	Initial Operational Capability
LM	Laboratory Module
LVLH	Local Vertical, Local Horizontal
MAS	Mission Analysis Study
OCZ	Operational Control Zone
OTV	Orbital Transfer Vehicle
OMV	Orbital Maneuvering Vehicle
PCM	Power Conditioning Module
PMAD	Power Management and Distribution
RMS	Remote Manipulator System
RCS	Reaction Control System
SE&I	System Engineering and Integration
SSTF	Space Station Task Force
SOC	Space Operations Center
SOW	Statement of Work
SSCM	Space Station Cost Model
TEA	Torque Equilibrium Attitude
TDRS	Tracking and Data Relay Satellite
WCS	Waste Control System

## 1.0 SUMMARY AND CONCLUSIONS

A brief space station configuration concept study was conducted at JSC to define and evaluate three space station configuration concepts characterized as follows:

- o Building Block (SBC-type) Configuration

- Built up by interconnecting of essential elements, i.e., minimum hardware launch to orbit

- Modules earth oriented

- Solar arrays sun tracking

- o Delta Truss Configuration

- Rigid overall configuration

- Area available on truss substructure for mounting hardware/mission equipment

- Near solar inertial flight orientation

- o Big "T" Truss Configuration

- Stiff overall configuration

- Area available on truss substructure for mounting hardware/mission equipment

- Modules near earth oriented

- Gravity-gradient flight orientation

- Minimum drag orientation solar array (streamline), solar array semi-solar oriented

Each of the above configuration concepts were sized and defined to meet the initial operational capability and growth system requirements utilized by the NASA Headquarters Concept Development Group. Following this definition, each configuration concept was evaluated in terms of user, crew, operation and safety accommodations; engineering considerations including assembly and growth.

structural dynamics and control, communications, element interfaces, thermal control, and power; and system cost.

The major conclusions of the study were:

- o All three configuration concepts met the requirements set forth for this study. Depending upon the evaluation criteria utilized, some of the configurations perform functions in a superior fashion to others. None of the concepts were found unacceptable.

- o The total cost for the IOC system (L T&E plus first unit) was not a strong discriminator between concepts. The total cost difference between the three configuration concepts was less than 10%.

- o The number of STS launches to place the IOC system in low earth orbit (6 to 7, depending on configuration concept) was also not a strong discriminator.

- o A significant difference from the user and crew operations perspective is that the Delta and "T" place some of the equipment, including observation instruments, significant distances from the pressurized modules. Thus, these configurations imply the use of "long distance" EVA and RMS operations, which are viewed as undesirable.

- o From the standpoint of growth and mission versatility, the Delta and (to a lesser extent) the "T" are seen to be advantageous.

- o The design driver of minimum propellant for RCS orbit altitude maintenance ("T" configuration) appears not to be important in selecting a station concept for the 270 n.m. altitude. If lower altitudes are required, this could substantially alter the propellant usage.

- o While the users tend to prefer a velocity-vector, local vertical orientation, an inertially-oriented station such as the Delta-truss appears to be adequate from both the standpoint of user requirements and proximity operations.

o The Building Block and "T" configurations were similar with respect to the communication and tracking function; however, the Delta-truss configuration requires additional antennas for the same coverage.

In addition to the design and evaluation data discussed above, a number of system design and operations issues were identified during the study. One of the most significant issues identified was the space station housekeeping power, which was found to be in the 45 to 50 kw range at IOC versus 15 KW originally assumed by the CDG.

## 2.0 INTRODUCTION

### 2.1 Purpose and Objectives

The purpose of this document is to summarize the results of a brief special emphasis space station configuration study conducted at the Johnson Space Center from November 2 to December 16, 1983. The objectives of the study were as follows:

- a. Define candidate Space Station configuration concepts to meet the NASA Headquarters Concept Development Group (CDG) requirements.
- b. Produce engineering and programmatic data on these concepts suitable for NASA and industry dissemination.
- c. Produce a data base for input to the CDG's evaluation of generic Space Station configurations and for JSC use in the critique of the CDG's generic configuration evaluation process.

It should be noted that this study is not a general Space Station configuration study aimed toward definition of new and/or optimized space station concepts. Rather, specific configuration concepts were selected at the out-set for refinement of definition to meet the CDG requirements and for evaluation in terms of selected criteria. Moreover, system and subsystem selections and design approaches were based on trade-off study results from previous studies. In some instances, where trade study results were not available, decisions were made based on engineering judgment to facilitate system definition within the study time allowed. In such instances, the decisions were noted and identified as issues for future study.

Section 3.0 of this summary report provides an overview description of each configuration concept. Section 4.0 presents functional description and evaluation of each configuration in terms of user, crew, operation, and safety

accommodations. Engineering and cost evaluations are also provided in section 4.0. Section 5.0 summarizes the results of the cost analysis and delineates the technical and programmatic issues identified for future study.

## 2.2 Background

JSC has been involved in space station study activities, both in-house and contracted for several years. The in-house study activity was intensified shortly after May 20, 1982, when the Space Station Task Force Group (SSTF) was established at NASA Headquarters. The systems working group of the SSTF identified a large number of space station "trade studies" within the purview of the system definition (Book 5) activity. JSC supported these trade study activities by performing approximately 30 different system and subsystem studies. The initial results of these studies have been documented in Book 5 and related documents. To provide a means of conducting these studies in an organized fashion, an in-house space station study statement of work (SOW) was produced by the Space Station Project Office and was implemented by the JSC Systems Engineering and Integration (SE&I) Panel organization.

The SOW defined a comprehensive list of system level and subsystem level tasks, including configuration alternatives definition and evaluation. The SOW identified three configuration concepts for study: a modular, building block concept such as the Space Operations Center (SOC), which had been under study at JSC since 1979; a triangular truss structure concept (delta-truss) previously proposed by JSC (reference 1-2) and concepts involving the use of spent STS external tanks (ET), briefly described in reference 1-3. Detailed study of the ET concepts were not undertaken because a brief study indicated limited capability to meet program requirements and excessive cost for the required unique launch system (reference 1-4).

During the course of the study, another truss structure concept with the characteristics of low aerodynamic drag with an earth oriented flight mode was introduced. This concept was identified as the big "T" concept. In addition, the SOW study was expanded to include definition of flight test bed concepts that could be utilized for development testing and subsequently used as elements of an operational space station.

The mission and associated system requirements initially utilized for the SOW study were based on an early assessment of the Mission Analysis Study (MAS) results (reference 1-5). The requirements thus developed were generally consistent with the final results of those produced by the MAS contractors; however, when the requirements were synthesized by the Mission Requirements Working Group and subsequently adopted by the CDG during May 1983, several of the requirements were significantly more demanding than previously indicated by most of the MAS contractors. Figure 2.2-1 shows a summary comparison of the MAS contractor, CDG, baseline in-house study requirements. Note that the CDG requirements for crew size and power are roughly twice those for the MAS and in-house baseline studies.

The special emphasis configuration study, which is the subject of this summary report, utilized the same basic configuration concepts defined in the SOW study. A major task of the study was to resize the configurations and to rearrange and augment elements of the configurations to meet the current Headquarters CDG requirements shown in figure 2.2-2.

MISSION REQUIREMENTS SUMMARY (IOC/GROWTH)

	MAS	CDG	IN-HOUSE BL
CREW SIZE	3-5/8-12	8/14	3/7
POWER (KW)	20-30/60-80	75/150	30/50
ATTACHED PYLDS (PORTS/MOUNTS)	R&E LAB/ SEVERAL LABS	YES/+RES. (4 MOUNTS)	1/4
R&D LAB (PRESS. VOL.)	120M <sup>3</sup>	120M <sup>3</sup>	( 100M, GROWABLE)
SMART TMS	--/YES	YES	NOT CONSIDERED
ORBIT	LOW INCL. 200-270 NM	28.5	28.5 - 270NM
PLATFORM/FF	1 PLATFORM (HIGH INCL) POST IOC	PLATFORMS (15KW) POLAR-28.5	NOT CONSIDERED
SPACE BASED OTV	EXPENDABLE/ SB AEROBRAKED	--/YES (IOC)	NOT CONSIDERED
DATA	----	100 MBPS	TBD
ORIENTATION REQUIRED	VARIABLE	?	SOC-EARTH ORIEN. TRUSS-SOLAR

FIGURE 2.2-1

### 3.0 CONCEPT OVERVIEW

Three configuration concepts have been defined for evaluation in this study: building block, delta, and the "T." Each concept emphasizes a different set of design drivers.

The building block concept attempts to minimize structure and subsystem hardware. It uses the pressurized modules as the structural foundation of the station. The core station is earth-oriented and the solar arrays, mounted on booms, are oriented toward the sun.

The delta uses a triangular truss structure for independent attachment of station elements to maximize rigidity and enhance controllability and mission versatility. The delta is approximately solar-oriented with the array, mounted on one face of the triangle, at a constant angle to the orbit plane to eliminate secular gravity gradient torques. Solar orientation simplifies thermal control. The "T" minimizes aerodynamic drag by maintaining the array parallel to the velocity vector. It also uses a truss structure for enhanced rigidity, element independence, and mission versatility. The "T" is earth-oriented and is arranged for gravity gradient stability. The solar array is approximately twice as large as a fully oriented array. The CDG requirements shown in figure 2.2-1 were interpreted as requiring the module lengths, viewing requirements, etc., as shown in figure 2.2-2 for the purposes of defining concepts for this study.

FIGURE 2.2-2

CONFIGURATION DRIVING REQUIREMENTS

	<u>IOC</u>	<u>GROWTH</u>
<b>PRESSURIZED MODULES (SEGMENTS)</b>		
HAB (8 - 14)	40 FT.	70 FT. (EQUIVALENT)
COMM/CONTROL	20 FT.	2 X 20 FT.
LABS	2 X 20 FT.	120 FT. (EQUIVALENT)
<b>OBSERVATIONS</b>		
EARTH	LAB & RACK	LAB & RACK
SOLAR	RACK	RACK
STELLAR	RACK	RACK
POWER & COOLING (BUSS)	75 KW	150 KW
ORBIT MAINTENANCE	270K MI	270K MI
OMV	ONE WITH HANGAR 14,000 LB. FUEL	TWO WITH HANGARS 28,000 LBS. FUEL
OTV	NONE	TWO WITH HANGARS 100,000 LB. FUEL
SATELLITES	ONE WITH HANGAR EXTERNAL RACK SPACE	ONE WITH HANGAR EXTERNAL RACK SPACE

### 3.1 Building Block Configuration

#### 3.1.1 General Arrangement

The building block concept utilizes the pressurized modules as a structural base to which the component parts of the station are attached. The pressurized modules at IOC (figure 3.1-1) are arranged in a quadrangle for safety and efficient internal crew movement. Electrical power generation and conditioning, radiators and antennas are mounted on two booms perpendicular to the plane of the quadrangle.

The growth configuration (figure 3.1-2) adds two quadrangles of pressurized modules. Additional power and radiator components are mounted on the existing booms.

Hangars, manipulators, and other external elements are attached to berthing ports at the corners of the quadrangles.

#### 3.1.2 Function/Operation

The normal attitude of the building block configuration places the pressurized modules in the orbit plane with the long dimension of the quadrangle vertical. This is intended to provide gravity gradient stability, provide approach paths for the Orbiter, OMV and OTV, and permit adequate earth and celestial viewing. Reorientation in pitch is required for orbit reboost because of the thruster location.

Two Orbiter berthing ports are provided. Ports are also available for installation of temporary modules in addition to manipulators, hangars, etc.



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BUILDING BLOCK IOC

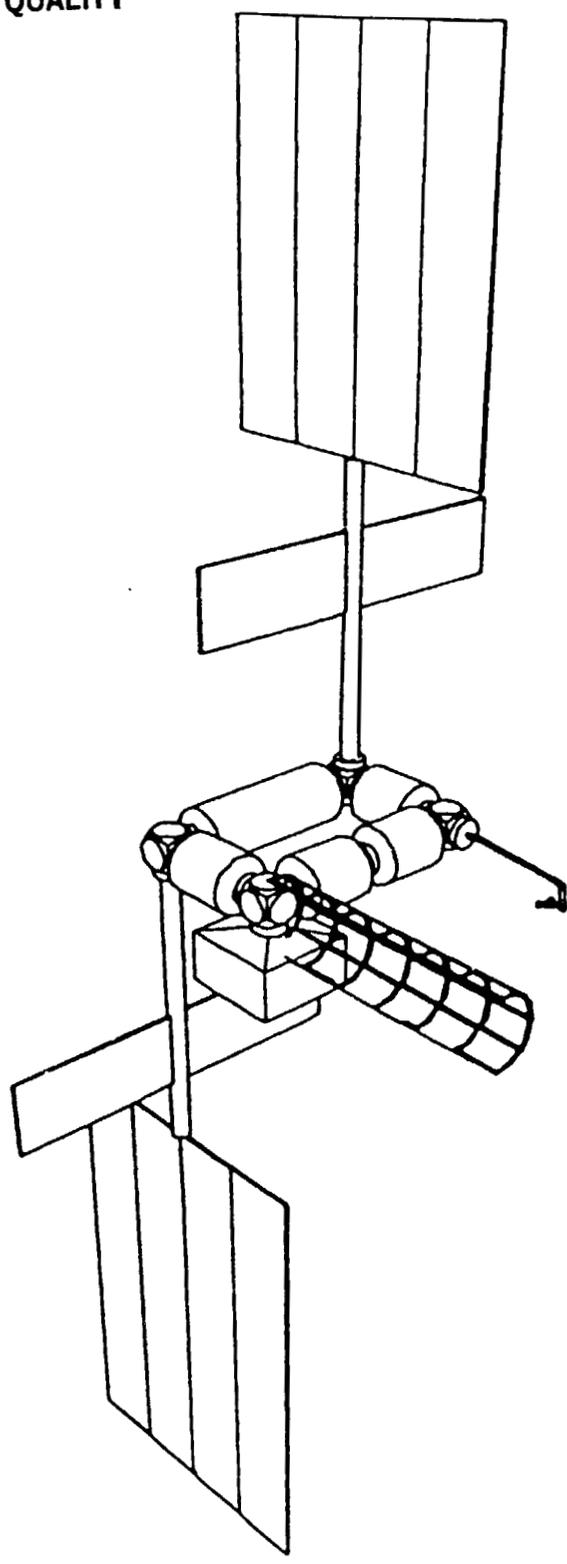


Figure 3.1-1b



BUILDING BLOCK  
GROWTH CONFIGURATION

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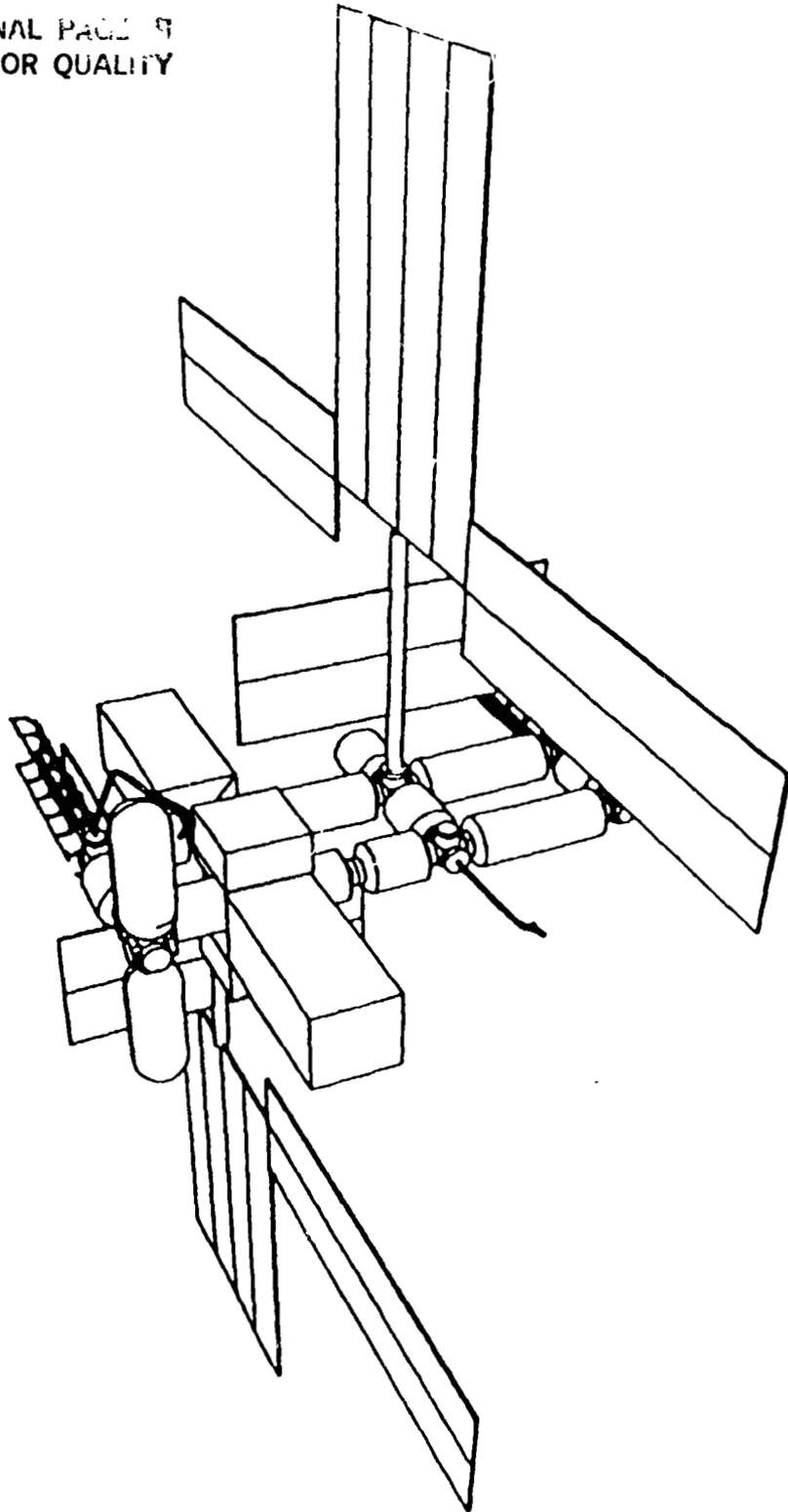


Figure 3.1-2b

### 3.1.3 Subsystem Type and Distribution

The table below summarizes the location of subsystem components within the station:

SUBSYSTEM COMPONENT LOCATION SUMMARY

	C/CM	HM	LM	LOG.	IM	BOOM
ECLSS	X	X	X	/	-	-
THERMAL CONTROL	X	X	X	X	/	X
PROPULSION/RCS	X	-	-	-	-	-
CCMM/TRACKING	X	/	/	/	/	X
DATA MANAGEMENT	X	(X)	/	/	/	/
ELECTRICAL POWER	/	/	/	/	/	X
MECHANISMS	X	X	X	X	X	X
CREW ACCOMMODATIONS	(X)	X	/	/	/	-
GNC	X	(X)	-	-	-	-

X PRIMARY LOCATION OF MAJOR COMPONENTS

(X) BACKUP LOCATION OF MAJOR COMPONENTS

/ LOCATION OF SOME MINOR COMPONENTS

- NO SUBSYSTEM COMPONENTS

### 3.1.4 Mass Properties

The estimated mass properties of the building block configuration are summarized in the following table. Element weights include associated subsystems. Although these estimates do not include an allowance for weight growth, some growth can be expected to occur. This would increase the weights and inertias given, but would not appreciably alter the relative magnitudes of the inertias.

(+)

BUILDING BLOCK

	UNIT MASS LB.	IOC	QUANTITY	GROWTH
C/CM	27,700	2		2
HM	51,300	1		2
SINGLE LM	27,700	2		6
DOUBLE LM	51,300	-		1
IM	11,300	4		8
LOGISTICS	27,700	1		1
POWER SYSTEM	8,050	2		4
BOOM	580	2		2
MANIPULATOR	2,000	1		3
OMV HANGAR	3,600	1		2
OTV HANGAR	7,100	-		2
OTV PROP. TANK	6,600	-		1
SATELLITE SVC. STR.	5,200	1		2

	IOC	GROWTH	
		W/O OTV PROP.	W/OTV PROP.
MASS, LB(BUILDING BLOCK)	263,060	571,360	697,360
C.G., IN. X	946.5	950.2	1,020.2
Y	-0.6	-0.8	-0.7
Z	1,114.1	1,180.3	1,040.2
$I_{xx}, 10^6 \text{ SLUG-FT}^2$	9.316	41.063	55.925
$I_{yy}$	6.769	40.230	57.262
$I_{zz}$	.392	14.388	19.054
$I_{xy}$	0.047	0.016	0.023
$I_{xz}$	-1.001	-1.067	-7.853
$I_{yz}$	-1.291	-1.947	-1.962

(+)



## 3.2 Delta Concept

### 3.2.1 General Arrangement

In the delta concept, the functional elements of the station are mounted on a large deployable triangular truss structure for maximum rigidity. One face of the structure is covered by solar arrays. The other two faces support radiators, power conditioning equipment, experiments, payloads, etc. Pressurized modules are mounted on the truss opposite the solar arrays in two parallel rows. At IOC, the pressurized modules form a quadrangle at one end of the truss (see figure 3.2-1). A tunnel is used to close the quadrangle.

The growth phase (figure 3.2-2) doubles the length of the solar array truss and adds short extensions to the other two sides for rigidity and to support power system radiators. Pressurized modules are added to the IOC set to fill the edge of the truss.

Hangars are located within the triangle to use the truss as primary structure and the radiators as part of the hangar skin.

### 3.2.2 Function/Operation

The delta configuration is approximately solar oriented with the Y principal axis perpendicular to the orbit plane. Gravity gradient torques in roll and yaw are therefore nulled; pitch torque is cyclic and can be absorbed by control moment gyros. Mass distribution is such that the Y principal axis is approximately  $20^{\circ}$  from the Y body axis. From March to September, the solar array is tilted toward the north to minimize the solar angle of incidence. The array is oversized by 11% to compensate partially for angle of incidence losses. At the equinox, a posigrade maneuver is executed to place the station in a transfer





DELTA TRUSS IOC

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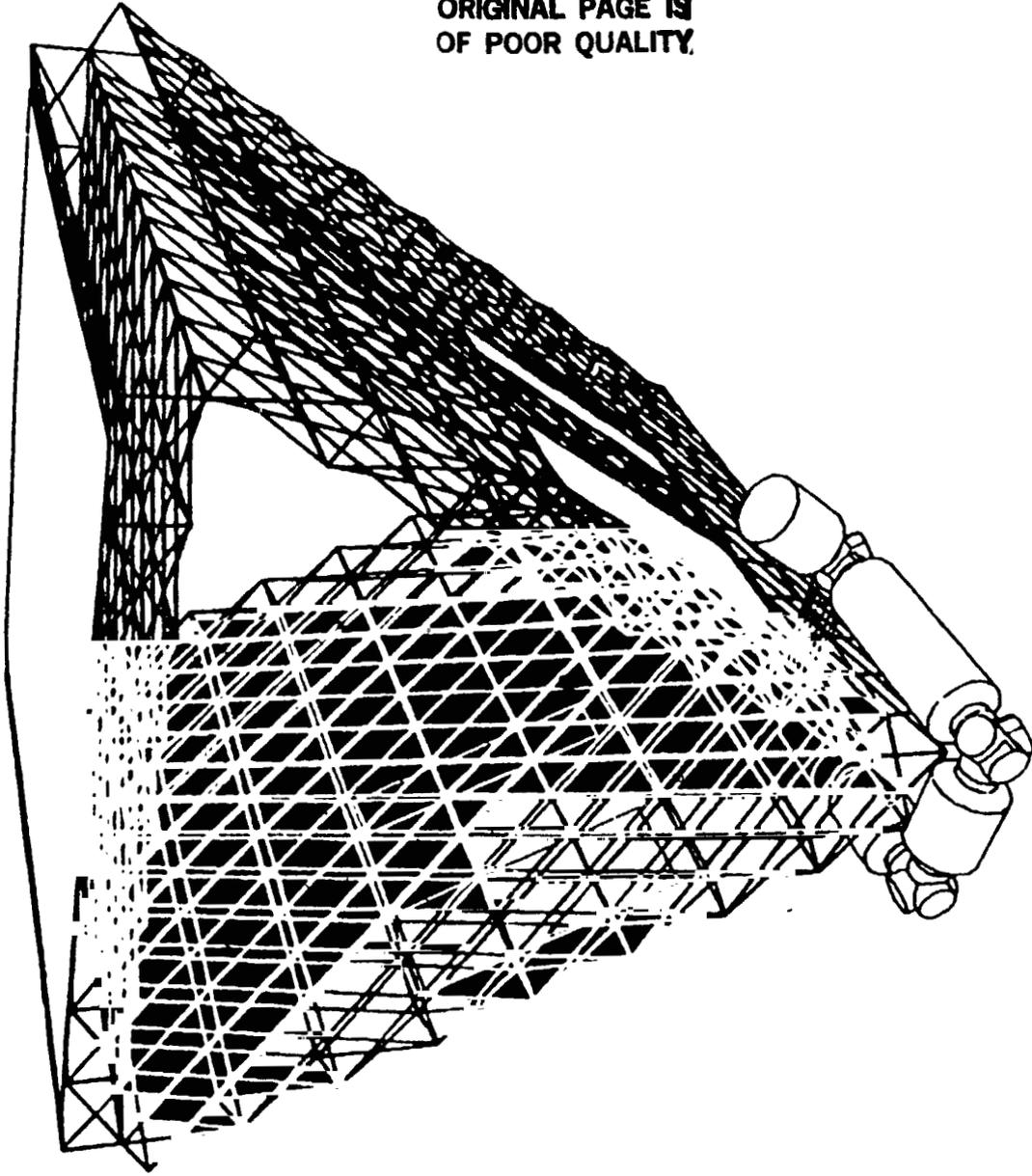
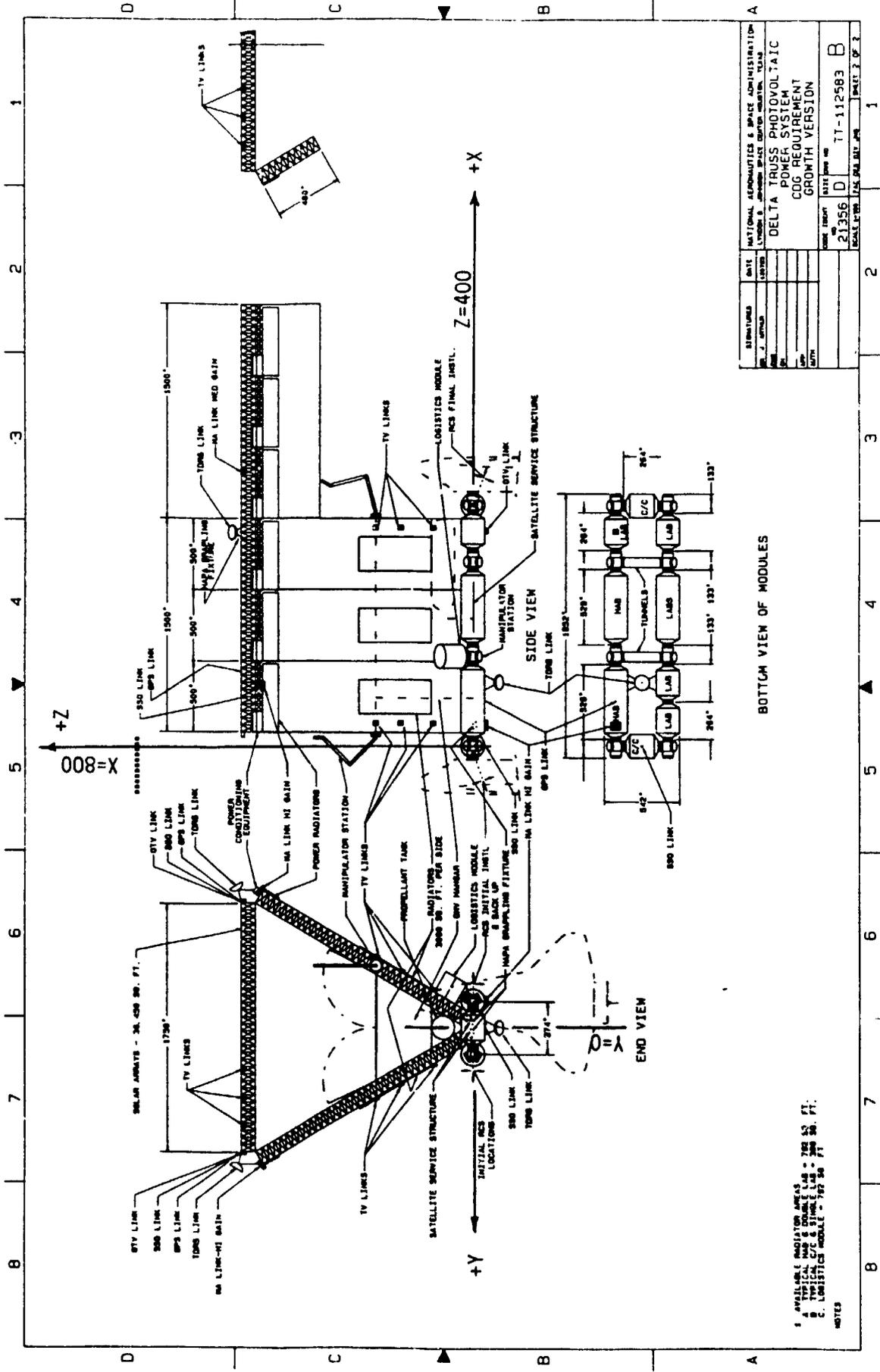


Figure 3.2-1b

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DATE	NATIONAL AERONAUTICS & SPACE ADMINISTRATION
WORKSHEET	DELTA TRUSS PHOTOVOLTAIC POWER SYSTEM
NO.	COG REQUIREMENT GROWTH VERSION
REV.	
BY	
CHECKED	
DATE	
NO.	21356 D
PROJECT	TT-112583 B
SCALE	AS SHOWN
FIGURE	1
SHEET	2 OF 2

BOTTOM VIEW OF MODULES

- NOTES
- 1. AVAILABLE RADIATOR AREAS
  - 2. TYPICAL C/C & STIMULE LAB = 200 SQ. FT.
  - 3. LOGISTICS MODULE = 782 SQ. FT.

Figure 3.2-2a

DELTA TRUSS BUILD-UP

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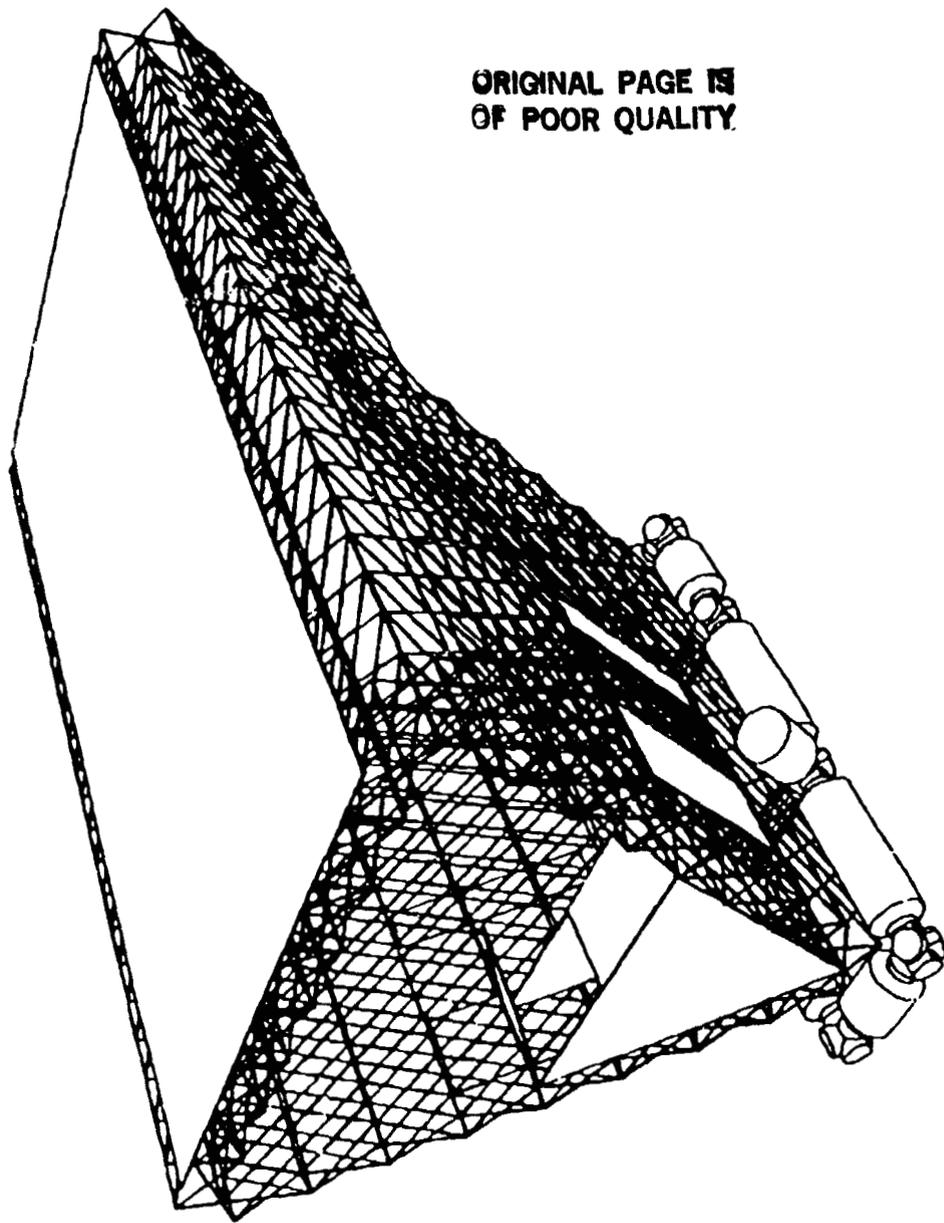


Figure 3.2-2b

ellipse for orbit makeup. After completing this maneuver, the station is rotated 180° about the Z axis and a second posigrade maneuver circularizes the orbit. In March, the procedure is repeated. In this way, orbit decay is made up every six months, and thrusters are needed at only one location on the station.

### 3.2.3 Subsystem Type and Distribution

The table below summarizes the location of subsystem components within the station.

SUBSYSTEM COMPONENT LOCATION SUMMARY

	C/CM	HM	LM	LOG.	IM	TRUSS
ECLSS	X	X	X	/	-	-
THERMAL CONTROL	X	X	X	X	/	X
PROPULSION/RCS	X	-	-	-	-	-
COMM/TRACKING	X	/	/	/	/	X
DATA MANAGEMENT	X	(X)	/	/	/	/
ELECTRICAL POWER	/	/	/	/	/	X
MECHANISMS	X	X	X	X	X	X
CREW ACCOMMODATIONS	(X)	X	/	/	/	-
GNC X (X)	-	-	-	-	-	-

- X PRIMARY LOCATION OF MAJOR COMPONENTS
- (X) BACKUP LOCATION OF MAJOR COMPONENTS
- / LOCATION OF SOME MINOR COMPONENTS
- NO SUBSYSTEM COMPONENTS

### 3.2.4 Mass Properties

The estimated mass properties of the Delta configuration are summarized in the following table. Element weights include associated subsystems. Although these estimates do not include an allowance for weight growth, some growth can be expected to occur. This would increase the weights and inertias given, but would not appreciably alter the relative magnitudes of the inertias.

DELTA

	UNIT MASS LB.	IOC	QUANTITY	GROWTH
C/CM	27,700	1		2
HM	51,300	1		2
SINGLE LM	27,700	2		4
DOUBLE LM	51,300	-		1
IM	10,000	4		8
TUNNEL	1,090	1		2
LOGISTICS	27,700	1		1
POWER SYSTEM	5,590	3		6
TRUSS - IOC	10,110	1		-
GROWTH	15,340	-		1
MANIPULATOR	2,000	1		3
OMV HANGAR	4,320	1		1
OTV HANGAR	8,520	-		1
OTV PROP. TANK	6,600	-		1
SATELLITE SVC. STR.	2,080	1		2

	IOC	GROWTH	
		W/O OTV PROP.	W/OTV PROP.
MASS, LB (DELTA)	238,470	508,460	634,460
C.G., IN. X	1,165.8	1,679.8	1,723.9
Y	-62.8	-46.1	-36.9
Z	573.1	554.7	565.7
$I_{xx}, 10^6$ SLUG-FT <sup>2</sup>	13.574	27.370	27.563
$I_{yy}$	14.090	59.301	60.977
$I_{zz}$	8.577	48.167	49.822
$I_{xy}$	-0.915	-1.407	-1.184
$I_{xz}$	3.029	7.682	7.949
$I_{yz}$	-2.185	-4.436	-4.381

### 3.3 Big "T" Configuration

#### 3.3.1 General Arrangement

The "T" concept clusters the pressurized modules and most operational support facilities at the lower end of a vertical planar truss. Solar arrays, antennas and astronomical sensors are mounted on a horizontal planar truss at the upper end of the vertical truss. The IOC configuration, shown in figure 3.3-1, includes the complete vertical truss and half of the solar array truss. The pressurized modules are grouped at one corner in a quadrangular arrangement. In the growth configuration (figure 3.3-2), the other half of the array truss is added at the top of the vertical truss. The additional pressurized modules fill the bottom edge of the vertical truss.

Hangars and other operational support facilities are mounted above the pressurized modules, as are the thermal control system radiators. Radiators for the electrical power system are located under the solar array truss.

#### 3.3.2 Function/Operation

The "T" configuration is maintained in an earth-fixed attitude with the two trusses parallel to the velocity vector. This orientation minimizes drag and is gravity gradient stable.

The solar array truss is rotated about the velocity vector up to  $17^{\circ}$  from the horizontal to maintain at least nominal power output as Beta varies up to  $52^{\circ}$ .

Several Orbiter berthing ports are available. These and others are also available for installation of temporary modules and payloads. Space is also available on the truss for unpressurized payload attachment.

Orbit makeup is accomplished by thrusters mounted on the IOC C/C module.



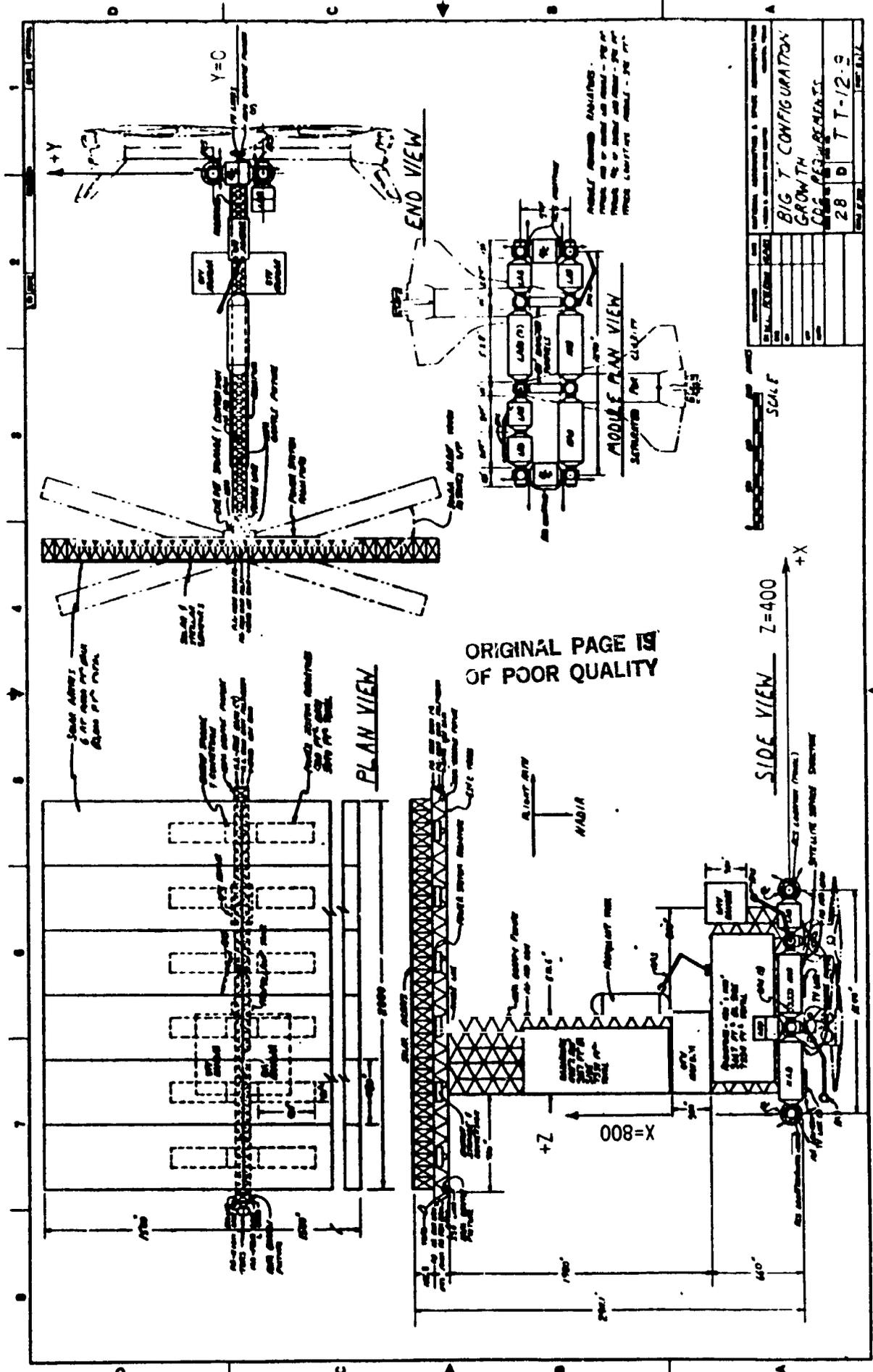


Figure 3.3.-28

BIG "T" IOC

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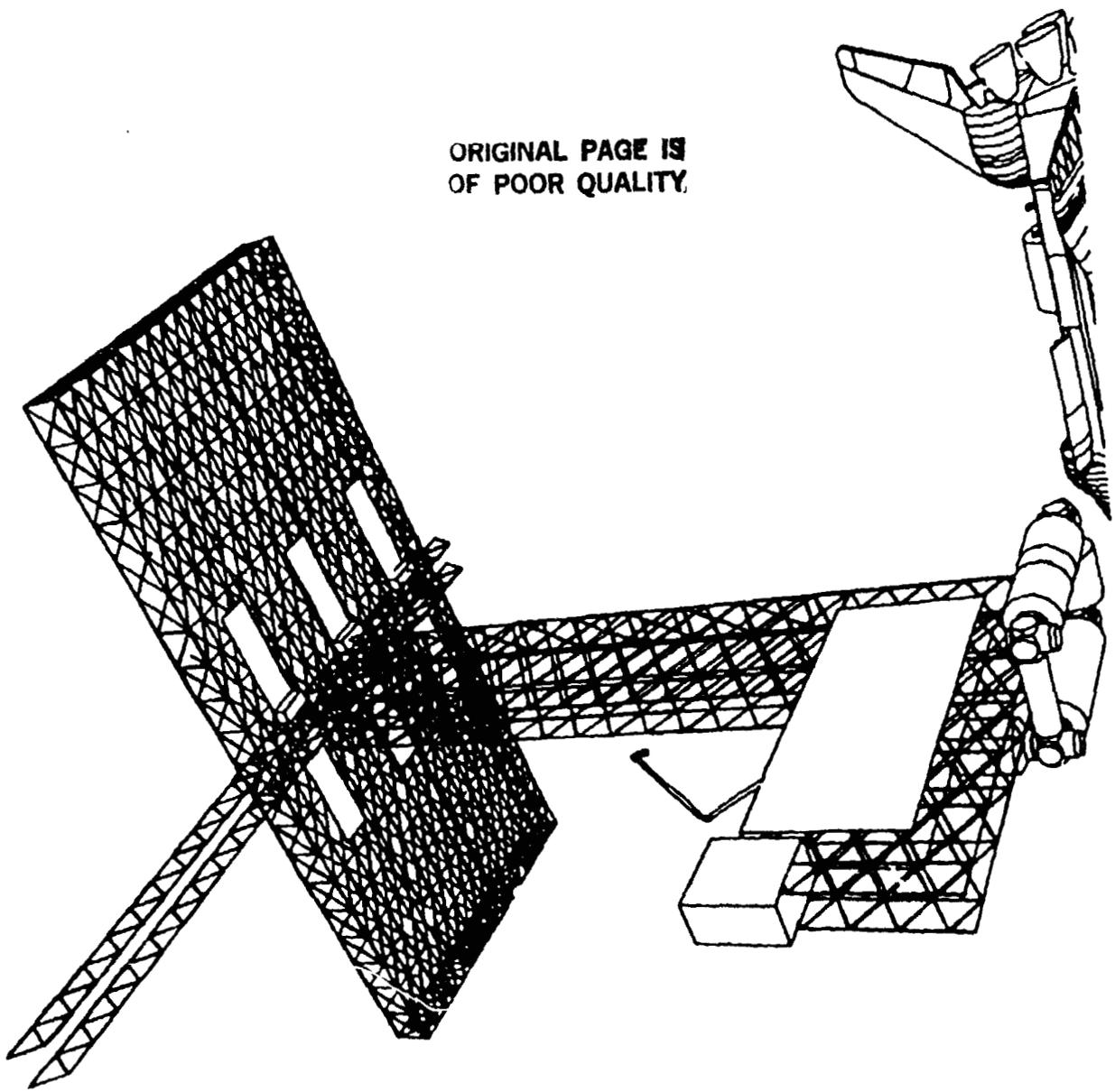


Figure 3.3-1b

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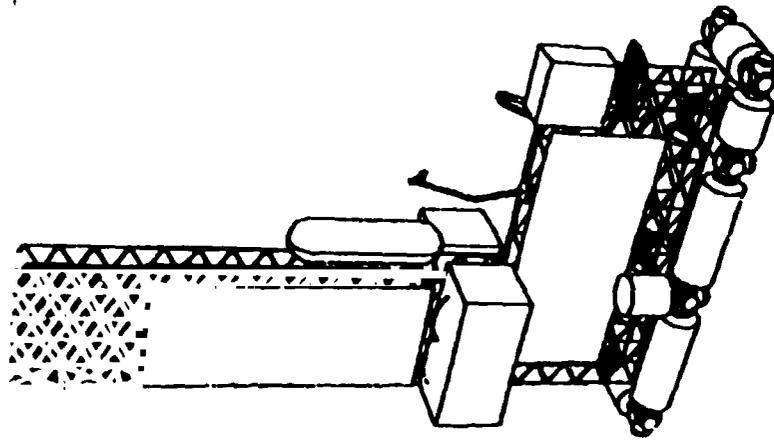


Figure 3.3-2b Big "T" Growth Configuration

### 3.3.3 Subsystem Type and Distribution

The table below summarizes the location of subsystem components within the station.

SUBSYSTEM COMPONENT LOCATION SUMMARY

	C/CM	HM	LM	LOG.	IM	TRUSC
ECLSS	X	Y	X	/	-	-
THERMAL CONTROL	X	X	X	X	/	X
PROPULSION/RCS	X	-	-	-	-	-
COMM/TRACKING	X	/	/	/	/	X
DATA MANAGEMENT	X	(X)	/	/	/	/
ELECTRICAL POWER	/	/	/	/	/	X
MECHANISMS	X	X	X	X	X	X
CREW ACCOMMODATIONS	(X)	X	/	/	/	-
GNC	X	(X)	-	-	-	-

- X PRIMARY LOCATION OF MAJOR COMPONENTS
- (X) BACKUP LOCATION OF MAJOR COMPONENTS
- / LOCATION OF SOME MINOR COMPONENTS
- NO SUBSYSTEM COMPONENTS

### 3.3.4 Mass Properties

The estimated mass properties of the "T" configuration are summarized in the following table. Element weights include associated subsystems. Although these estimates do not include an allowance for weight growth, some growth can be expected to occur. This would increase the weights and inertias given but would not appreciably alter the relative magnitudes of the inertias.

"T"

	UNIT MASS LB.	IOC	QUANTITY	GROWTH
C/CM	27,700	1		2
HM	51,300	1		2
SINGLE LM	27,700	2		4
DOUBLE LM	51,300	-		1
IM	11,300	4		8
TUNNEL	1,090	1		2
LOGISTICS	27,700	1		1
POWER SYSTEM	11,010	3		6
TRUSS - IOC	8,770	1		-
GROWTH	14,320	-		1
MANIPULATOR	2,000	1		3
OMV HANGAR	3,600	1		1
OTV HANGAR	7,100	-		2
OTV PROP. TANK	6,600	-		1
SATELLITE SVC. STR.	2,080	1		2

	IOC	GROWTH	
		W/O OTV PROP.	W/OTV PROP.
MASS, LB.(T)	257,870	555,320	681,320
C.G., IN. X	1,147.9	1,608.1	1,605.7
Y	-17.1	-7.9	-6.5
Z	769.3	772.2	893.2
$I_{xx}, 10^6 \text{ SLUG-FT}^2$	46.006	96.768	106.572
$I_{yy}$	47.824	126.427	136.334
$I_{zz}$	9.649	46.160	46.246
$I_{xy}$	-0.324	0.063	0.060
$I_{xz}$	-1.167	0.736	0.545
$I_{yz}$	0.139	0.133	0.249

### 3.4 Subsystem Summary

#### 3.4.1 Environmental Control and Life Support

The ECLS uses a regenerative CO<sub>2</sub> removal subsystem to collect the metabolically generated CO<sub>2</sub>. The CO<sub>2</sub> collected is delivered to a CO<sub>2</sub> reduction subsystem in which the CO<sub>2</sub> is converted to water via hydrogenation. The water produced by CO<sub>2</sub> reduction and the humidity condensate collected in the heat exchanger for cabin temperature and humidity control are used together as potable water for drink and food preparation after being sterilized through a post-treatment process. The O<sub>2</sub> supply is provided by a water electrolysis process which draws water from hygiene water storage/supply. The hygiene, shower and urine water recovery subsystem employs a phase-change process with pre and post-treatments to produce quality water for hygiene, shower, and electrolysis uses. The N<sub>2</sub> supply is provided by a cryogenic or high pressure gas nitrogen storage.

#### 3.4.2 Active Thermal Control Subsystem (ATCS)

The ATCS uses body-mounted radiators on each module to dissipate local heat loads. Excess loads are transported by a two-phase thermal bus to a central deployed radiator system. The two-phase system operates at a nearly constant temperature and requires much less power than a single-phase system.

Radiators (body-mounted and deployed/truss-mounted) for the Space Station will use heat pipes of a high capacity monogroove configuration. In this approach, the deployed or truss-mounted radiators will be constructed in space with a RMS. The heat pipe radiator elements are plugged into contact heat exchangers. Each individual radiator element (about 1' wide by 50' long) can be removed and replaced if damaged.

### 3.4.3 Propulsion

The propulsion system has been sized primarily for orbit maintenance at 270 NM. The systems can also provide significant quantities of CMG angular momentum dump capabilities.

The system concept which has been chosen for this study is monopropellant hydrazine ( $N_2H_4$ ). Five years with zero maintenance is a typical design life time. All proposed systems incorporate a blowdown pressurization system.

The use of a single propellant with a blowdown pressurization system reduces the number of components to less than one-half of the components in an actively pressurized bi-propellant system. This is expected to significantly enhance the overall reliability of the system and reduce the maintenance required over the life of the station.

### 3.4.4 Communications and Tracking (C&T)

The normal Space Station/ground uplink and downlink channels will operate through a relay satellite at S-band, Ku-band, millimeter wave (mm-wave), or optical frequencies. The communication links between the Space Station and Orbiter will operate at S-band frequencies. The links between the Space Station and space platforms, free-flyers, EVA, OMV, and/or manned/unmanned OTV's will be at S-band, Ku-band, mm-wave or optical frequencies.

The communication system will be capable of transmission, reception, and processing of voice, telemetry, commands, wideband data, television (TV), and text and graphics. The system will include the capability for private communications (including any communications security requirements). Services provided by the internal C&T system include video, audio, commands, telemetry, data and C&T management/control/distribution.

### 3.4.5 Avionics

Space Station avionics comprises several independent subsystems: navigation, guidance and control, integrated DDC, data management, facilities management, operations planning and scheduling, payload operations, and traffic control. The goal was to achieve a distributed data management approach where each subsystem is as autonomous as possible, with interactions between subsystems reduced to a minimum.

The navigation subsystem maintains the current state vector and inertial attitude for the entire Space Station utilizing Global Positioning Satellite receivers and a number of star trackers located on the various modules.

The guidance and control subsystem accepts information and commands from ground, crew, and other subsystems, processes appropriate software logic and issues torque or delta V commands to momentum exchange or propulsion devices to control Space Station attitude and orbital altitude.

Integrated displays and controls provide crew capability for startup, initialization, operational moding, manual proportional inputs, safing, and shutdown of all Space Station subsystems. It employs multi-function control devices and displays wherever possible in order to minimize the number of dedicated switches, controls, readouts, etc.

The flight data management subsystem (FDMS) provides the mechanism for all intra-Space Station data and information exchange among subsystems, payloads, D&C, other vehicles and ground. For purposes of total system integration, verification, and hardware/software commonality, the FDMS will specify a standard bus interface unit (BIU) and high order language for subsystem applications software. The BIU will interface the user (subsystem) with the station-wide data network. The network will be reconfigurable and adaptable to support Space Station buildup, operational growth, and contingency control.

Facilities management, operations planning and scheduling, payload operations and traffic control provide the data bases and computational capability required to carry out these functions.

#### 3.4.6 Structure

The pressurized modules are constructed of all-welded, integrally machined skin-stringer panels of 2219 aluminum plate. Meteoroid penetration considerations dictate a wall thickness of 0.060" with an 0.040" bumper 4" away from the pressure shell. Stringers and ring frames provide necessary stiffening.

The Delta and Big "T" configurations utilize a deployable tetrahedral planar truss as a structural foundation. The truss is constructed of graphite/epoxy tubes and molded end fittings for low thermal expansion.

#### 3.4.7 Electrical Power

The photovoltaic system chosen for this study is a flexible, planar array utilizing large area (5.9 cm x 5.9 cm) silicon cells. The cells will be attached to a flexible kapton (or similar material) substrate instead of the more conventional rigid aluminum honeycomb. Since the Station will last longer than the 10-year array life goal, provisions must be made to change out solar array blankets.

The 25 kW energy storage unit comprises an alkaline fuel cell for power generation, an alkaline electrolysis cell for energy storage as oxygen and hydrogen gases, tankage, a heat exchanger, power conversion and regulation, and supporting structure.

Power distribution throughout the Station is three-phase, 400 V, 20 kHz over four redundant buses. Controllers in the modules convert the power to other forms as required by users.

#### 3.4.8 EVA

At least two interconnect modules are equipped as airlocks, including controls, pumpdown provisions and suit stowage.

The EMU will be of modular design to facilitate recharge, repair and replacement. The Space Station MMU will also be modular so that modules can be repaired inside the Station.

#### 3.4.9 Crew Accommodations

Crew accommodations in the habitation module include private sleeping compartments, a galley/wardroom, hygiene and waste management provisions, and exercise and health maintenance facilities. Contingency crew provisions are duplicated in the command/control module.

The galley includes ovens, freezer, refrigerator, dishwasher, trash compactor, hot and cold water dispensers, a handwasher and storage lockers. The wardroom serves as a dining, meeting and recreation area.

Each private compartment contains a sleep restraint, a video/computer terminal for work and entertainment, an audio system with controls, a bulletin board and desk combination, a ceiling light for room illumination, an adjustable reading light, and storage lockers. There is approximately 100 ft<sup>3</sup> of free space in each private compartment.

The personal hygiene facility consists of three cubicles with latching doors for privacy; each is large enough for convenient doffing and donning of clothing. The first cubicle contains the commode. The next two cubicles are identical, each containing a combined unisex urinal, handwasher, and full body shower.

The health maintenance facilities consist of a biomedical instrumentation rack, treadmill, exercycle, storage cabinets, and a look-in station.

## 4.0 CONCEPT FUNCTIONS DESCRIPTION AND EVALUATION

### 4.1 Introduction

The desirable features or evaluation criteria were identified and discussed in Volume I. The criteria were defined in terms of user accommodations, system engineering, operations, safety, programmatic features, and technology availability. In concert with the CDG's work on the subject, the criteria in the user accommodation and system engineering areas were subdivided into view factors, access and clearance, arrangement versatility, dynamics and control, and assembly and growth. An attempt was made to include not only the basis for quantifying the configurations performance or required functions such as orbit maintenance and attitude control, but also for evaluating those features which may be desirable such as compatibility with tethers for science.

Except as dictated by configuration differences, the same basic subsystem concepts were applied to all three Space Station configurations. This practice extended to the size, interior provisions, and arrangement of pressurized modules, such that differences in costs, performance, and crew and user evaluations should be dependent primarily on the differences on the configuration concepts. Some discussion of alternative subsystem types, and the rationale for selection of subsystems, are contained in Volume II of the report.

Although weighting has not been assigned to these criteria, such weighting will be necessary to obtain a quantitative overall evaluation. This step was not considered necessary at this stage of the concept development.

### 4.2 Summary Evaluation

Some of the most important conclusions that can be drawn from this study concern those variables which do not appear to be strong discriminators between the three different configurations. The first of these is cost. Despite the

attempt to minimize the total hardware requirements in the Building Block configuration, its costs to IOC, as shown in table 4.2-1, is actually higher than that of the Delta configuration, which includes an extensive truss structure absent from the Building Block configuration. Furthermore, even the addition of twice the solar array size to the "T" resulted in its cost being only 10% greater than that of the delta; a difference considered marginally significant at the level of the cost analysis. Second, the number of launches to reach the IOC state was found to be  $\pm$  one launch out of seven, again not significant at the level of the current manifesting study. The extensive vehicle dynamics study concluded that the propellant requirements differed, between the low-drag "T" and the relatively high drag Building Block, by less than 2,500 lbs. every 90 days - again not a significant discriminator. Refer to table 4.2-2. The operations study also failed to find any of the configurations unacceptable from either an assembly or other operations standpoint; i.e., rendezvous and docking procedures are not significantly complicated by the inertial orientation of the Delta. Although the momentum storage requirements for the three configurations differ somewhat, that is also not considered a discriminating factor since all three are well within the state-of-the-art, and the cost impact of additional CMG units is minimal.

TABLE 4.2-1  
 COST COMPARISON  
 (1984 \$)

<u>CONFIGURATION</u>	<u>DDT&amp;E</u>	<u>COST</u>	<u>IOC TOTAL</u>
BUILDING BLOCK	\$5.7 B		\$8.2 B
DELTA	5.7 B		8.0 B
"T"	6.0 B		8.7 B

TABLE 4.2-2  
 PROPELLANT REQUIREMENT SUMMARY  
 Pounds per 90 days, ISP = 220 sec

<u>PHASE</u>	<u>CONFIGURATION</u>		
	<u>BUILDING BLOCK</u>	<u>DELTA</u>	<u>"T"</u>
IOC	1,500	1,500	700
GROWTH	3,000	2,400	590

From a user accommodation standpoint, the use of a TEA flight mode for all three configurations was found to be highly desirable since it significantly reduces the need for RCS firings and hence, minimizes the periods of acceleration disturbances and sensor contamination. The basic earth orientation of the building block and "T" configurations is considered more desirable than the inertial orientation of the Delta for stellar and earth observations, but the capabilities of the Delta are found to be adequate; this difference is not a discriminator between the configurations.

The Building Block configuration provides the opportunity for solar region observations from a pressurized laboratory element, while the Delta provides this capability only from the command and control module and the "T" provides almost no such opportunity. However, there is no recognized requirement for such directly manned observations, and the placement of solar sensors on the solar array trusses of the "T" and Delta configurations provides excellent fields of view and minimizes the contamination encountered.

The most important discriminators from a user standpoint appear to be those associated with versatility and growth. The way in which the Building Block concept is configured in this study provides laboratory modules on the growth configuration in addition to those required. This provides more user pressurized volume than that contained in the Delta or "T" concept. However, the utilization of these modules is severely restricted by the difficulty of their removal for reconfiguration or repair. In addition, the extreme difficulty of increasing the power on the Building Block concept beyond that originally planned implies limitations to the uses of the station. The compact nature of the Building Block also limits the usefulness of the available berthing ports for payloads since clearance and access are limited.

The "T" and Delta configurations provide easy access to the berthing ports for payloads; and the exposed truss sections between the two "legs" of the module arrangement provide large versatile and accessible areas for not only earth viewing instruments, but unpressurized payloads of other types.

The separation of the solar and stellar viewing instruments on the solar array truss of the "T," and of the solar instruments on the Delta, from the modules is seen as a disadvantage from the standpoints of access by EVA or manipulators and for signal, command, etc., transmission. Thus, the "spread out" configuration of the "T" and Delta provide both advantages and inconveniences from a user standpoint.

The basic crew accommodations provided by each configuration are essentially the same since interior and module arrangement options were not included in the study. However, the external configuration was found to affect crew accommodation in the aspects of EVA operations and external viewing. In general, the larger Delta and "T" configurations were considered undesirable because of the long distances between the pressurized modules and equipment and experiments mounted on the solar arrays. These distances are considered significant because the length of time required to reach these destinations for equipment maintenance or experiment servicing was perceived to be substantial and because direct visual depth perception is lost from the position of an observer in the modules. The viewing capability thought to be desirable includes continual direct visual contact with an EVA crewman and with the RMS end effector from the interior, as well as the ability to visually inspect the major elements of the station. From the viewing standpoint, none of the configurations as defined was judged to have the desired number of windows, but the Delta and "T" were further considered undesirable because the truss structure inherently obstructs some fields of view.

The structural dynamic differences between the three configurations are significant from a control system standpoint; the Building Block concept, in particular, would require a more sophisticated design, with attendant implications on verification, both of the structural math models and the control software. The interface and mechanical systems requirements of each of the three configurations are found to be significantly different. The Building Block concept utilizes a universal, although complex, interface between modules to provide all utility connections as well as to perform the structural functions. In addition, a highly complex mechanism is required to connect the oriented solar arrays, antennas, and radiators to the module assembly. This specific interface is expected to require maintenance since it is in continuous use, and no means of performing this maintenance has been identified. This is, in fact, viewed as a major technical challenge associated with the Building Block configuration.

The mechanical and interface systems required with the Delta configuration are essentially all associated with initial deployment or reconfiguration, except for the RMS and berthing systems common to all configurations. The many different mechanisms associated with placement of major elements on the truss structure have not been fully defined, but the number of different systems involved is seen as some disadvantage. However, it is noted that these will each be somewhat simpler than the universal interfaces associated with the Building Block configuration. Notably absent from the Delta is the continuously moving interface with the solar array boom. Further, the truss-mounting of all major elements makes the interfaces between modules, and the level of redundancy required to compensate for loss or removal of a module, less demanding. In contrast, the large size of the Delta (and also the "T") requires a longer reach for the RMS, and perhaps the use of more joints in the RMS, arms than does the Building Block configuration.

The "T" configuration, although requiring a mechanism for tilting the solar array truss, shares most attributes with the Delta from an interface and mechanical systems standpoint. Since the rotation of the truss is only through  $+17^{\circ}$ , the problems associated with continuously moving interfaces on the Building Block configuration are not present. Further, no moving fluid connections appear necessary. The large truss structures associated with the "T" and the Delta can be considered mechanisms, and an apprehension exists as to the success of the deployment of these trusses. The most significant uncertainty, and hence apprehension, associated with these trusses appears to be in the addition of truss area to an already deployed truss. This operation is required to establish the IOC "T" configuration, and hence, is seen as a disadvantage. However, this same type of operation is also required to expand the Delta to the growth configuration.

In the thermal control area, specific differences are found in the required radiator area on the three configurations, as shown in table 4.2-3. These differences are inherent in the configuration, and show an advantage for the delta. Since the configuration also avoids the necessity for rotary joints in the coolant loops, this is considered significant. The "T" configuration suffers the disadvantage of not only requiring added radiator area for the power modules because of the oversized power module capability, but also because of poor radiator viewfactors which impede rejecting heat from the modules.

The Delta configuration appears to be preferable from a power system standpoint. The solar array can be expanded in any desired increments, with individual packaged modules consisting of solar array, conversion and storage equipment, and radiator panels. No moving connections are required. The oversizing of the array by 10% to account for Beta angle losses is not a

TABLE 4-2-3

THERMAL CONTROL EVALUATION SUMMARY

<u>FACTOR</u>	<u>BUILDING BLOCK</u>	<u>DELTA</u>	<u>T</u>
THERMAL ENVIRON	25% BLOCKAGE 30 B/H-FT <sup>2</sup> ABSORBED	1% BLOCKAGE 20 B/H-FT <sup>2</sup> ABSORBED	11% BLOCKAGE 47 B/H-FT <sup>2</sup> ABSORBED
RADIATOR AREA	5346 FT <sup>2</sup> (DEPLOY) IOC	4966 FT <sup>2</sup> (TRUSS) IOC	9541 FT <sup>2</sup> (TRUSS) IOC
ORBITER IMPACT	15% RADIATOR BLOCK	15% RAD BLOCKAGE	15% RAD BLOCKAGE
DESIGN COMPLEXITY	DEPLOYED RAD	TRUSS RADIATOR INSTALLATION	TRUSS RADIATOR INSTALLATION
CERTIFICATION	GROUND/FLIGHT TESTING	GROUND/FLIGHT TESTING	GROUND/FLIGHT TESTING
SURFACE CONTAMINATION	CAN BE HANDLED	CAN BE HANDLED (LESS OF PROBLEM)	CAN BE HANDLED
COMMONALITY	SIGNIFICANT POTENTIAL	SIGNIFICANT POTENTIAL	SIGNIFICANT POTENTIAL
TECHNOLOGY STATUS	ESTABLISHED CAST PROGRAM	ESTABLISHED OAST PROGRAM	ESTABLISHED OAST PROGRAM

significant penalty. The Building Block configuration, other the other hand, is extremely limited in increment size based on the ultimate desired power, and probably is impractical to expand in no more than four increments. Rotating joints capable of transmitting conditioned power are required on the Building Block configuration. The "T" configuration, while sharing some of the attributes of the Delta, requires twice the capacity in the solar array and electrolysis units. To minimize storage requirements, a more complex power control system is envisioned which takes advantage of the power available from the array at low sun incidence angles.

The power profile analysis discussed in Volume II is noteworthy in that the power levels required at IOC for operation of the Space Station, exclusive of that dedicated to payloads, was found to be on-the-order of 50 KW. Thus, if the payload power levels of 60 KW for IOC and 120 KW for growth are accurate, the IOC station may require 50% more power than currently projected. Some level of power above 150 KW would also be expected for the growth station. On this basis, the practicality of adding power to the station in increments, without severe penalties, should be considered an extremely attractive feature. This feature is most evident in the Delta, while it appears to be totally absent in the Building Block configuration. The "T" configuration, while it possesses the capability of additions to the truss size, may raise the issue of practicality above the 150 KW level simply due to the extremely large cell array required. One other disadvantage to the Building Block configuration is associated with the minimal structure of the deployed solar array and the requirement for the OMV, Orbiter, OTV, etc. to operate in close proximity to the arrays, since they are mounted on booms connected to the module assembly. The disadvantage is that plumes from the RCS of the proximity-operating vehicles will impact the array at significant incidence angles and at relatively close distances. The resulting forces could

disturb not only the solar array blanket, but also the entire highly flexible structure. Although detailed analysis remains to be accomplished, the resulting motions could cause severe problems with the structure, blanket, and perhaps with vehicle attitude control.

The communications system is shown to be very sensitive to vehicle orientation, highly favoring the velocity-vector orientation of the Building Block configuration and "T" concepts. This derives from the requirement to communicate with proximity-operating vehicles in basically the same orbit. To meet a full time coverage requirement for such communications, spherical coverage is required on the Delta. Antenna requirements are summarized in table 4.2-4. Although this is not viewed as a technology problem, some system complexity is added to manage the increase in antennas required for the Delta in addition to their cost and maintenance requirements.

TABLE 4-2-4

ANTENNA REQUIREMENTS SUMMARY

<u>Communication Link</u>	<u>BUILDING BLOCK</u>		<u>DELTA</u>		<u>"T"</u>	
	<u>Number of Antennas</u> <u>IOC</u>	<u>Growth</u>	<u>Number of Antennas</u> <u>IOC</u>	<u>Growth</u>	<u>Number of Antennas</u> <u>IOC</u>	<u>Growth</u>
SPACE SHUTTLE ORBITER	1	1	3	3	1	1
MULTIPLE ACCESS LINK	2	2	3	3	4	4
TRACKING AND DATA RELAY SATELLITE	1	1	3	3	1	1
GLOBAL POSITIONING SYSTEM	1	1	3	3	1	1
TELEVISION	2	10	6	18	4	12
ORBITAL TRANSFER VEHICLE	0	2	0	3	0	2
SPACE SHUTTLE ORBITER RENDEZVOUS RADAR	2	2	2	2	2	2
RENDEZVOUS	2	2	3	3	2	2
MULTIPLE TRACKING	0	2	0	5	0	2

## 5.0 PROGRAMMATICS

### 5.1 Costs

#### 5.1.1 Groundrules and Assumptions

The following groundrules and assumptions were used in the cost analysis for the three configurations:

- o The Space Station Cost Model (SSCM) developed by Flanning Research Corporation (PRC) was used to develop hardware and system level costs.
- o The concept was treated as one work package.
- o Only the IOC configuration was costed.
- o No learning was assumed.
- o No explicit reserve was included.
- o No STS flight costs were included.
- o Subsystem costs were allocated to the modules on the basis of weight.
- o Costs are expressed in millions of 1984 constant year dollars. Since SSCM outputs costs in 1982\$, the inflation adjustment was made using the NASA R&D inflation index (1.175 for 1982 to 1984 dollars).
- o Program level costs (including fee) were included using the Code B factors.
- o Complexity factors considered to be 1.0 except the following:
  - o Closed loop ECLS was costed using the open loop ECLS CER with 1.6 complexity factor. Factor based on CDG trade study.
  - o Berthing and docking adapter used a 0.8 complexity factor and used the ASTP adapter as an analogy.
  - o Complexity factor of 0.6 used for fuel cell based on JSC analysis.
  - o GSE complexity factor of 0.8 was used, based on CDG cost estimate.

### 5.1.2 Cost Overview

The cost of the Building Block, Delta truss, and Big "T" configuration in 1984 dollars at IOC is \$8.2 billion, \$8.0 billion, and \$8.7 billion respectively. For the Delta configuration, the costs of the truss and tunnel elements (additive for this alternative) were offset by the deletion of the solar boom equipment, one C/C module, and the satellite support system. The big "T" configuration is the most costly of the three alternative configurations. This is primarily due to the additional truss structure, additional solar array requirements, and more fuel cells. However, as a comparison of the costs for all three configurations would indicate the difference is relatively small (less than 10 percent). Table 5.1 shows the cost breakout for the DIT&E phase and production phase for the three configurations. It is immediately evident that the majority of the cost of the program is in "overhead" costs, such as system level and program level tasks. Approximately 75 percent of the DDT&E costs are in this category, contrasted to approximately 25 percent for hardware development. Roughly 40 percent of the production costs are system and program level costs, leaving approximately 60 percent actual hardware production.

The comparative cost analysis was performed for the three concept configurations to identify the areas of major cost impact. However, cost reductions could be realized by adopting new and innovative methods of doing business from those used in past space programs.

TABLE 5.1

<u>CONFIGURATION</u>	<u>COST</u>		
	<u>DDI&amp;E</u>	<u>PRODUCTION</u>	<u>IOC TOTAL</u>
Building Block	\$5.7B	\$2.5B	\$8.2B
Delta	5.7B	2.3B	8.0B
Big "T"	6.0B	2.7B	8.7B

## 5.2 Issues

### 5.2.1 Introduction

This section provides a summary of the requirements and design issues identified but not resolved during this study. An issue was defined as a consideration where questions existed in one or more of the following areas:

1. Whenever requirements definitions were inadequate.
2. Where options or alternative approaches exist for future study.
3. Where inadequate information exists to permit detailed evaluation.
4. Where development questions such as risk and technology availability exist.

The list of requirements issues applies to all three of the configurations studied. In the list of design issues, the particular configurations (Building Block, Delta truss, or big "T") in which the issue was most pronounced is identified.

### 5.2.2 Requirements Issues

1. Thermal control for hangars, satellite servicing areas, payloads, and instrument racks.
2. Proximity operations and co-orbiting satellite communications continuous coverage.
3. Station operations power.
4. Payload bay docking module requirements for buildup and operations.
5. Orbiter hard docking/berthing.
6. Module return.
7. Single (44 ft) or double (22 ft) laboratory module.
8. Crew activity, equipment, and utility for OMV, OTV, and satellite servicing.

9. Pressurized module viewing.
10. Relationship between platforms and Space Station.

### 5.2.3 Design Issues

1. Alternate power source options (solar thermal).
2. Alternate approaches to crew safety (dual egress vs. safe haven).
3. Alternate module arrangements (linear vs. racetrack vs. raft vs. "spoke").
4. RCS location.
5. Fixed vs. oriented boom-mounted radiators - Building Block
6. Deployed vs. erectable structure.
7. Assembly of truss elements - Delta, big "T".
8. Interface definition for other elements with trusses - Delta and big "T".
9. Connecting tunnel interfaces with truss - Delta and big "T".
10. Plume impingement effects.
11. Maintenance of boom rotary joints.
12. Solar array high voltage - plasma interactions.
13. Viewing capability from modules - Delta, big "T".
14. Long distance EVA - Delta, big "T".
15. RMS requirements and implementation.
16. Local shadowing and/or blockage of solar arrays.
17. Use of Orbiter vs. station RMS vs. automatic mechanisms vs. EVA for establishing interfaces during buildup.
18. Sizing of utilities in modules for growth.
19. Number of pressurized ports to be provided on interface modules - Delta and big "T".

#### 5.2.4 Operations Accommodations Issues

1. Separation and rendezvous/return lighting considerations.
2. Traffic control procedures during proximity operations
3. Communications considerations during proximity operations.
4. Plume impingement/contamination
5. Operation control zone considerations
6. Vehicle orbital transfer trajectory considerations
7. Quiescent free-flyer separations and controls

#### 5.2.5 Communications and Tracking

1. Antenna location, coverage, and obscuration
2. Location of subsystem hardware such as radiators which would cause antenna interference
3. Antenna coverage requirements in relation to space station orientation

#### 5.2.6 User Accommodations

1. Reduction of common equipment, i.e., one long module vs. two short modules for same function
2. Providing "adequate" volume for users.

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