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N91-17024

SPACE TRANSPORTATION AVIONICS TECHNOLOGY SYMPOSIUM

WILLIAMSBURG, VIRGINIA

NOVEMBER 7-9, 1989

SPACE STATION FREEDOM AVIONICS TECHNOLOGY

WHITE PAPER

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PROGRAM DESCRIPTION

The SSFP encompasses the design, development, test, evaluation, verification, launch, assembly, operation and utilization of a set of spacecraft in low Earth orbit (LEO) and their supporting facilities. The spacecraft set includes, as shown in Figure 1, the Space Station Manned Base (SSMB) and a European Space Agency (ESA) provided Man-Tended Free Flyer (MTFF) at an inclination of 28.5 degrees and nominal attitude of 410 km, a USA provided Polar Orbiting Platform (POP) and an ESA provided POP in sun-synchronous, near polar orbits at a nominal altitude of 822 km. The SSMB will be assembled using the National Space Transportation System (NSTS). The POP's and the MTFF will be launched by Expendable Launch Vehicles (ELV's): a Titan IV for the US POP and an Ariane for the ESA POP and MTFF.

The U.S. POP will for the most part use derivatives of systems flown on unmanned LEO spacecraft. This paper concentrates on the SSMB portion of the overall program.

The SSMB or "Station" as referred to from here on will have the capability to be permanently manned with a crew of eight, and to have a nominal lifetime of at least 30 years. The advances over previous stations can be appreciated in Figure 2, which contrasts it to scale with Skylab and MIR. Figure 3 shows the principal Station elements and identifies the NASA Centers and international partners responsible for

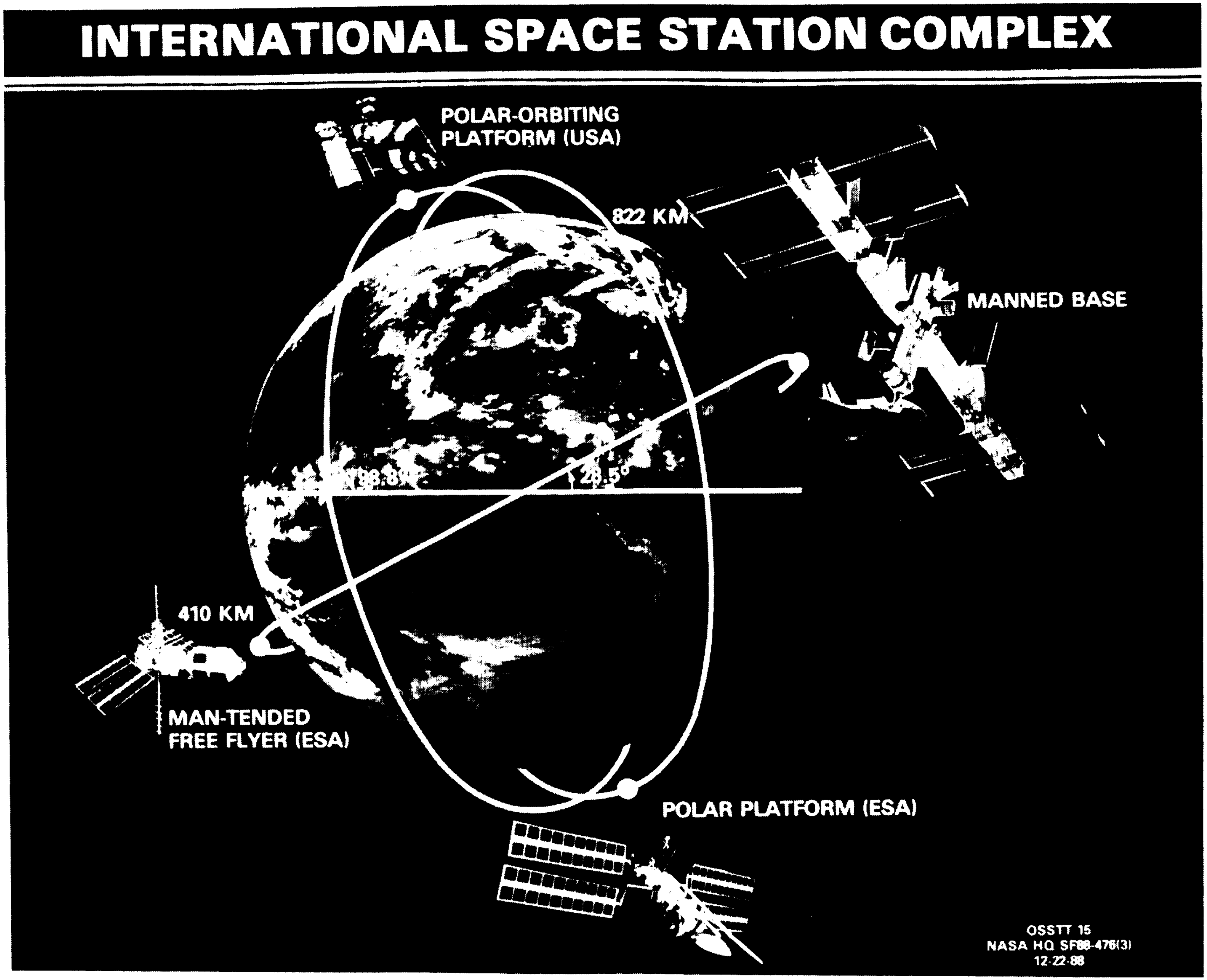
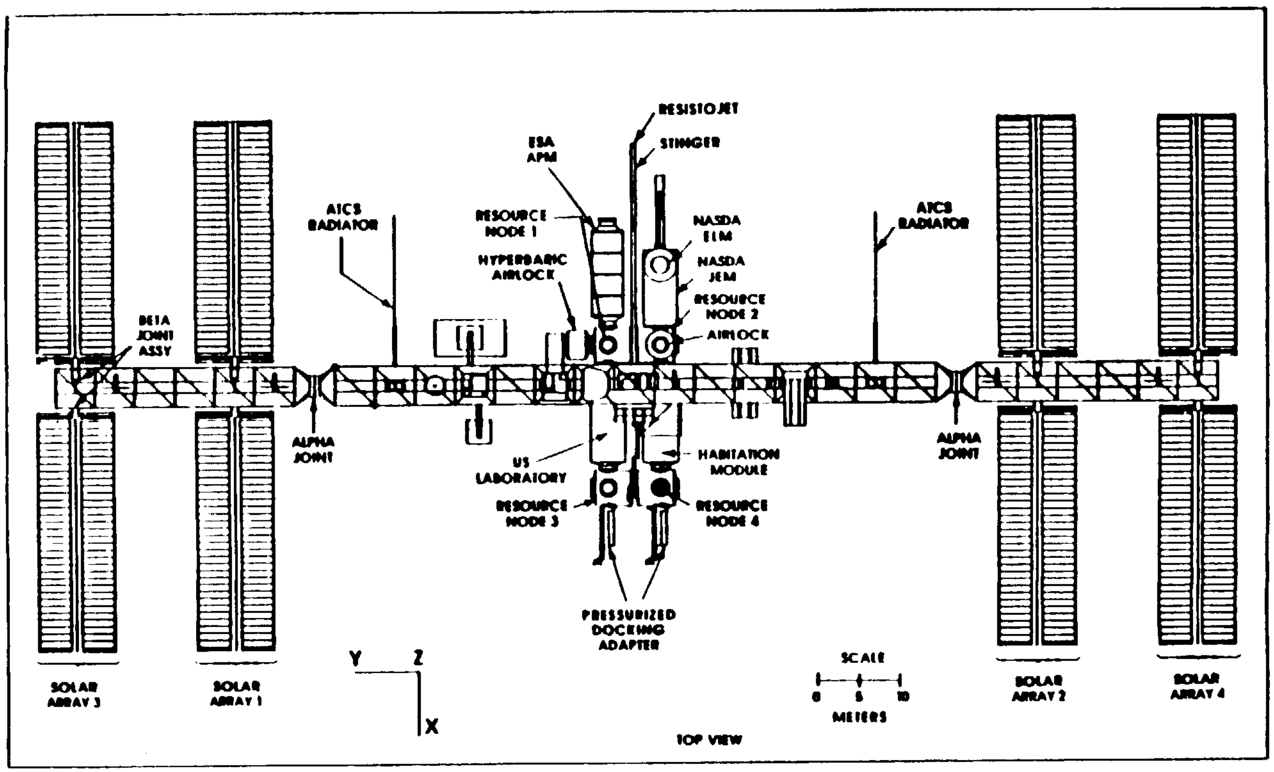
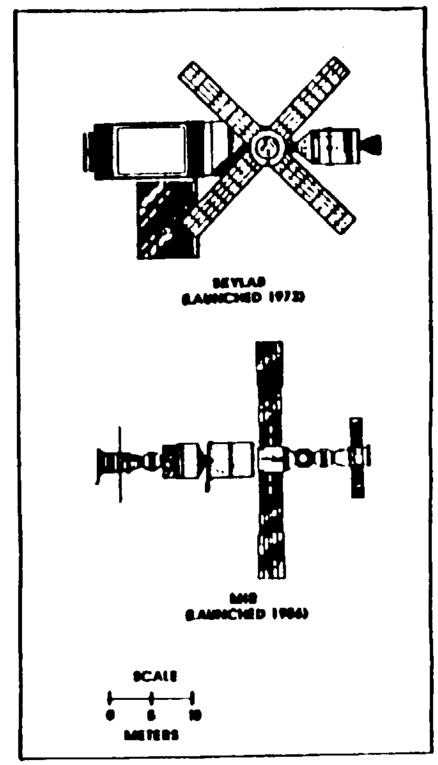

INTERNATIONAL SPACE STATION COMPLEX
POLAR-ORBITING
PLATFORM (USA)
822 KM
MANNED BASE
98.8°
28.5°
410 KM
MAN-TENDED
FREE FLYER (ESA)
POLAR PLATFORM (ESA)
OSSTT 15
NASA HQ SF88-476(3)
12-22-88

FIGURE 2

SPACE STATION FREEDOM MANNED BASE





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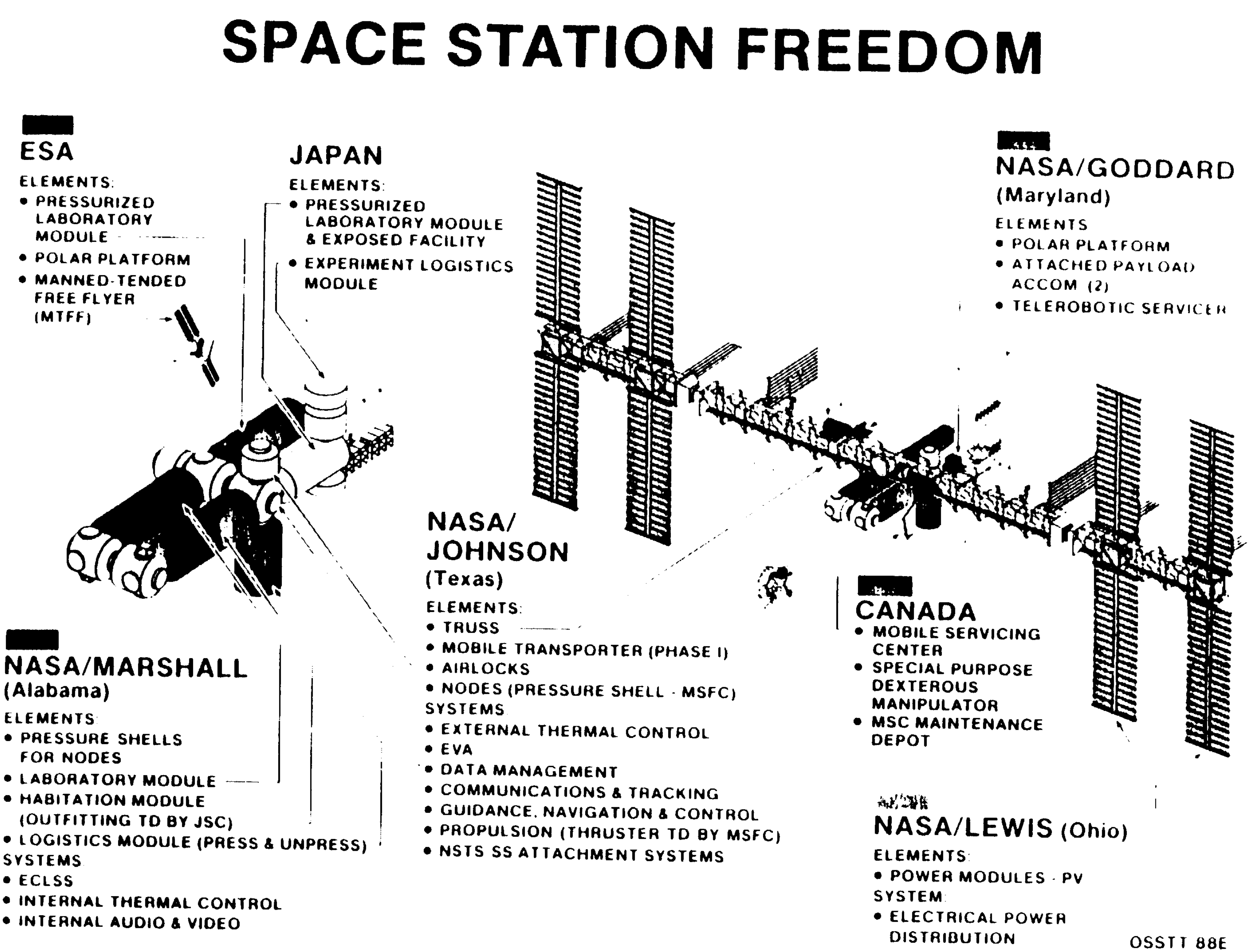
SPACE STATION FREEDOM
ESA
ELEMENTS:
• PRESSURIZED LABORATORY MODULE
• POLAR PLATFORM
• MANNED-TENDED FREE FLYER (MTFF)
JAPAN
ELEMENTS:
• PRESSURIZED LABORATORY MODULE & EXPOSED FACILITY
• EXPERIMENT LOGISTICS MODULE
NASA/GODDARD
(Maryland)
ELEMENTS
• POLAR PLATFORM
• ATTACHED PAYLOAD ACCOM (2)
• TELEROBOTIC SERVICER
NASA/MARSHALL
(Alabama)
ELEMENTS
• PRESSURE SHELLS FOR NODES
• LABORATORY MODULE
• HABITATION MODULE (OUTFITTING TD BY JSC)
• LOGISTICS MODULE (PRESS & UNPRESS)
SYSTEMS
• ECLSS
• INTERNAL THERMAL CONTROL
• INTERNAL AUDIO & VIDEO
NASA/JOHNSON
(Texas)
ELEMENTS:
• TRUSS
• MOBILE TRANSPORTER (PHASE I)
• AIRLOCKS
• NODES (PRESSURE SHELL - MSFC)
SYSTEMS
• EXTERNAL THERMAL CONTROL
• EVA
• DATA MANAGEMENT
• COMMUNICATIONS & TRACKING
• GUIDANCE, NAVIGATION & CONTROL
• PROPULSION (THRUSTER TD BY MSFC)
• NSTS SS ATTACHMENT SYSTEMS
CANADA
• MOBILE SERVICING CENTER
• SPECIAL PURPOSE DEXTEROUS MANIPULATOR
• MSC MAINTENANCE DEPOT
NASA/LEWIS (Ohio)
ELEMENTS:
• POWER MODULES - PV SYSTEM
• ELECTRICAL POWER DISTRIBUTION
OSSTT 88E

these elements. The configuration has evolved from extensive analyses of scientific and commercial user requirements as well as transportation considerations, and engineering and technology factors. The program proposed as a result of the recent configuration budget review does not make major changes in the avionics complement at the completion of the assembly sequence, with the exception of a change from AC to DC primary power distribution.

Station elements will be attached to an 80 meter transverse boom oriented perpendicular to the velocity vector. Four pressurized cylindrical modules will be located in the center of the Station. The Habitation module will provide living quarters, and the United States, ESA, and Japan will each develop a laboratory module. The Japanese module also has an exposed facility. Also, pressurized and unpressurized logistics carriers will provide supplies and equipment.

There will be four resource nodes, located at each end of the Habitation and U.S. Laboratory modules. The nodes will be smaller pressurized cylinders that will generally serve as command and control centers, and as pressurized passageways to and from the various modules. The nodes may also accommodate some experiment racks and will provide additional pressurized space.

Certain nodes will also contain berthing mechanisms for temporary attachment of either the Space Shuttle or the logistics modules. They will also have attaching elements to connect the node to the truss and modules. Two cupolas will be attached to node ports to allow direct viewing of external activities. The nodes will also contain docking equipment and hatches. There will be a single hyperbaric airlock to support extravehicular activities (EVA).

The Station will be powered by two power modules, each composed of two pairs of photovoltaic arrays. The T-shaped power modules will be attached to either end of the transverse boom with two alpha joints, which will rotate to point the solar arrays toward the sun. The power modules will supply an average total of 75 kilowatts (kW) of electrical power. The boom will be equipped with attach points providing power and other utilities to accommodate external scientific payloads.

Other features of the Station will include a Canadian Mobile Servicing System, shown in Figure 4. This system will be used to assist in the assembly of the Station and for a number of servicing tasks. There will also be a Flight Telerobotic Servicer (FTS), shown in Figure 5, which will be used for maintenance and which will also be used in the assembly of the Station.

The elements are the major pieces of hardware that are assembled to make up the Station, and comprise the hardware that is not involved with distributing a utility or service. Distributed systems, in contrast, provide those functions whose end-to-end performance is located in two or more elements. The Station will have a number of distributed subsystems which will provide data management, thermal control, communications and tracking, guidance, navigation and control, environmental control, human life support and fluid management.

The Assembly Sequence perhaps is the most challenging aspect of the program. The Sequence has evolved and will continue to evolve through the preliminary design phase now in progress. Figure 6 is an example of a Sequence requiring 20 NSTS missions to reach assembly complete. A current estimate lists 29 missions including logistics flights. Each increment in the Sequence must meet NSTS payload weight, volume, and CG constraints, obey limits on EVA assembly time, and result in a viable spacecraft ready for the next increment. The avionics systems will be challenged to meet the requirements of many different configurations on-orbit.

The current schedule for development of the Station is shown in Figure 7. The next key event is the Preliminary Design Review (PDR) and preparations for that are in progress throughout the program, with reviews at the subsystem level beginning this

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FIGURE 6
EXAMPLE OF
SPACE STATION FREEDOM ASSEMBLY FLIGHT SEQUENCE

FREEDOM

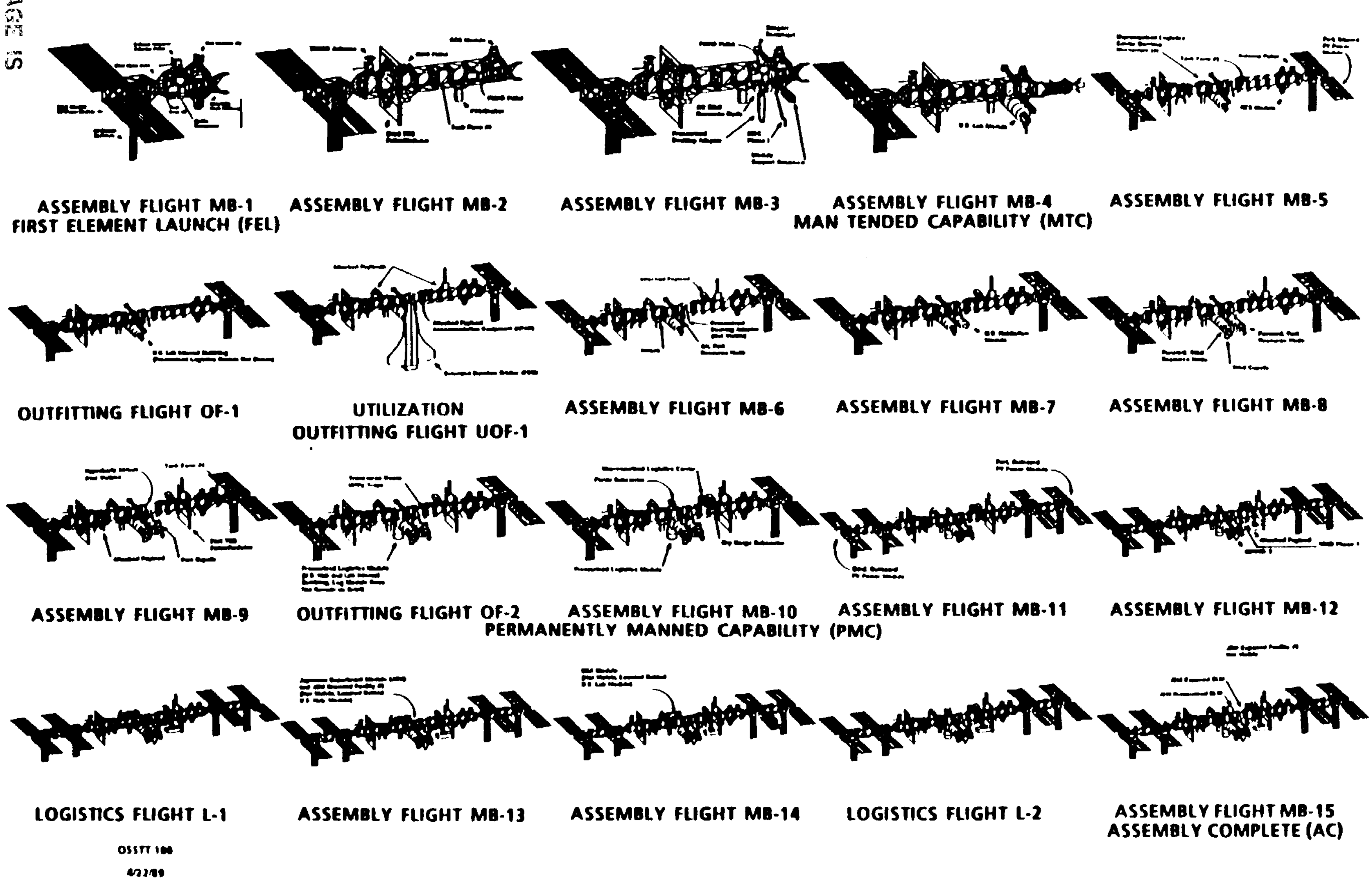

FIGURE 7
SPACE STATION FREEDOM PROGRAM
PROGRAM SCHEDULE

MANNED BASE	BASELINE	PROPOSED
Phase C/D Start Date	Dec 1987	
Preliminary Requirements Review	Jun 1988	
Preliminary Design Review	Aug 1990	
Critical Design Review	May 1992	
Training Facility ORD*	Mar 1993	
Control Center ORD*	Mar 1994	
Processing Facility ORD*	Sep 1994	
Flight Readiness Review	Jan 1995	
First Element Launch	Mar 1995	
Man Tended Capability	Nov 1995	Apr 96
Permanent Manned Capability	Dec 1996	Jul 97
Assembly Complete	Feb 1998	Aug 99
FLIGHT TELEROBOTIC SERVICER		
Phase C/D Start Date	Jul 1989	
Preliminary Design Review	Jan 1990	Dec 90
Critical Design Review	May 1991	Jun 92
Development Test Flight	Dec 1991	Aug 91
Demonstration Test Flight	Jun 1993	Nov 93
Flight Unit Availability	Mar 1995	

* ORD = Operational Readiness Date

year. Phasing down of the DDT&E effort in the nineties should provide an opportunity to begin introducing evolutionary and growth development activity that could expand capabilities at the turn of the century. An example of an enhanced Station serving as a transportation node is shown in Figure 8. Featured are a dual keel providing more real estate, solar dynamic power modules to increase power, and accommodations for servicing. Other avenues of enhancement could support a Mars exploration initiative or increased research and development.

The principle avionic subsystems and related topics are discussed in the following sections with emphasis on the technical challenges and the anticipated paths for evolution.

ELECTRIC POWER SYSTEM (EPS)

The EPS provides a critical resource to the Station using PV modules as described earlier. The system includes NiH_2 batteries and power distribution hardware as shown in the top level architecture diagram of Figure 9. The baseline is now a totally DC system from the arrays through primary, secondary and tertiary distribution. Primary is at 160 V and secondary is at 120 V. There will be a development activity to obtain the necessary switch-gear to handle the 75 kW output power level. AC power for primary distribution was scrubbed in the recent program rephasing.

The estimates of power for housekeeping and power for users will continue to be refined as the design proceeds, but it is clear that the allocations will challenge experiment and system developers and the overall power management activity. Current estimates for housekeeping power are given in Figure 10 to indicate where improvements might bring significant benefits. DMS has the major requirement in avionics, but there is a challenge across the board is to improve efficiency and to enable an effective power management strategy.

LUNAR EVOLUTION REFERENCE CONFIGURATION
LEO Transportation Node

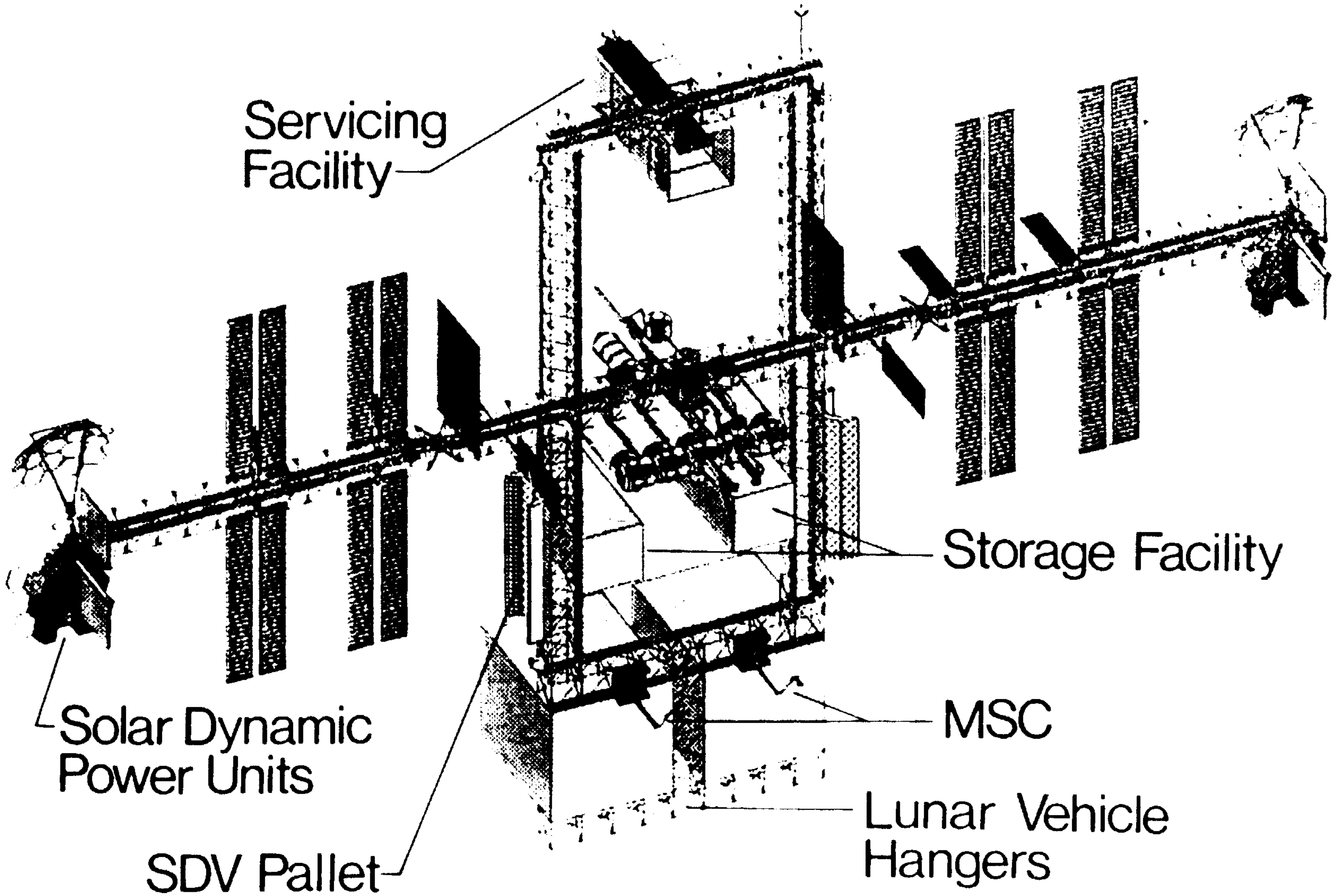

FIGURE 9
END-TO-END ARCHITECURE

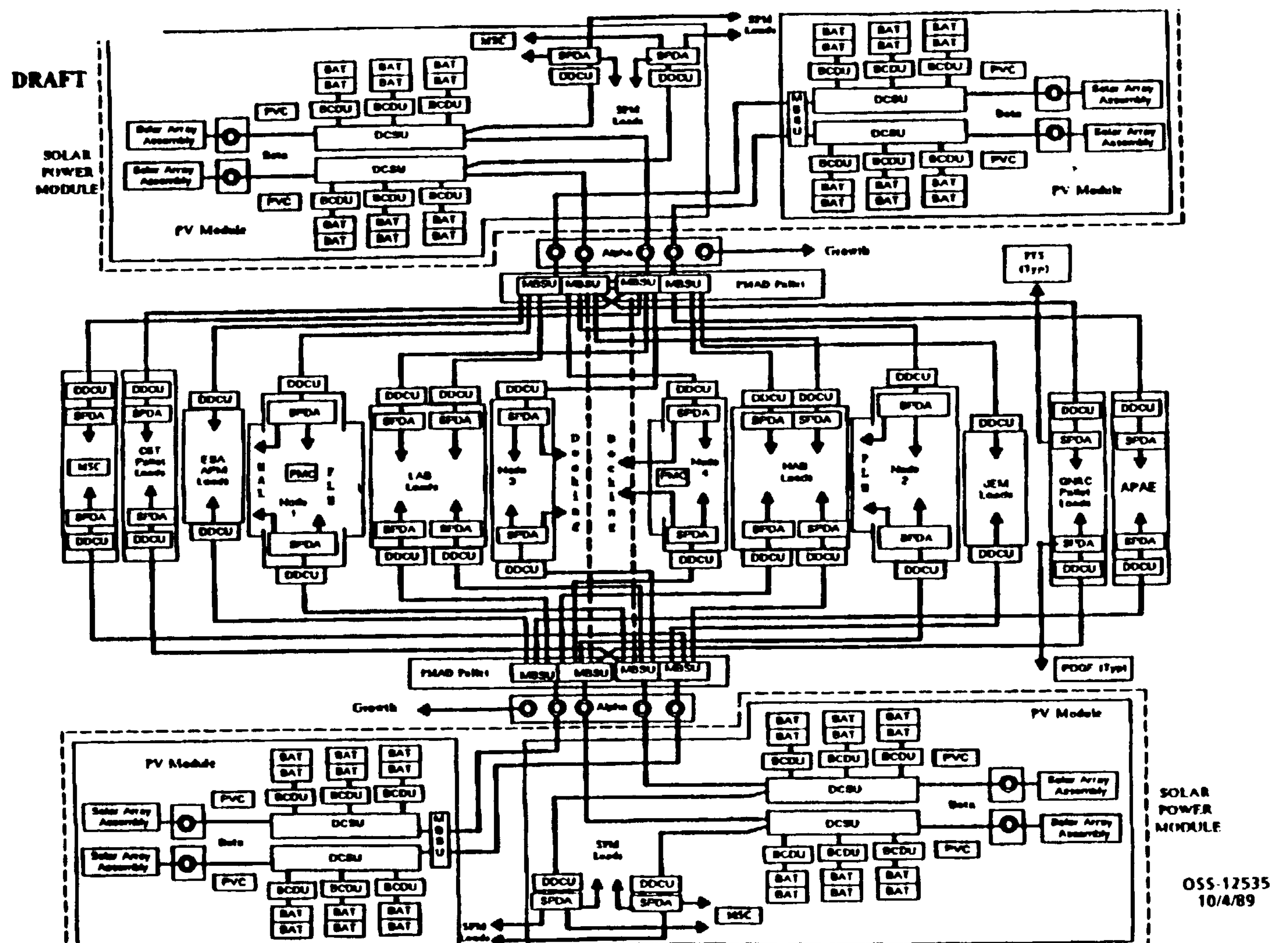

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FIGURE 10
HOUSEKEEPING POWER ESTIMATES

Distributed System	Assembly Complete* (kW•hr/hr)	
ECLSS	10.89	
Propulsion	1.35	
Internal Thermal	2.97	
External Thermal	0.61	
Fluids	1.35	
C&T	1.77	
Internal A/V	1.25	
GN&C	0.57	
DMS	4.94	
Man-Systems	4.30	
EVA	0.13	
Mechanisms	0.85	
Element Unique	4.48	
Distribution Losses	3.76	
CSA	2.76	
ESA	2.37	(5.02)**
NASDA	3.77	(1.89)**
TOTAL	48.12*	(55.03)**

Notes: No reserves included
* *Assumes U.S. Lab active and International Lab quiescent*
** *All labs active*

The growth path for the EPS would be to implement the Solar Dynamic Module shown in Figure 11 and to implement an AC primary distribution at 440 V and 20 kHz. The Solar Dynamic approach using a solar concentrator and Brayton cycle has higher efficiency than the PV and presents a smaller area with less drag than PV. In addition, the energy storage would employ a material phase change instead of batteries. The reduction in logistics resupply and the on-orbit changeout task relative to solar cells and batteries would be significant. The Solar Dynamic Modules would provide 25 kW increments and be symmetrically positioned outboard of the initial PV modules. Solar Dynamic requires accurate pointing and a basic PV capability should always be retained to recover from a degraded pointing condition.

DATA MANAGEMENT SYSTEM (DMS)

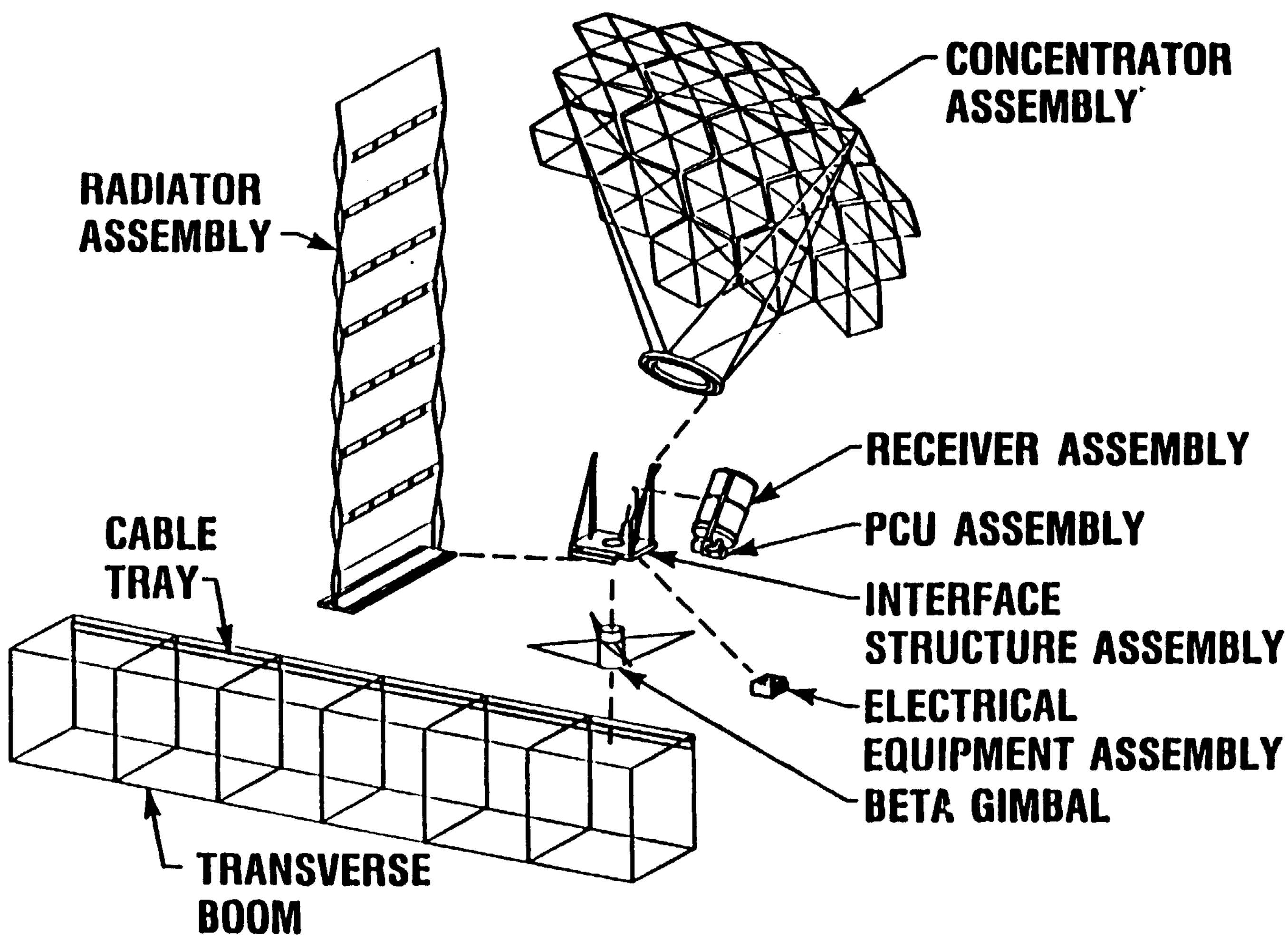
There has been general agreement that the DMS presents one of the top technical challenges in the Station program. The challenge arises from its size and complexity. The DMS will provide the hardware and software resources necessary to support the data processing and control needs of the other distributed systems, the elements and payloads. It will also provide a common operating environment and human-computer interface for the command and control of systems and payloads by both the crew and the ground operators.

The DMS will be made up of five subsystems corresponding to the five major DMS functions:

- Human-computer interface,
- Data acquisition and distribution,
- Data storage and retrieval,
- Application program processing, and
- Time generation and distribution.

FIGURE 11
SPACE STATION FREEDOM

SOLAR DYNAMIC POWER MODULE ASSEMBLIES



The major features of the DMS are given in Figure 12, and an overview schematic is given in Figure 13. Key features of the software development are the choice of ADA as the standard language and the definition of a Standard Software Environment (SSE) capability for commonality across the program. Some of the challenges facing the DMS development are:

- Ensuring common design guidelines are properly allocated to all software generated across the program.
- Establishing standard interfaces with international partners and the ground environment.
- Meeting power resource allocations.

COMMUNICATIONS AND TRACKING (C&T) SYSTEM

The C&T System, together with the DMS and associated ground systems, forms the Space Station Information System (SSIS). There is a major challenge in defining the overall end-to-end data system and controlling its configuration. The C&T System provides capability for sending audio, video, operational data and experiment data to the ground and for receiving command data from the ground using the Tracking and Data Relay Satellite System (TDRSS). A functional block diagram is shown in Figure 14.

The space to ground Ku Band link will use the full capability of TDRSS at 300 Mbps. The operational housekeeping data portion of this will be 2 Mbps. In addition, there will be an S-Band link to be used during early assembly flights and as a backup in the operational phase. An emergency link separate from TDRSS has been proposed that would carry only voice.

FIGURE 12
MAJOR DMS FEATURES

FREEDOM

REQUIREMENT	IMPLEMENTATION
Processing Architecture	- Distributed
On Board Data Distribution	- Combination of LAN's and Busses. (1553,802.4, FDDI) Payloads and Core Systems Separated
Controls and Display	- Multipurpose and Application Consoles, Fixed and Portable
Software	- ADA, Standard Interfaces, Common Services
Data Storage	- Replicated and Stand-Alone DMBS
Time Generation	- Independent Network, Use GPS for UTC Interface
Autonomous Operations	- OMS/OMA Command and Control Architecture
Integration, Test and Verification	- Common Test Environment
Software Development	- Common SSE
Processor	- INTEL 80386
LAN Data Rate	- 100 MBPS
Mass Storage	- Magnetic Disk
Standard Backplane	- Multibus II
Packaging	- MIL STD 1788

SELECTIONS YET TO BE MADE

Software, COTS vs. Custom	- Operating Systems, DBMS, DMS Services
Redundancy Management	- Levels, Techniques and Automation Factors
MPAC	- CRT's and Liquid Crystals, Network Interfacing
Time Services	- Time Code and Interfaces
DBMS Architecture	- Distributed or Centralized
End-to-End Network Protocols	- CCSDS, ISO/OSI
Security/Privacy	- TBD (Object Classification, Encryption of Data)

FIGURE 13
DMS OVERVIEW SCHEMATIC

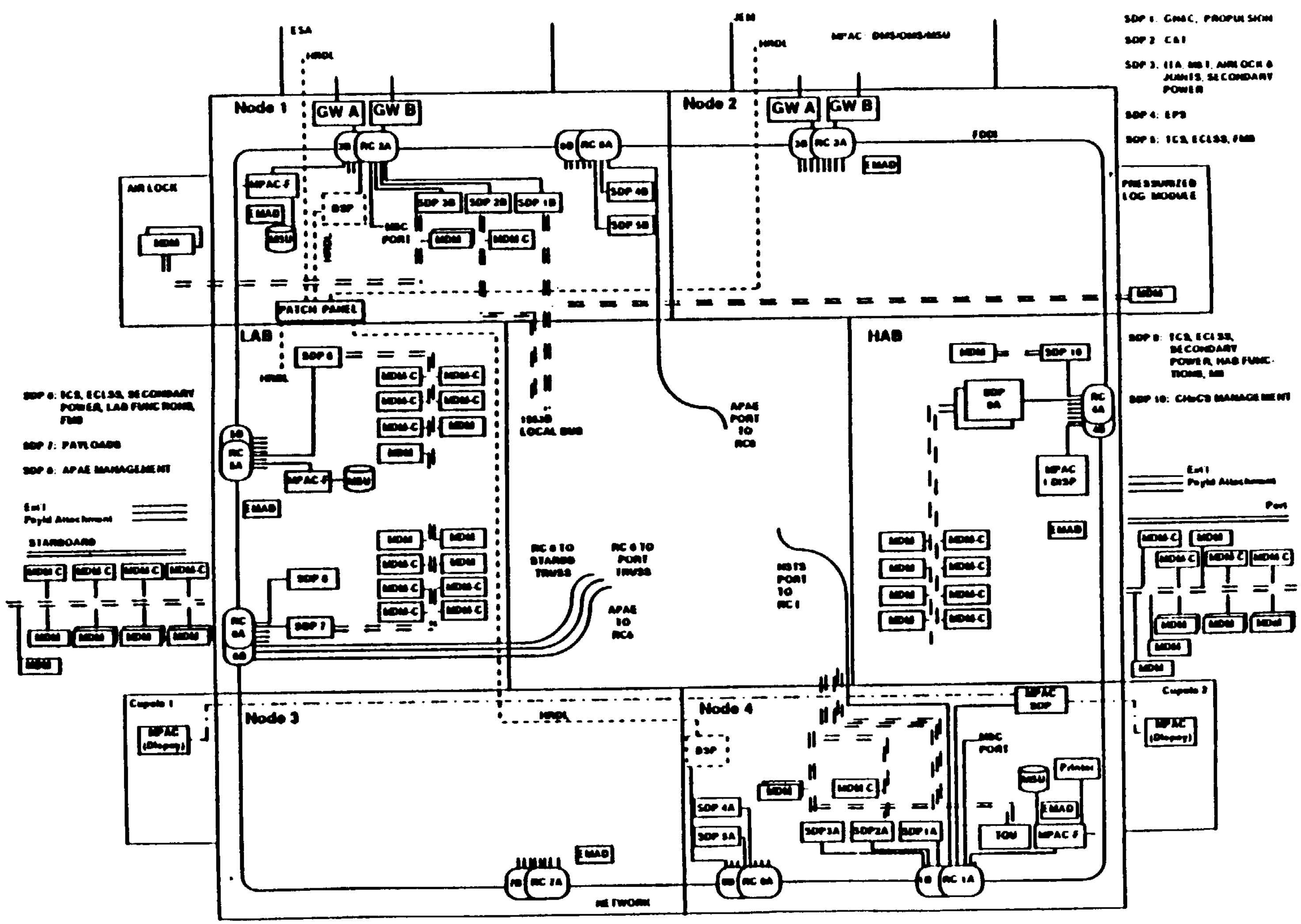


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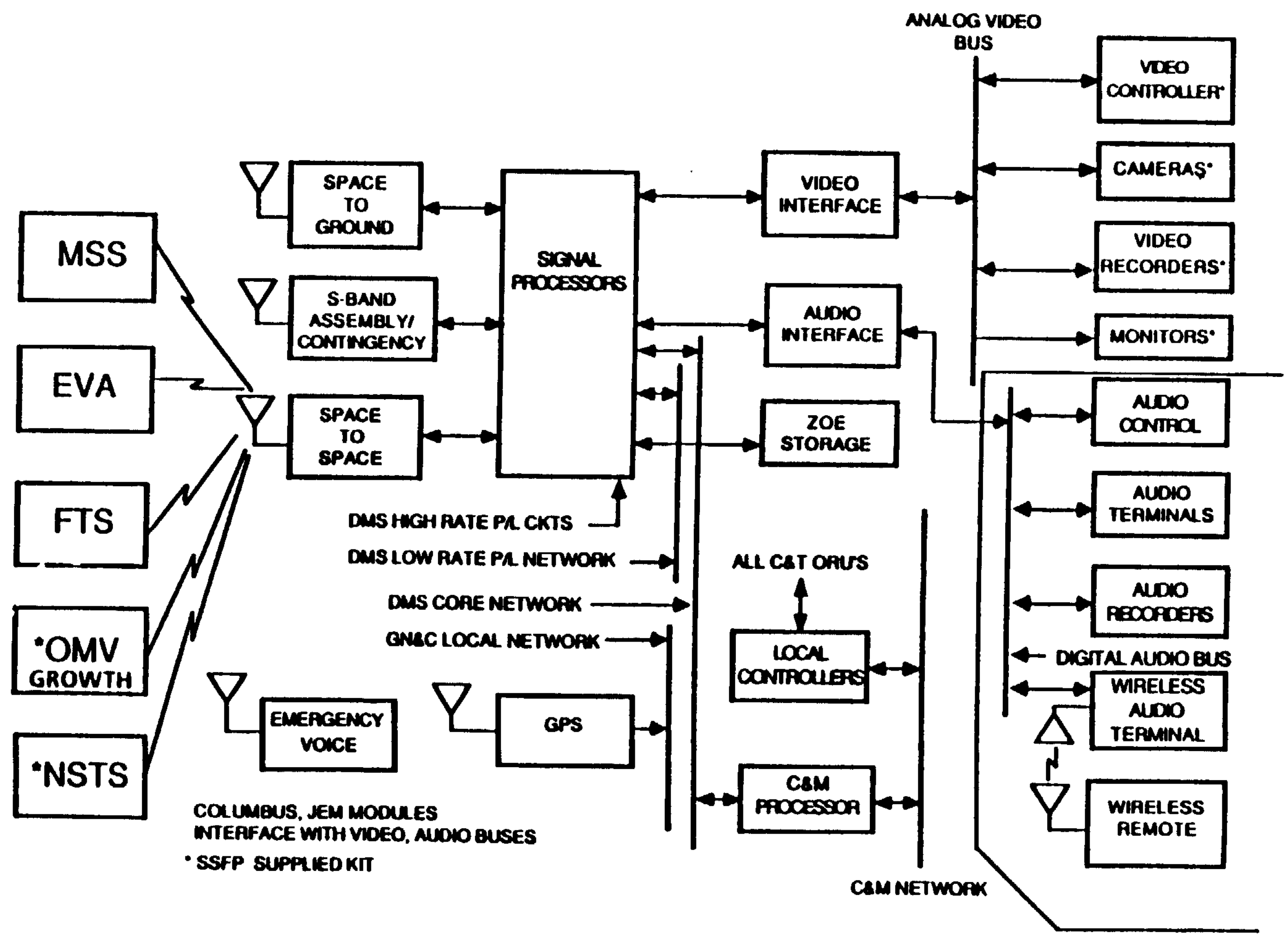
FIGURE 14
C&T FUNCTIONAL BLOCK DAGRAM

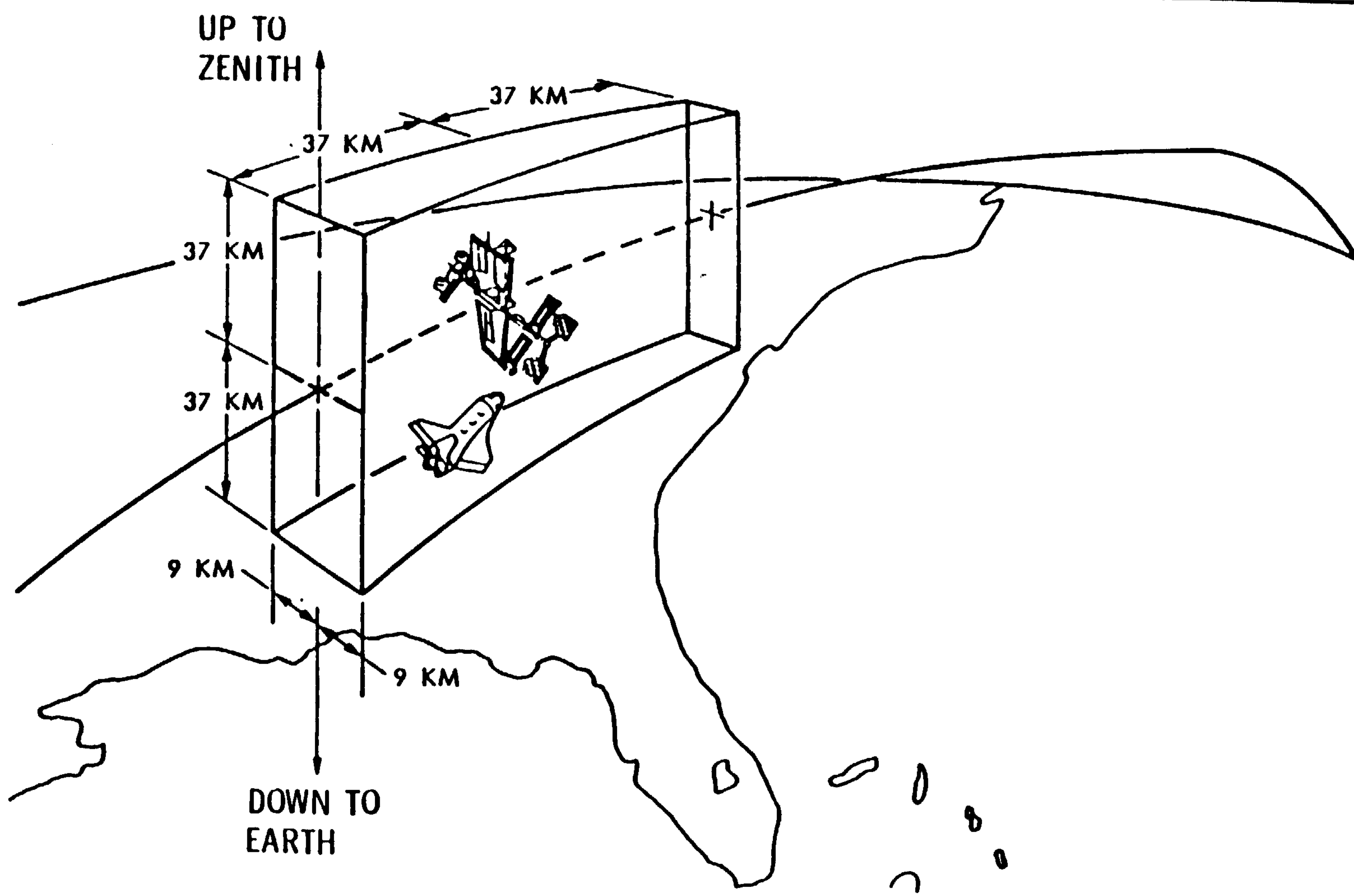


A Command and Control Zone (CCZ), shown in Figure 15, will be established around the Station. It will reach to 37 km behind, above and below the Station and 8 km on each side of the orbit plane. In this zone, the Station will control approaching unmanned vehicles, such as an OMV. Within about 1 km, the Station will control EVA operations and the FTS. The EVA operations are slated to use UHF as now done with the NSTS Orbiter. The FTS communications would be at Ku Band (separate from TDRSS) to provide the necessary bandwidth for video channels used for controlling FTS. Both these frequency choices face regulatory problems; there is potential interference from DOD transmitters at UHF, and from commercial satellite ground transmitters at Ku Band. OMV control is a growth capability.

The main growth path for C&T would be to utilize the planned capability for the Advanced TDRSS at 600 Mbps in Ka Band where the greater bandwidth is available. Also, the cluster communication would move to Ka Band where a primary allocation can be expected and interference from ground station transmitters minimized. There also is potential for optical communications that would expand the data rates while at the same time avoiding regulatory and interference issues. For the video subsystems it probably will be necessary to evolve to whatever High Definition Television (HDTV) standards emerge in the nineties.

The tracking role in C&T will be provided by the Global Positioning System (GPS). This DOD system will be operational using a total of 24 satellites in orbits at about 10,000 nmi. The high accuracy position, velocity and time reference data enable autonomous operations for Station. In addition, GPS will be particularly useful in rendezvous operations where a differential GPS scheme can be used for highest accuracy when the approaching vehicle also has GPS capability. A challenge is to obtain the assured access to GPS with a design that minimizes the program impact of DoD security requirements.

FIGURE 15
COMMAND AND CONTROL ZONE



GUIDANCE, NAVIGATION AND CONTROL (GN&C) SYSTEM

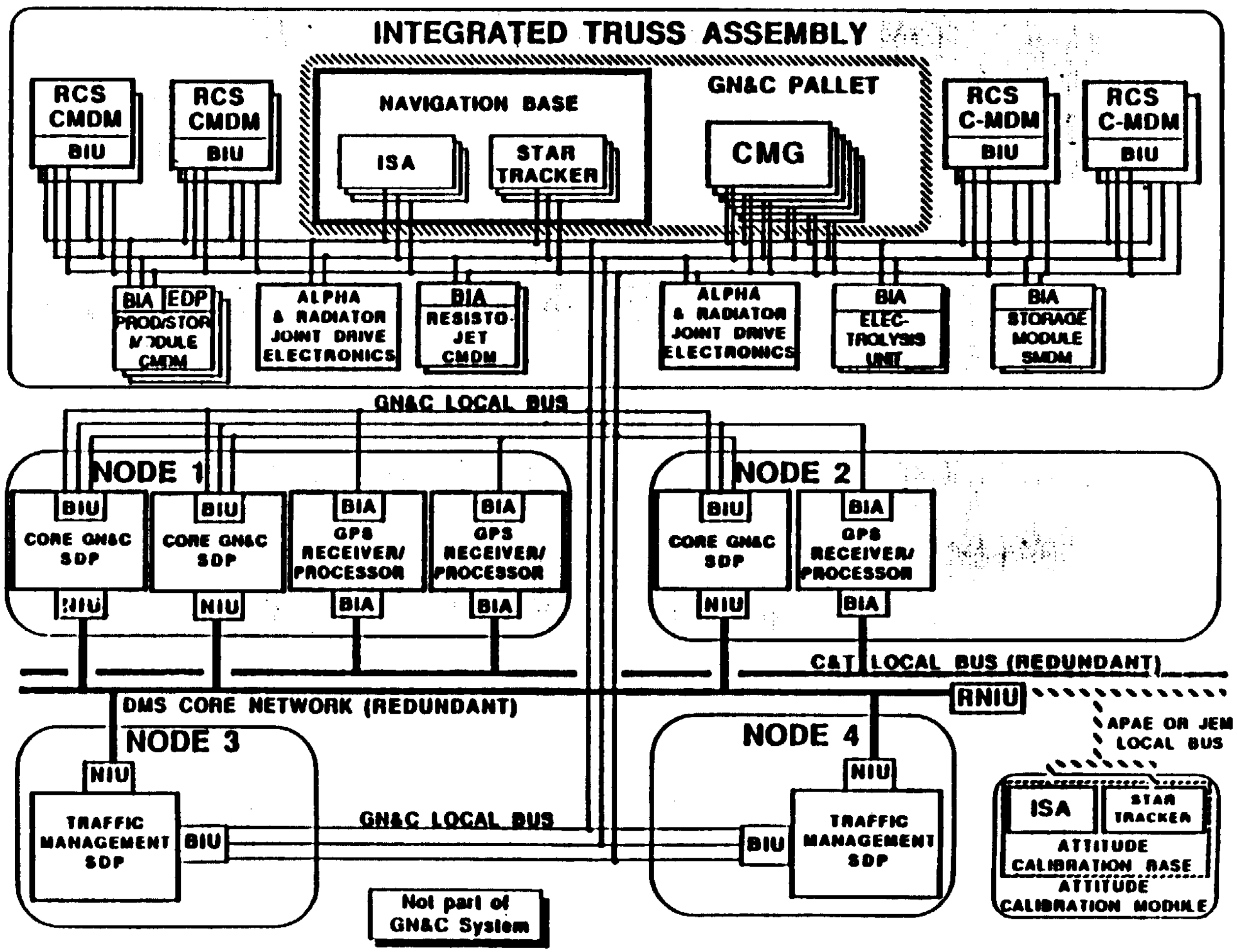
The GN&C System controls the Station attitude, controls reboost, determines pointing angles for the solar arrays, thermal radiators, and antennas, and controls vehicle traffic around the Station. The GN&C System architecture is shown in Figure 16. Major components include star trackers, inertial sensor assemblies, and control moment gyroscopes mounted on a navigation base. Also included are electronics to control: reaction jets, a resistojet for reboost, the truss alpha joints and the thermal radiator beta joints.

In addition to the traffic management function involving control and/or monitoring of vehicles in the control zone, as described earlier, the GN&C controls docking and berthing operations, and collision avoidance maneuvers. The latter includes maneuvers to avoid space debris that is predicted to be on a collision course with Station. The requirements for collision avoidance need to be established and the possible role of on-board sensors needs to be studied.

The Station flies in a local-vertical, local-horizontal (LVLH attitude, keeping the truss perpendicular to the flight direction) within 5 degrees. A torque equilibrium attitude (TEA) strategy is used to minimize attitude control torque over an orbit. A key requirement is to maintain an attitude such that a microgravity environment is established to meet materials science experiment requirements.

Understanding the interaction between control and structure to arrive at an acceptable overall system that meets the needs for stability and microgravity will be a challenge. Perhaps the major challenge is to provide a system capability that evolves successfully through the many stages of the Assembly Sequence.

FIGURE 16
GN&C SYSTEM ARCHITECTURAL HARDWARE SCHEMATIC



AUTOMATION AND ROBOTICS (A&R)

The Station program is committed to the use of A&R technology both in the Station's operation and evolution. The importance of this thrust has been emphasized by recent program reviews that have revealed significant potential shortfall in the ability of EVA alone to maintain the external hardware. There also is a premium on IVA so that as much of this resource as possible is available for experiments.

The avionics systems will make substantial use of automation to manage the control and scheduling of resources in power, communications, momentum control and data flow. In addition, there will be extensive use of automated failure detection and isolation for all systems, and also for recovery in the case of time critical systems.

There are two key robotic systems that have been noted earlier: the FTS and the MSS. The FTS will be able to perform the following tasks:

- Install and remove truss members
- Install a structural interface adapter on the truss
- Changeout Orbital Replacement Units (ORU)
- Mate the thermal utility connectors
- Assemble the thermal radiators

The robotic components of the MSS are the Space Station Remote Manipulator System (SSRMS) and the Special Purpose Dexterous Manipulator (SPDM). The SSRMS provides the following functions:

- Assist in assembly and external maintenance
- Maintain attached payloads
- Transport hardware and payloads about the Station
- Retrieve and deploy free-flying satellites and platforms

- Berth/deberth the Shuttle Orbiter

The SPDM will provide a dexterous capability to reduce and complement the crew's EVA's. The SPDM will be able to:

- Connect and disconnect utilities
- Attach/detach interfaces and covers
- Mate/de-mate connectors
- Provide lighting and closed circuit TV monitoring of work areas for EVA and IVA crews
- Clean surfaces
- Inspect and monitor areas of difficult access
- Manipulate small payloads without standard grapple fixtures

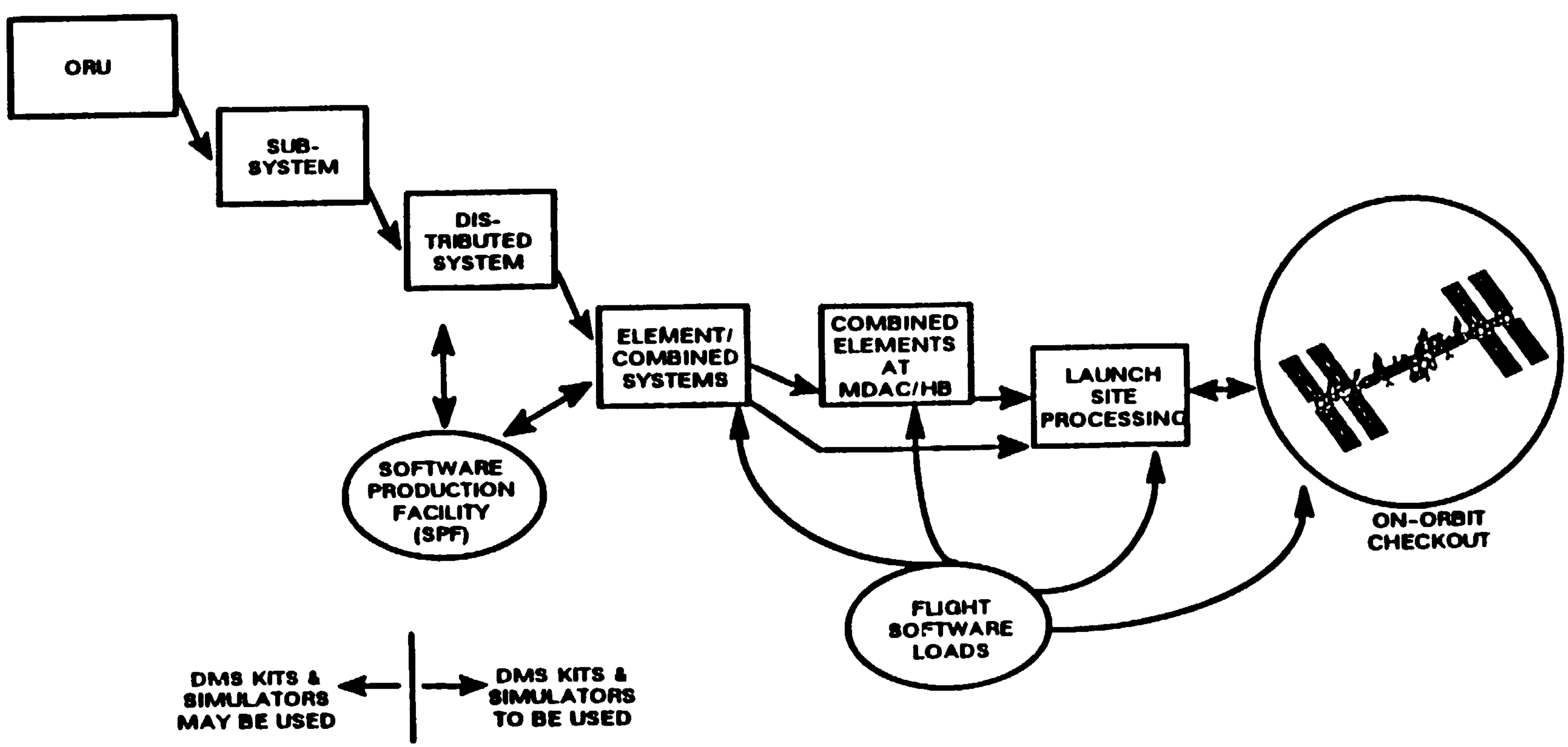
INTEGRATION AND VERIFICATION

Verification is the process that will confirm that the Station's hardware and software meet all of the design requirements specified. This is particularly important because unlike previous space programs, the Station cannot be completely checked out on the ground prior to launch. Due to its size, the Station will have to be launched in segments and assembled on-orbit as described earlier. To help ensure the successful completion of the assembly, and its operational safety while it is being assembled and operated, it is vital that critical testing be done on the ground before its segments are launched. An overview of the integration and verification process is given in Figure 17.

The flight hardware will initially be built in small units, such as ORU's, and then assembled into larger and larger units, until finally they are assembled into a launch package at the Kennedy Space Center (KSC). Throughout this process, the units will be tested to verify their compliance with the requirements. The initial testing will be

FIGURE 17
SYSTEM ENGINEERING & INTEGRATION

OVERVIEW OF I & V FOR THE SSP



done at contractor and subcontractor facilities all over the country, as well as in Europe, Japan and Canada.

Final testing will be accomplished at the contractor's facility for the EPS, at JSC for the Truss Assembly, and at MSFC for the Lab and Hab Modules. At the JSC facility, shown in Figure 18, the first few launch packages will be assembled together and checked out, using both flight hardware and simulators. This ground test will significantly increase confidence that Station can be successfully assembled and operated on-orbit. Once the tests are complete, then the individual launch packages will be shipped to KSC for final checkout and launch. All other launch packages will be shipped directly to KSC from their assembly sites.

After the Lab and Hab Modules are checked out at MSFC, they also will be shipped to KSC for final checkout and launch.

Once the launch package is on-orbit, it will be assembled and attached to the Station. Then, it will be checked out to verify its operational readiness. This will include verifying that it can be operated in an unmanned mode, and that manned operations could be subsequently resumed after its' unmanned mode.

Like the flight hardware, the flight software will also be checked out during a series of tests as the software is assembled into larger and larger units. In its early phases, the software will be checked out at a contractor's or subcontractor's facility. For example, software residing in an ORU will be verified when the ORU is tested. The contractors and subcontractors will develop the flight software at Software Production Facilities (SPF's) all over the country, as well as in Europe, Japan and Canada. NASA will provide Data Management System (DMS) kits to integrate the contractor's hardware and software. The DMS kits will emulate the interface between the contractor's hardware and software and the DMS.

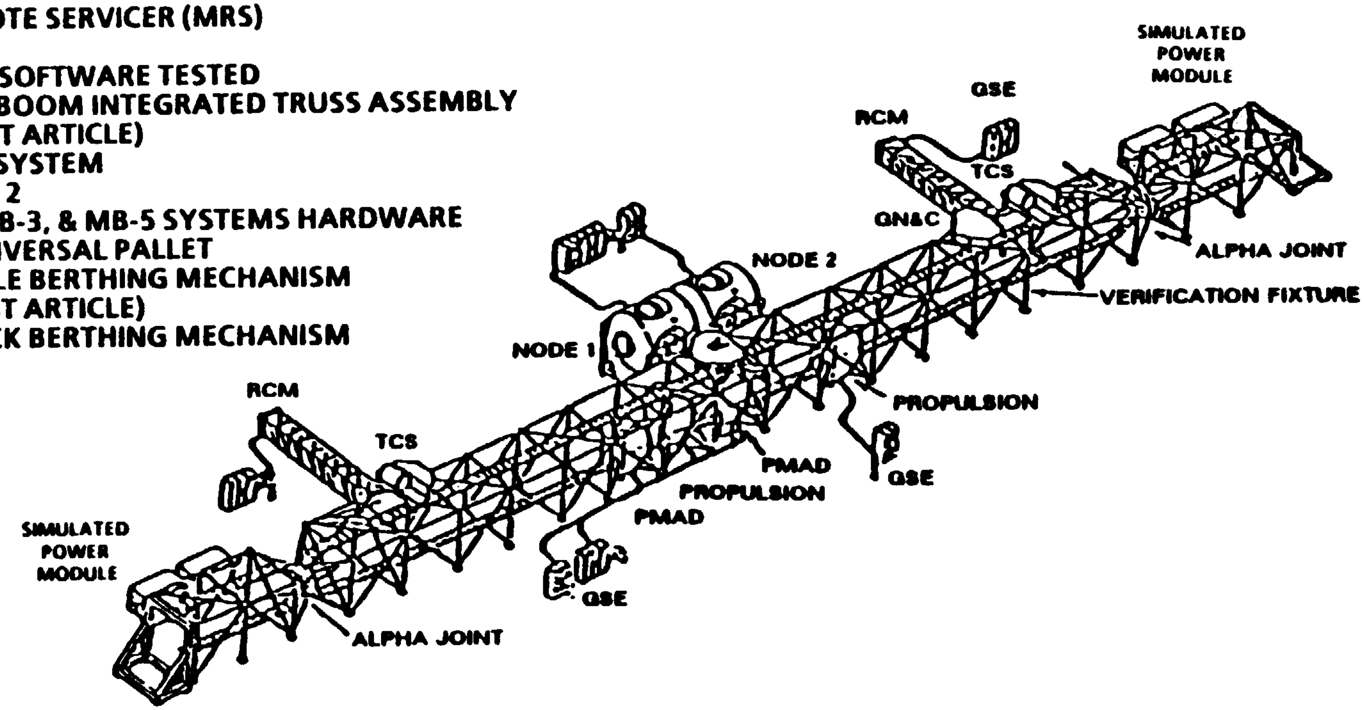
FIGURE 18
SYSTEM ENGINEERING & INTEGRATION

FREEDOM

INTEGRATED TRUSS ASSEMBLY VERIFICATION

HARDWARE SIMULATED
- FLIGHT TELEROBOTIC SERVICER (FTS)
- POWER MODULE
- MOBILE REMOTE SERVICER (MRS)

FLIGHT HARDWARE/SOFTWARE TESTED
- TRANSVERSE BOOM INTEGRATED TRUSS ASSEMBLY (GROUND TEST ARTICLE)
- PROPULSION SYSTEM
- NODES 1 AND 2
- MB-1 THRU MB-3, & MB-5 SYSTEMS HARDWARE
- PAYLOAD UNIVERSAL PALLET
- NODE/MODULE BERTHING MECHANISM (GROUND TEST ARTICLE)
- NODE/AIRLOCK BERTHING MECHANISM



At present, there are no plans for a single facility to integrate the entire flight software package that will be on-board any given flight configuration. The need for such a facility remains to be established.

RELIABILITY, MAINTAINABILITY, AND REDUNDANCY

Reliability and maintainability features of the avionics complement will be especially important in that they will govern the availability of equipment on-orbit, dictate the burden for maintenance levied on the crew and robotics, and impact the logistics resupply flights by NSTS. The current estimate is up to eight NSTS flights per year will be needed for the logistics functions and crew rotation.

An appropriate ORU configuration will be determined for each system considering failure rates and capabilities of both crew and robotics, with emphasis on the latter for external equipment. There will be assessments of reliability and maintainability, but there are no contractual requirements in this area.

Supporting the product assurance effort is an Electrical, Electronic, and Electromechanical (EEE) parts policy that dictates Level S parts or equivalent for critical functions, and recommends Level S for other functions. Involving these requirements in the beginning of development should in many cases avoid the major costs that NSTS experienced in levying higher EEE part reliability requirements on existing designs.

The redundancy policy requires two-fault tolerance for crew safety and Station survival and single-fault tolerance for mission critical support. There is no requirement for other functions. The level of redundancy must be determined prudently for each function, because additional hardware raises the overall failure rate and adds burden to the maintenance function. Unlike what is possible for the NSTS, this burden must be dealt with on-orbit.

EVOLUTION

The planned operational lifetime of 30 years necessarily implies that an evolution capability should be an important requirement. The baseline configuration is to have the hooks and scars to make this capability possible. An important evolutionary path for the Station would be to support two critical functions for the Human Exploration Program. Station would primarily serve as an integrated transportation node providing facilities for vehicle assembly, testing, processing, and post-flight servicing, as well as providing crew support (including IVA and EVA), data management and communications, and logistics to accomplish these activities. It would also provide the resources necessary to verify the research and technology required to support the new initiative. Much of this research and development has to be performed and tested in the space environment; activities which are ideally suited to the Station. The technology development and research areas are broadly categorized as In-Space Operations, Humans in Space, Spacecraft Design Technology, and Lunar/Mars Mission Simulation. A concept for the transportation node building on the dual keel configurations was shown earlier in Figure 8.

RECOMMENDATIONS

Advances in avionics technology can help meet the challenges that have been noted for Station. Some of these challenges are summarized in Figure 19. Since Station will continue to evolve, improvements could be introduced when ready. The most critical areas appear to be those that would make more power and crew time available to users. This implies more efficient power generation, distribution and management, and greater power efficiency for all avionics with particular attention to DMS components. Crew time can be freed up for users with greater application of A&R, including artificial intelligence and expert systems, and by providing a high level of inherent reliability.

FIGURE 19
AVIONIC SYSTEMS CHALLENGES

FREEDOM

AREA	CHALLENGE
Electric Power	DC Switchgear Development Evolution to Solar Dynamic & AC power
Data Management	Complexity Verification
Communication and Tracking	End-to-End Definition Regulatory Environment Evolution to Ka Band & HDTV
Guidance, Navigation, Control	Assembly Sequence Structural Interaction Microgravity Collision Avoidance
Automation and Robotics	Significant Assembly & Maintenance Role
General	Power Efficiency Reliability Maintainability Upgrades & Evolution