NASA-TM-87667 19860023035

NASA Technical Memorandum 87667

SYSTEM IMPACTS OF SOLAR DYNAMIC AND GROWTH POWER SYSTEMS ON SPACE STATION

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July 1986

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LIST OF ACRONYMS

ARCD	Articulated Rigid Body Controls Dynamics Program
cg-cp	center of gravity - center of pressure offset
CMG	Control Moment Gyro
C&T	Communications & Tracking
DYLO	Dynamic Loads Program
ECLSS	Environmental Control/Life Support Subsystem
EMI	Electromagnetic Interference
EMU	Extravehicular Mobility Unit
EPS	Electrical Power Subsystem
EVA	Extravehicular Activity
FOV	Field of View
GN&C	Guidance, Navigation, & Control
IDEAS	Interactive Design and Evaluation of Advanced Spacecraft
IDMS	Information & Data Management Subsystem
I/F	Interface
IOC	Initial Operational Capability
kg	kilograms
m	meter
MMU	Manned Maneuvering Unit
MRMS	Mobile Remote Manipulator System
N-m	Newton-meter
N-m-s	Newton-meter-second
OL	Orbit Lifetime program
OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
PV	Photovoltaic
PVPS	Photovoltaic Power Subsystem
PV75	Photovoltaic 75kW IOC Configuration
PV75P	Photovoltaic 75kW Configuration with Payloads
PV300P	Photovoltaic 300kW Configuration with Payloads
RCS	Reaction Control System
rf	radio frequency
RFI	Radio Frequency Interference
SAP	Structural Analysis Program
SD	Solar Dynamic
SDPS	Solar Dynamic Power Subsystem
SD75	Solar Dynamic 75kW IOC Configuration
SD75P	Solar Dynamic 75kW Configuration with Payloads
SD300P	Solar Dynamic 300kW Configuration with Payloads
SRMS	Shuttle Remote Manipulator System
S&MS	Structures & Mechanisms Subsystem
STS	Space Transportion System
+S	With Shuttle Docked
TEA	Trim Equilibrium Angle
TCS	Thermal Control Subsystem

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SYSTEM IMPACTS OF SOLAR DYNAMIC AND GROWTH POWER SYSTEMS ON SPACE STATION

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ABSTRACT

Concepts for the 1990's Space Station envision an initial operational capability with electrical power output requirements of approximately 75 kW and growth power requirements in the range of 300 kW over a period of a few years. Photovoltaic and solar dynamic power generation techniques are contenders for supplying this power to the Space Station. A study was performed to identify growth power subsystem impacts on other Space Station subsystems. Subsystem interactions that might suggest early design changes for Space Station were emphasized. Quantitative analyses of the effects of power subsystem mass and projected area on Space Station controllability and reboost requirements were conducted for a range of growth station configurations. Impacts on Space Station structural dynamics as a function of power subsystem growth were also considered.

INTRODUCTION

The results of a study to assess the impacts of Space Station growth power generation subsystems on other Space Station subsystems are documented in this report. The Initial Operational Capability (IOC) Space Station (ref. 1) with a 75 kW photovoltaic power subsystem was assumed as the baseline for this study. This study also covers power growth of photovoltaic or solar dynamic subsystems to 300 kW output. The main thrust of the study was to identify interactions between the power subsystem and other Space Station subsystems that might suggest early design changes (IOC scars). These system impacts are discussed, and quantitative analyses of the impacts on controllability and structural characteristics are given.

This study spanned the phase of Space Station evolution that overlapped the August 1984 IOC concept, the February 1985 Power System IOC update, and the start of Phase B contractual studies when the IOC "power tower" configuration was baselined. This report documents results for this power tower concept. At the present time, another configuration, the "dual keel" concept has been baselined. The structural configuration and subsystem designs may continue to change during the definition phase, and discussions of interactions are meant to suggest possible impacts rather than those of a specific current configuration. Although many of the interactions apply to the Space Station in general, the controllability and structural characterization analyses are highly configuration dependent.

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SPACE STATION SUBSYSTEM IMPACTS

The Space Station subsystems as listed in reference 1 and adjuncts, such as payloads and the STS that would operate in the vicinity of the Station were examined for interactions relative to the basic characteristics of each growth power subsystem. Subsystem aspects such as on-orbit assembly, pointing tolerances, aerodynamic drag, field-of-view blockages, RFI, contamination effects, etc., were considered as a function of power subsystem growth and evolution. Table 1 summarizes the impacts of power subsystem growth on subsystems for various growth requirements, space environments, or power subsystem attributes. The impacts are rated as: (1) major timeline or subsystem design change, (2) nominal impact, (3) minor interface or design note or (4) none identified. These impacts, organized by power subsystem characteristic, are discussed in this section. These impacts are also organized by subsystem and are presented in table form in appendix A.

Subsystem impacts that are expected to be covered by standard interface procedures are not documented in this analysis. Rather, an attempt is made to list some of the impacts that might surface during major changes from the IOC or that might require an IOC scar (or design change). For example, Electromagnetic Interference/Radio Frequency Interference (EMI/RFI) for the interface between the Photovoltaic Power Subsystem (PVPS) and the Communications & Tracking (C&T) subsystem will be controlled by standard interface specifications. The Solar Dynamic Power Subsystem (SDPS) growth designs, however, are not well defined at this time; specifically, neither the type of heat engine/alternator nor the power management and distribution scheme has been defined. Therefore a possible scar for the IOC C&T subsystem is the allocation of space, connections, etc., for input notch filters to be tailored to a future solar dynamic design.

Table 1. System Impacts of Solar Dynamic and Growth Power

Requirements, Environments or Attributes	Sub-System or Adjunct								
	GNC	C&T	IDMS	Prop	ECLSS	Thermal	Structure & Mech.	Payloads Modules STS	EVA OMV OTV
Power System Assembly	3	4	3	4	4	4	2	2	1
Power System Pointing	1	4	2	1	3	2	1	3	3
Drag Area	1	2	4	1	4	2	4	3	3
Rotating Machinery	2	3	4	3	4	4	3	3	4
Structural Stiffness	2	3	4	4	4	4	1	3	4
Radiator Requirements	3	2	3	2	4	3	3	3	3
Reflected Energy	3	2	3	4	4	3	3	3	2
EMI/RFI	2	2	2	4	4	4	4	3	3
Contamination	3	3	4	3	4	2	3	3	3
Thermal Utilization	4	4	4	2	2	1	2	3	3

(1) Major Impact
(2) Nominal Impact
(3) Minor Impact
(4) None Identified

Power Subsystem Assembly Impacts

A major impact on extravehicular activity (EVA) and other crew activity may result if on-orbit assembly is required for buildup and alignment of a solar dynamic power subsystem. Reference 1 addresses the timeline requirements for an IOC photovoltaic Space Station buildup wherein the solar panels are automatically deployed. On-orbit SDPS assembly will require longer timelines and more extensive use of Space Station support systems. Support systems which may be impacted, as on-orbit assembly requirements are defined, include the Shuttle Remote Manipulator System (SRMS), the Mobile Remote Manipulator System (MRMS), the Manned Maneuvering Unit (MMU), and the Orbital Maneuvering Vehicle (OMV). If a solar dynamic concept is used for IOC or as a part of a hybrid growth power subsystem, the additional time required for assembly, collector pointing alignment, fluid management, and system checkout will be a function of the SDPS design selected and cannot be defined at this time. Maintenance requirements for an active fluid-mechanical subsystem will also lengthen timelines because of the complex nature of some tasks, such as fluid replacement.

Power Subsystem Pointing Impacts

The solar dynamic power subsystem has more stringent pointing requirements than the photovoltaic power subsystem (PVPS). The PVPS pointing requirement is approximately 1.0 degree, and the loss of power because of degraded pointing depends on the cosine of the resulting pointing error. The SDPS pointing requirement is currently specified at 0.1 degree pointing accuracy, and the power produced reduces to zero quickly as the focused energy moves out of the receiver aperture. The more stringent SDPS pointing requirement will likely be met by individual sensing and pointing systems at each collector location. Ideally, the pointing requirements for the Electrical Power Subsystem (EPS) and the Guidance, Navigation, and Control (GN&C) subsystem would be independent of each other, with the GN&C subsystem orienting the Space Station for coarse pointing in the range of 1 to 5 degrees and the EPS providing fine pointing for the individual collectors. In operation, however, an interplay between the subsystems will likely be required. For example, a single degraded or failed collector pointing subsystem may result in high intensity thermal energy at the edge of the solar receiver aperture. This condition requires immediate action to avoid receiver burnout and will be detected by either the Information and Data Management System (IDMS) or the EPS. Action to avoid burnout will be accomplished by a GN&C induced maneuver. The GN&C subsystem will be required to provide off-Sun pointing (an alignment where the solar panels or collectors are pointed away form the Sun) coordinates throughout an orbit, to orient the selected individual collector using only beta-joint control (as the alpha-joint continues to orient the unaffected collectors), and to meet all operating constraints. An example of such a constraint is the requirement to avoid sweeping a high intensity collector beam through a region where EVA activity is in progress. The EPS/GN&C interface may represent a major subsystem-to-subsystem impact for which design interface requirements must be detailed when the Space Station operational requirements and failure modes and effects are better determined.

In view of the more stringent pointing needs of the SDPS, the requirement that the Reaction Control System (RCS) provide backup pointing for a failed Control Moment Gyro (CMG) system results in an additional design consideration for the propulsion subsystem. Control inputs normally directed to the CMG system must interface with the RCS to provide the pointing accuracy required to maintain station orientation.

Because the SDPS has tighter pointing requirements, the Structure and Mechanism Subsystem (S&MS) may require increased structural rigidity to meet growth conditions. One potential constraint for alpha- and beta-joint design may be a requirement that the joints have the same stiffness as the attached truss sections.

Operation of SDPS collectors slightly misaligned with the Sun may cause burnout of the receiver or support structure as discussed previously. Consequently, additional interaction between the IDMS and the pointing mechanisms of the power subsystem may be necessary to provide early indication and correction of power subsystem pointing problems.

The loss of thermal energy input to the receiver is significant for either pointing errors or operational modes that point the SDPS collectors away from the Sun. This drastic loss of thermal energy impacts growth Space Station subsystems that might be designed to utilize large amounts of EPS waste thermal heat (such as the Environmental Control/Life Support System (ECLSS), Propulsion, or the Thermal Control Subsystem).

Aerodynamic Drag Impacts

Drag and solar pressure differences between the various photovoltaic and solar dynamic cases produce different gravity gradient trim requirements, CMG inputs and/or CMG sizings, and RCS desaturation and reboost requirements.

The effects of drag and solar pressure on a number of photovoltaic (PV) and solar dynamic (SD) power subsystem configurations (both IOC and growth) are given in Section III. These configurations include a wide range of Space Station projected areas, masses, and altitudes. Mass and area properties of these configurations are given in appendicies B and C. The results show the impacts on the GN&C subsystem as variations in the gravity gradient trim angle, the angular momentum storage requirements (appendix D), and the fuel required for altitude maintenance (appendix E). Also, the RCS fuel required for attitude control in the event of CMG failure is presented in appendix D.

As the drag area increases with increasing power subsystem size, orbit decay rates may increase thus shortening Space Station reboost intervals. This will impact the operational timelines of EVA, MMU, and STS activity. Reboost requirements are presented in Section III for each configuration.

A secondary impact pertains to those components of the Space Station which will be designed to take advantage of waste thermal heat. At various times the Space Station may operate in a streamline mode in which various large drag area components are oriented such that the total aerodynamic drag event, power generation can also be reduced as well as available waste heat. Consequently, the waste heat users may have limited operation during streamlined operations.

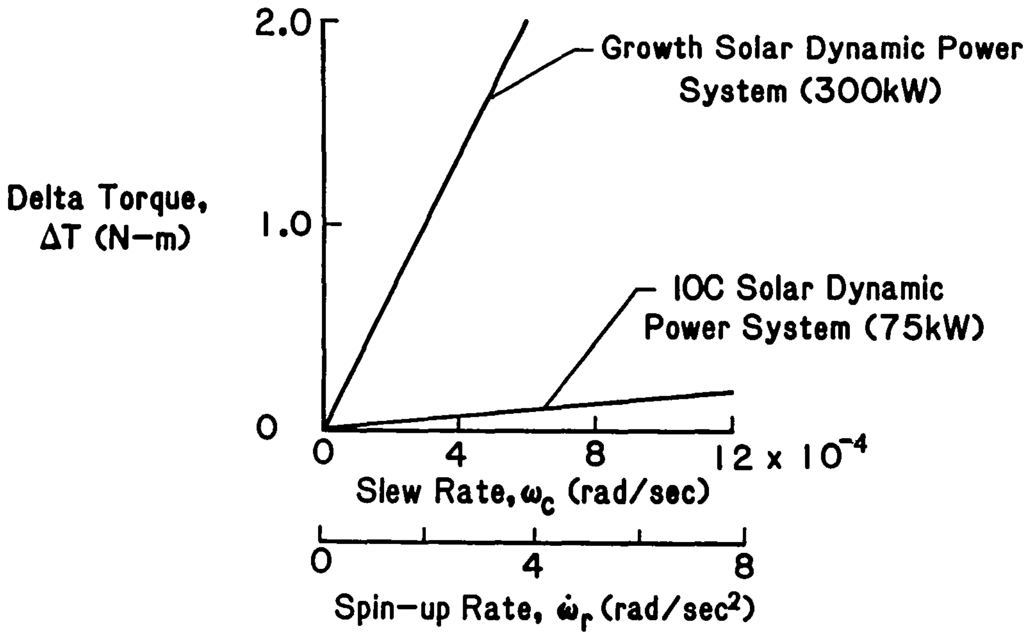
Rotating Machinery Angular Momentum Impacts

The solar dynamic power generation concept has turbines, generators, pumps, and moving fluids and gases; and each of these has an associated amount of angular momentum. This angular momentum may significantly change the loads, vibrations, and total angular momentum of the Space Station. Changes in the angular momentum of the Space Station may impose additional requirements on the angular momentum storage system or may produce a need for angular momentum cancelling techniques in the mechanical design of the SDPS components. Additionally, the angular momentum change because of changes in power output or collector reorientation (slewing) may induce torques that will impact other subsystems on the Space Station.

At present, the detailed characteristics of the solar dynamic system have not been defined to the point where changes in angular momentum of each solar dynamic unit can be predicted accurately. To estimate the magnitude of these effects, the 25 kW Organic Rankine solar dynamic concept (ref. 2) was used to obtain the approximate size and operating speeds of the major rotating component, namely, the alternator-turbine assembly. Based on this information (a polar moment of inertia of 0.006 kg-m^2 and an average operating speed of 60,000 rpm), the angular momentum contribution, of 40 N-m-sec per unit, was estimated. For the IOC configuration with four engines having identical spin-axis directions, the total angular momentum contribution is 160 N-m-sec, which is relatively small in comparison to the 3100 N-m-sec angular momentum capacity of a single Skylab CMG. This estimate does not include the pumps and fluid loops. An estimate of 400 N-m-sec per unit was assumed for the growth SDPS units because a model was not available. For the solar dynamic growth configuration with eight of the large units and identical spin-axis directions, a total angular momentum contribution of 3200 N-m-sec is calculated which is similar to the value for one Skylab CMG.

Variations in the angular momentum of the solar dynamic components induce torques which will affect various operational aspects of the station. One category of induced torques is related to a change in the spin velocity, or operating speed, of the solar dynamic unit. Such a change will occur during any change in power output (for instance, startup or shutdown) and will depend on the magnitude of the velocity change and the time over which the change occurs. In other words, the induced torque depends on the angular acceleration about the spin axis and the inertia of the spinning component. An estimate of the variation of induced torque as a function of spin axis angular acceleration is shown in figure 1 for both the IOC configuration with four small units and the growth configuration with eight large units.

A change in inertial orientation of the solar dynamic collector and engine assembly (i.e. during a slewing maneuver) may also induce a torque. The magnitude and direction of this torque depend on the magnitude and direction of the slew angle and the time over which the slew takes place.



Note: Angular Momentum of Solar Dynamic Units Not Defined at this Time. Values Shown are Preliminary Estimates.

Figure 1. Torque Variation with Solar Dynamic Engine Acceleration and Slew Rate

That is, the induced torque depends on the slew rate of the rotating unit. Figure 1 also illustrates the variation of torque magnitude with slew rate for both IOC and growth configurations. For the typical ranges of spin axis angular acceleration and slew rate (fig. 1), the torque values are relatively small compared to other torques experienced by the station (i.e. aerodynamic torques may be as high as 200 N-m), and therefore, should not pose a problem for the station attitude control subsystem. Should the accelerations or slew rates exceed these ranges, however, the induced torques may be high enough to impact the fine pointing systems used for power subsystem pointing. Because of the uncertainties related to the assumed design of the solar dynamic unit, the impact of its angular momentum has been listed as nominal in table 1 and appendix A. The use of counter-rotating individual solar dynamic units or matched counter-rotating units may eliminate these angular momentum and torque disturbances. The use of matched counter-rotating units may induce minor torques in the connecting structure; however, this is considered a minor design problem.

Although the induced torque values are small, they may help excite certain vibrational modes which could impact other subsystems. The excitement of certain modes produce accelerations that, when added with other accelerations already present, may violate the micro-g environmental requirement. These torques and vibrations could also degrade the fine pointing requirements of other subsystems (such as Communications and Tracking) and assorted payloads. For these reasons, providing the capability to add dynamic decouplers throughout the structure may prove to be an advantageous scar.

Structural Growth Impacts

Different structural characteristics exist for the variety of power subsystem configurations. Analysis, presented in Section III, provides vibrational modes and frequencies as a function of Space Station growth. Structural stiffness variations because of growth, coupled with tightened pointing requirements, as discussed earlier, may impact the GN&C and C&T subsystems. A major impact on the Structures and Mechanism Subsystem (S&MS) is the need to provide roll-ring joints to meet structural stiffness requirements for worst-case growth predictions or to provide scars to assure that change out of these joints is viable. Since the frequencies and mode shapes vary drastically for the various growth configurations, active damping or other structural control techniques may be necessary to minimize vibrations in the growth Space Station.

Radiator Size and Location Impacts

One major difference between the PVPS and SDPS is the size of the associated radiators. The efficiency of the solar dynamic system depends on the temperature difference between the engine heat source (the receiver) and the heat sink (the power subsystem radiator), and consequently, larger power subsystem radiators are required for efficient operation. These large radiators may impact several Space Station subsystems depending on their sizes and locations. Currently, several radiator configurations are being considered. For this study, the power subsystem radiator design is a single-sided radiator wrapped circumferentially around a collector and radiating perpendicular to the collector-Sun axis. Other potential designs not considered in this study include a single-sided radiator attached to the rear of a collector and radiating parallel to collector-Sun axis, and a two-sided radiator placed parallel to the collector-Sun axis either in front of or behind the collector.

Three subsystems impacted by radiator characteristics are the GN&C, C&T, and Thermal Control Subsystem (TCS). The 75 kW SDPS radiator area is approximately 400 m^2 compared to the collector area of 530 m^2. These large radiator areas contribute significantly to the orbital profile and magnitudes of aerodynamic drag and to the fuel and angular momentum storage requirements of the SD configurations. Also, because of the circumferential radiator configuration used in this analysis, there is no orientation of the dish-radiator assembly that can be used to provide a significantly reduced drag profile (which is required for streamline operation). Other radiator configurations and locations might provide better streamline characteristics.

The field of view (FOV) of the various communications and experiment antennas must be considered in choosing alternate radiator locations and orientations. A possible IOC scar may be that the C&T subsystem is required to designate relocation sites for antenna structural attachments for the alternate power subsystem growth paths.

The placement of power subsystem radiators may also impact the Space Station TCS. That is, whenever the FOV for the TCS radiators include portions of the PV and SD panels, collectors, or radiators, the TCS performance will degrade. This results in a need for more TCS radiator area. Future thermal trade studies for PV or SD growth paths may identify TCS scars that provide for TCS radiator relocation or add-on connectors and attachment points.

Reflected Energy Impacts

When the SDPS collector is aligned with the Sun and concentrating thermal energy at the receiver, there is a spatial region associated with the focused energy which is unsafe for any instrument or subsystem (including EVA) susceptible to high thermal energy density. As the collector moves off-Sun, the energy level of the concentrated beam drops, but the region of high energy density moves away from and beyond the receiver focal point, thus extending the unsafe zone. The impact of the unsafe zones on systems such as STS, EVA, payloads, MMU, etc., must be established by determining the intensity as a function of the Sun-collector angle and the distance from the collector. The impact of the unsafe zone on the S&MS is a requirement for thermal protection for those support structures that may be exposed to this thermal energy. The TCS impact because of increased heating was noted in the preceeding section.

Collectors in nonstandard positions (which may occur during change-out or repair) must have zones of safety established. In addition, even relatively low energy densities must be avoided by some light-sensitive subsystem components.

The collectors, solar panels, and radiators may also redirect rf energy in unanticipated ways. The C&T subsystem will provide the tests necessary to predict multipath and blockage as functions of the articulated positions of the members for normal operations. Directed rf energy anomalies may occur in various situations including: intermediate Space Station buildup phases for which antenna patterns were not obtained, for portions of the Space Station in nonstandard positions (such as a collector being moved by MRMS), or when new operational requirements are being implemented. Potential impacts from these anomalies are: an rf breakdown of low pressure gases in an unshielded container associated with a payload, EVA activity or Space Station subsystem; rf interference with an experiment; or nulls and sidelobes in normal antenna patterns. A resultant IOC scar may be that all subsystems and payloads that contain gases at low pressures are required to be shielded against rf breakdown.

Power Subsystem EMI/RFI Impacts

The IOC subsystem interfaces for EMI/RFI will be well established and tested prior to flight. For growth power subsystems, however, the SD electrical alternators, with alternating current outputs; the PV solar cells, with direct current outputs; and the associated conversion and conditioning requirements of each implies different EMI/RFI signatures. The new signatures may impact subsystems such as GN&C, C&T, and IDMS as well as payloads and nearby EVA or spacecraft. These subsystems could allow space and connection capability for additional filtering as the power subsystems grow.

Contamination Impacts

Reboost and control operations will result in large quantities of hydrazine by-products, with the total depending on power subsystem growth path and associated drag area. Other sources of contamination are subsystem leakage and waste disposal. Table 2 gives a partial list of the fluids and gases associated with the power subsystems.

The impacts of contaminants around the Space Station on subsystems are: a change in the thermal properties of collectors, radiators, and other radiation surfaces; degradation of the solar cells; and contamination of optical surfaces. Vacuum-exposed experiments and near-vicinity activities (such as EVA) may also be impacted. For some concentrations of escaping gases, rf breakdown may be possible.

Table 2. Potential Contaminants from Power Subsystems

Application	Candidate Material
Organic Rackine Solar Dynamic	Toluene ($C_6H_5CH_3$)
Rankine Solar Dynamic	Steam
Brayton Solar Dynamic	Air
Sterling Solar Dynamic	Helium-Xeon
Heate Storage	NaF, KF, LiF, CaF_2 NaCl, Na_2CO_3, K_2CO_3
Fuel Cell	Hydrogen-Oxygen

Thermal Energy Utilization Impacts

Several kilowatts of the 75 kW of electrical power generated for IOC Space Station will be used to supply resistive electrical heat to meet a variety of thermal needs. Some of these needs are listed in table 3.

Table 3. Potential Thermal Energy Users on Space Station

ITEM	SUBSYSTEM	DUTY CYCLE (HR/DAY)	POWER (WATTS)	THERMAL LOAD (BTU/HR)	OPERATING TEMP. (° F)
Oven	House Keeping	1.5	370 DC 45 AC	1416.42	--
Washer/Dryer	House Keeping	4.5	340 AC 15 DC	1211.63	--
Hot Water	House Keeping	2.0	200 AC 15 DC	733.81	125°
Humidity/Temperature Control Ventilation	ECLSS	24.0	400 (Total)	1365.22	--
Thermal Stability Lower Keel Propellant Tanks (6)	Propulsion	--	35	119.46	40°–100°
Thermal Stability Logistics Module Tanks (3)	Propulsion	--	35	119.46	40°–100°
Line Heating Station	Propulsion	--	640	2184.36	55°
Line Heating Logistics Module	Propulsion	--	20	68.26	55°
Totals	--	--	2115	7218.62	--

*Thermal Requirements for IOC Payloads and Servicing have not been Defined

If the SDPS is used and the Space Station power requirements and generation capabilities grow, the amount of low-grade waste thermal energy available to supplement high-grade electrical energy will be substantial. At the same time, the Space Station heating requirements will increase. A growth from PVPS to hybrid PV/SD could include changes to utilize waste thermal heat that would reduce the net electrical power requirement. Designs of IOC subsystems (such as TCS, propulsion, and ECLSS) should include scars to permit the use of waste heat available on growth SD configurations. Module designs should not preclude the utilization of available waste heat even though the IOC designs will likely use only electrical energy to satisfy heating requirements.

The IOC design for the S&MS may include the requirement to allow change-out of the alpha and beta joints from roll-ring to a combination of roll-ring and rotary fluid joints. Another consideration for S&MS scarring is the ability to attach and route thermal lines in a growth configuration.

QUANTITATIVE ANALYSES OF SELECTED IMPACTS

This section provides quantitative analyses of the different power generation concepts in two main areas: the effects of power subsystem mass and drag area on control and propulsion subsystem sizes; and the variation in structural characteristics of the Space Station configuration because of power subsystem masses and mass distributions.

Aerodynamic Drag Analysis

The "power tower" Space Station configuration (ref. 1) was used as a baseline for the analysis of the effects of aerodynamic drag and solar pressure on trim angle, angular momentum storage, and orbit maintenance requirements. The Space Station configurations and analysis techniques are described and are followed by a discussion of the results.

Twelve Space Station configurations were used in this analysis. They ranged from a 75 kW photovoltaic core Space Station to the 300 kW solar dynamic fully operational Space Station with all payloads and the Space Shuttle attached. Four of these configurations are shown in figure 2. Space Station masses and payload masses were obtained from reference 1. Power subsystem masses and areas (including radiators) for the 75 and 300 kW levels were obtained from subsequent modifications to reference 1. These 12 configurations represent various power subsystem growth options and provide a range of mass and area properties (tabulated in appendicies B and C) which were coupled with different operating altitudes and flight modes to estimate the variations of Space Station aerodynamic drag performance with varying power subsystem design. To illustrate the trends, six configurations are presented in this section: the photovoltaic (PV75) and solar dynamic (SD75) 75 kW IOC Space Stations with no payloads, the same power level settings but with increased mass because of added payloads (PV75P and SD75P), and the 300 kW growth photovoltaic (PV300P) and solar dynamic (SD300P) stations with a full complement of payloads and 12 modules. Figure 2 shows representative IOC and growth configurations with the Shuttle docked, and figure 3 shows the Space Station power subsystem mass and area comparisons for these six configurations (without Shuttle attached). The mass properties for all 12 configurations are given in appendix B.

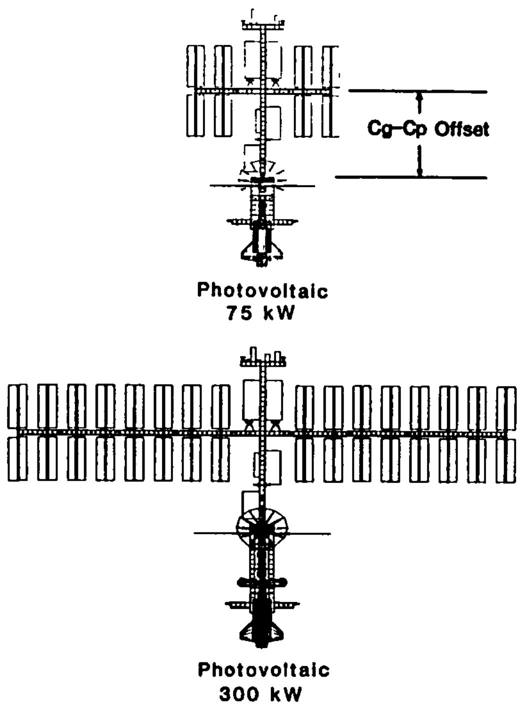


Figure 2. Typical Space Station Configurations

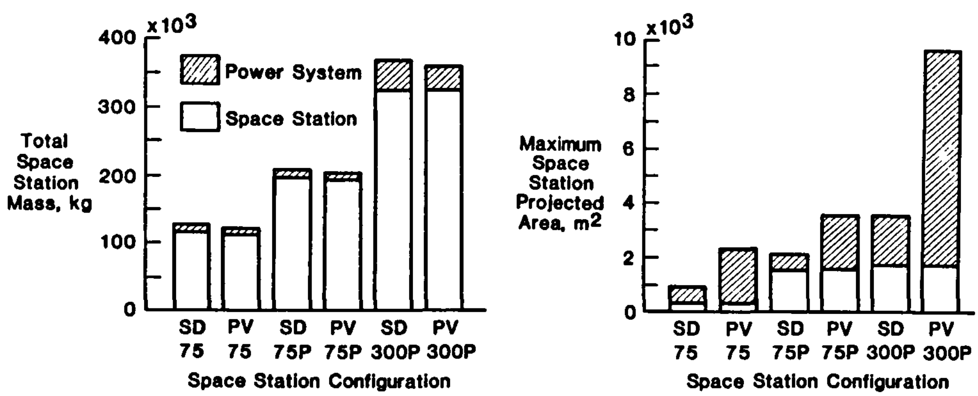


Figure 3. Space Station Mass and Projected Area

The effects of mass and area properties on attitude and orbit maintenance were analyzed using two computer programs included in the Interactive Design and Evaluation of Advanced Spacecraft software package (ref. 3). One program is the Articulated Rigid Body Control Dynamics (ARCD) program (ref. 4). This program uses data on spacecraft mass and area properties and orbital parameters such as altitude, inclination, spacecraft orientation and maneuver rates, day of year, and mean solar flux to calculate angular and linear momentum requirements and CMG and fuel estimates for attitude and altitude maintenance. The mean solar flux is used to calculate an atmospheric density profile (ref. 5) which varies as a function of altitude, inclination, and time of year. A two-sigma, worst-case density model is used for this analysis. The second analysis program, Orbit Lifetime (OL) program (ref. 6), uses similar orbital information and density profile data, as well as the spacecraft ballistic coefficient,to calculate orbital decay rates and days in orbit. This output is used to determine reboost and resupply intervals. Using the set of configurations and the programs discussed above, series of calculations were performed to determine resulting controllability requirements. Analyses were performed on the six configurations at altitudes of 407, 463, 500, and 555 km (or 220, 250, 270, and 300 nm). Two flight modes were examined: a normal flight mode where the station is maintained in a gravity-gradient stabilized orientation with the solar arrays or collectors articulating to track the Sun; and a second mode, where the station is maintained in a gravity-gradient stabilized orientation with the solar panels or collectors locked perpendicular to the flight path direction (simulating a condition of higher-than-normal drag area).

One characteristic of the power tower configurations addressed in this analysis is the existence of a sizeable offset between the center of gravity and center of pressure as illustrated in figure 2. This cg-cp offset produces a continuous aerodynamic torque on the Space Station about its y-axis. Although the magnitude of this torque changes as the power subsystem area articulates (as it tracks the Sun) and as atmospheric density changes, this torque always acts in the same direction, driving the momentum storage requirements to higher levels. By pitching the station slightly off vertical, gravity-gradient torques sufficient to balance (or cancel) the aerodynamic torques can be produced. The resulting pitching angle is defined as the trim angle or Trim Equilibrium Angle (TEA). The results of a controllability study presented herein were calculated using this trim method.

Another characteristic of this configuration is oscillation of control torque and angular momentum of the station through an orbit. This oscillation results from coupling of the projected areas produced by the articulation of the power subsystem arrays and collectors, and variations in atmospheric density through an orbit (because of diurnal effects). The case used in this study, a case where the maximum atmospheric density and maximum projected area occur at approximately the same time, produces a worst-case torque profile and peak momentum storage requirements. The density profiles and articulation time histories also depend on the Sun-Earth-Space Station orientation, a function of the orbit inclination, the season, and the year. Thus, the torque and angular momentum profiles as well as peak values may vary significantly, and the possibility exists that a more extreme worst case may be found.

Calculated control subsystem requirements for the six configurations without an attached Shuttle are given in figure 4. All calculations were performed for a flight mode where the power subsystem areas articulate to remain oriented toward the Sun. The trim angle, the angular momentum storage requirements, and fuel required for altitude maintenance during the 90-day resupply cycle at every operating altitude for each configuration are given in figure 4. As expected, the growth photovoltaic configuration requires significantly larger trim angles because of higher aerodynamic torques. The 75 kW photovoltaic configuration without payloads (PV75) also requires relatively large trim angles. This result is attributed to the much smaller mass and inertia of this configuration, and larger trim angles are required to maintain the necessary gravity-gradient torque. The 75 kW photovoltaic configuration with payloads (PV75P) does not require similarly large trim angles, because the masses of the payloads provide some of the required gravity-gradient torques. The lowest trim angles are required for the solar dynamic 75 kW configuration with payloads (SD75P), because this configuration has a relatively small area and a large mass and inertia. Although trimming the Space Station is important for reducing control requirements, too large a trim angle may hinder payload placement and pointing and may change the micro-g environment.

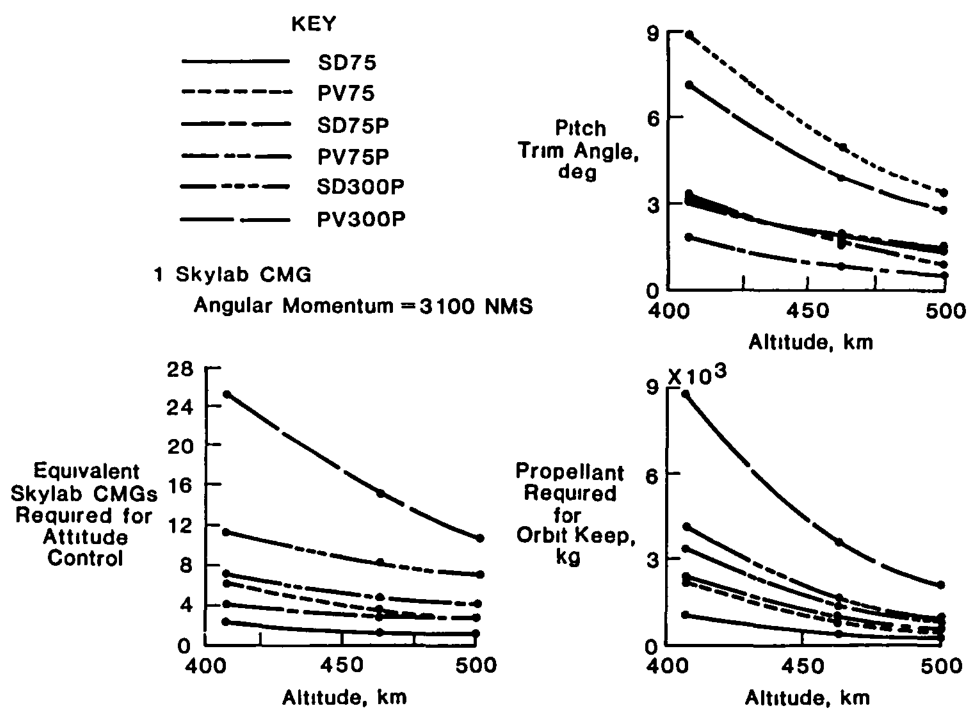


Figure 4. Control Subsystem Requirements--Normal Operation (No Shuttle)

The peak angular momentum requirements were calculated after determining the proper trim angle to eliminate secular angular momentum buildup. For convenience, this is expressed as an equivalent number of Skylab-type CMG's where one CMG equals 3100 N-m-s. These angular momentum requirements are calculated from the integral over the time of the delta torques experienced by the station during one orbit. Eight CMG's are provided in the IOC Reference Configuration (ref. 1) to meet the angular momentum requirements. (This estimate included emergency and reliability considerations.) However, as is shown in figure 4, the requirements for both the growth solar dynamic (SD300P) and growth photovoltaic (PV300P) configurations exceed this value. Consequently, in order to grow the station with either power concept, a resizing of the control subsystem will be required.

The trim angle and angular momentum requirements were based on a two-sigma density model to simulate a single orbit worst-case condition. However, over a 90-day resupply interval, the average density affecting the Space Station should be significantly lower. Consequently, the analysis of fuel requirements for orbit (altitude) maintenance was based on a one sigma density. Fuel requirements for this 90-day resupply interval are also given in figure 4. As was the case for the trim angle and the number of CMG's, the amount of fuel required to maintain a specific altitude was a direct function of the density profile. The fuel requirements for orbit maintenance are also a function of the spacecraft mass and the ballistic coefficient. That is, the ballistic coefficient determines the Space Station decay rate, and the mass is used to calculate the linear impulse needed for the delta velocity to maintain altitude. For example, the photovoltaic growth (PV300P) configuration has a high decay rate, and its mass is also quite large. Consequently, it requires significantly larger amounts of fuel for orbit maintenance than the other configurations. For this growth configuration and some of the other configurations at certain altitudes, the fuel requirement is significantly larger than the IOC Reference Configuration (ref. 1) requirement of 2200 kg. This analysis therefore indicates that a resizing of the propulsion subsystem fuel capacity will be required for growth to 300 kW and operations of certain configurations at lower altitudes.

The complete set of configurations were analyzed in a second flight mode. In this mode, the alpha-joints were locked, constraining the power subsystem panels and collectors to an orientation perpendicular to the flight-path direction. Results for this flight mode are shown in figure 5. This constant drag area produces larger average aerodynamic torques and consequently necessitates larger trim angles than the previous flight mode. Fuel required for orbit maintenance is also increased. For the photovoltaic 300 kW (PV300P) configuration, this increase is about 30 percent. The fuel requirements for the solar dynamic configurations do not increase as significantly, and CMG requirements are reduced. This is attributed to the large area and placement of the solar dynamic power subsystem radiators. During normal operation, the drag area for each solar dynamic unit varies with articulation. Because of the relative size and orientation of the radiator, the maximum area obtained during articulation is slightly larger than that for the collector alone. During this period of maximum area, the largest aerodynamic forces and torques are produced. For the locked-joint case, the largest area obtained is equal to the collector area. Consequently, the torques obtained are less than those for normal operation. The resulting angular momentum storage requirements, which are based on the maximum torque obtained, are also smaller. The fuel requirements for both flight modes (for the solar dynamic configurations) are equal because the average area and the resultant aerodynamic drag for both modes are equal.

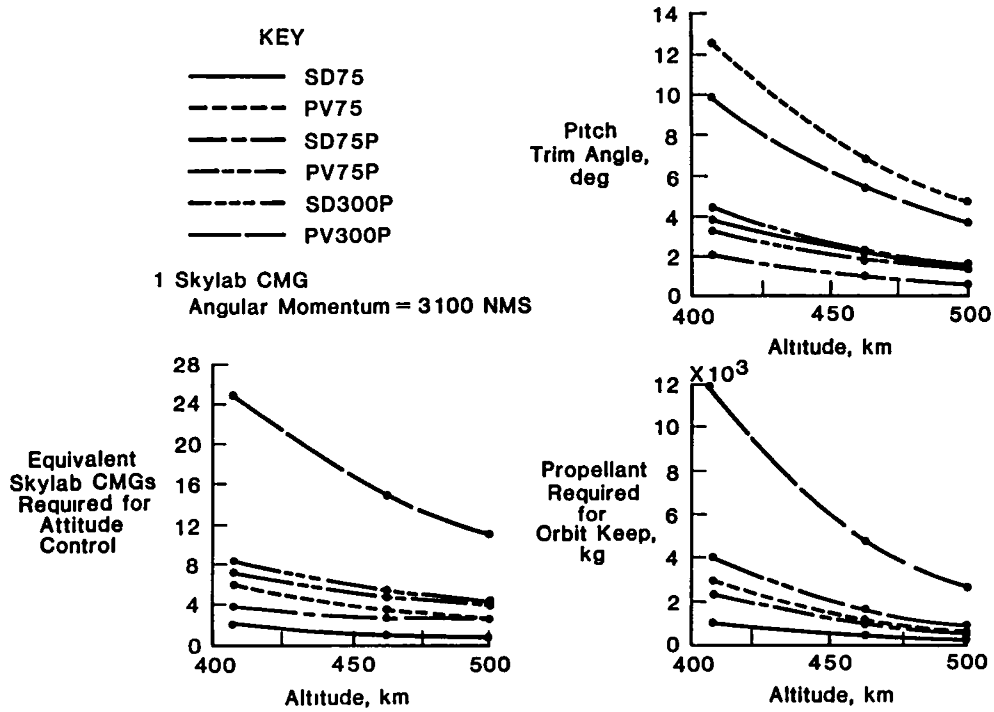


Figure 5. Control Subsystem Requirements--Locked Alpha Joint (No Shuttle)

Because the Shuttle may be attached to the station for as much as 25 percent of the time, it is important to consider the effects of the attachment on station controllability. Figure 6 gives the controllability results for the configurations under normal conditions with the Shuttle attached. The CMG and orbit-keep fuel results are similar to those for the configurations under normal operation (without the Shuttle attached). The CMG requirement is based on cyclic variations in aerodynamic torque, which are due, primarily, to the articulation of the solar arrays, collectors, and radiators. Attachment of the Shuttle does not add to the total articulating area, thus, there is no change in CMG requirements. However, the trim angles required to balance aerodynamic and gravity gradient torques do change. In fact, negative trim angles are found for some Shuttle-attached cases, and the absolute magnitude of the trim angles are smaller than for the normal cases without Shuttle attached. This result is due primarily to the significant increase in the products of inertia, arising from the Shuttle's large mass and placement at some distance from the station cg in both the z and x directions. Thus, the angle necessary to obtain sufficient gravity gradient torques is reduced. The Shuttle's presence also increases the ballistic coefficient of each configuration. The effect of the addition of the Shuttle on altitude maintenance fuel requirements is shown in figure 6.

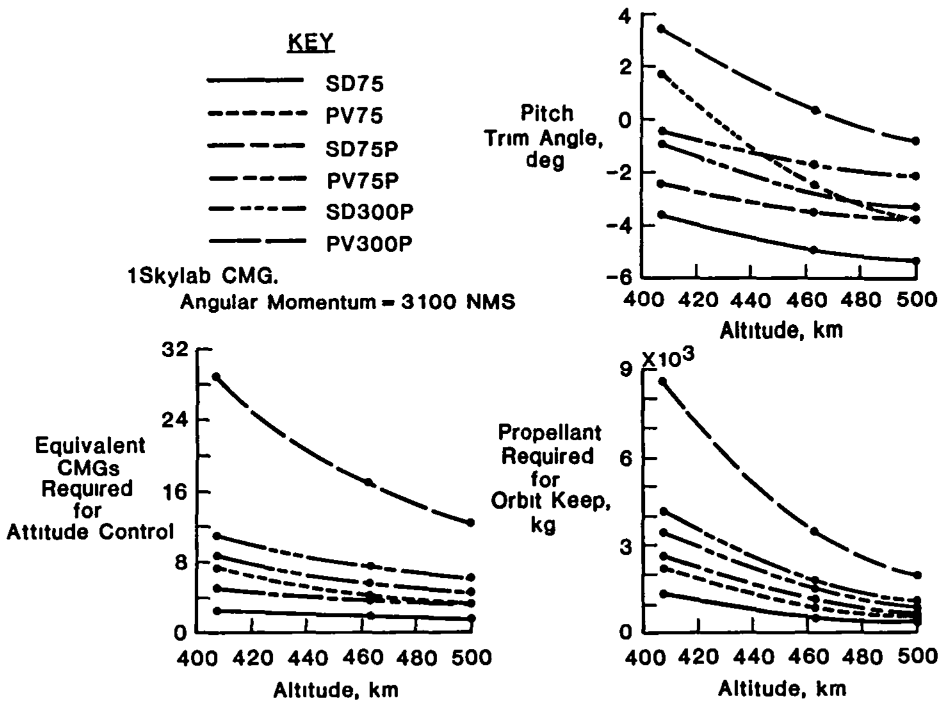


Figure 6. Control Subsystem Requirements--Normal Operation (With Shuttle Attached)

The orbital decay time comparisons for the two power-generation concepts are shown in figure 7. The decay time histories are only shown down to an altitude of 370 km. Below this altitude, the time required for decay to reentry is short, and reboost fuel requirements are prohibitive. This decay is very sensitive to the atmospheric density, which, for this analysis, was simulated by a worst-case, two-sigma, variable density model. Consequently, these results give a worst-case estimate. As the power subsystem and Space Station grow, the masses for the two power concepts grow at similar rates; however, the projected area for the photovoltaic concept grows significantly faster than for the solar dynamic concept, thus increasing overall Space Station projected area (fig. 3). The differences in resulting reduction of the ballistic coefficient for the growth configurations cause the orbit to decay faster for the photovoltaic growth configuration than for the solar dynamic growth configuration. This is illustrated in figure 7, where the PV300P configuration decays from an altitude of 500 km to 370 km in slightly over 100 days. In comparison, the PV75 configuration decays in 170 days, and the SD300P configuration decays in 240 days. When payloads are added to the SD75 configuration, the total Space Station drag area is doubled, whereas the mass is increased by about 75 percent. This reduces the ballistic coefficient for the SD75P configuration, which results in a much shorter decay time as illustrated in figure 7.

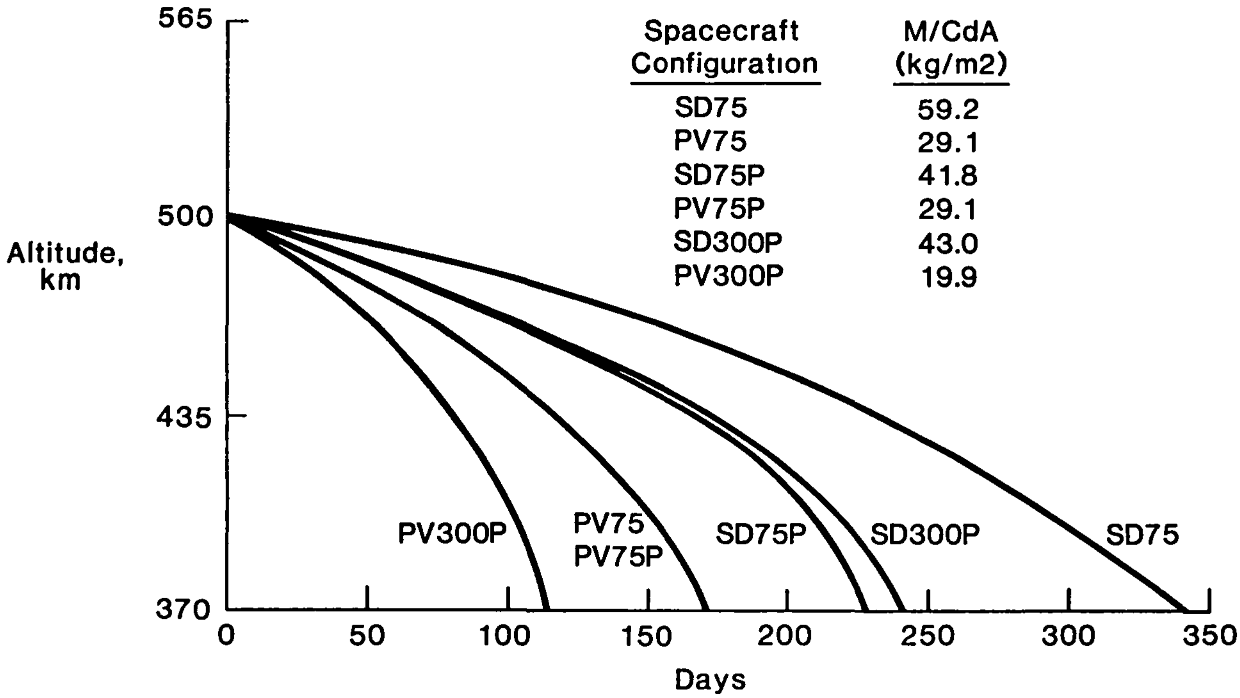


Figure 7. Orbital Decay Time Comparison (Maximum Solar Cycle, 2 Sigma Worst Case Density)

The diminished decay time for the PV300P configuration implies shorter reboost intervals for the station. This will increase the frequency of Shuttle flights needed to resupply the reboost fuel. Micro-g experiments which require long, uninterrupted time intervals will also be impacted. The decay time for the SD300P configuration, even though less than for the SD75 configuration, is significantly longer compared to the photovoltaic configurations. Thus, the SD300P configuration requires less frequent reboost operations and increases the time interval available for micro-g experiments.

Structural Stiffness Analysis

The growth of the Space Station power subsystem impacts rigid body controls, the dynamic structural characteristics, and load-carrying capabilities. This section discusses the results of a dynamic modal analysis of the IOC and growth configurations (no payloads and no Shuttle) outfitted with either solar dynamic or photovoltaic power-generation systems. The photovoltaic IOC equivalent beam model used in this study was derived from the IOC Reference Configuration (ref. 1). The dynamic modal analysis and loads analysis were performed using the Structural Analysis Program (SAP) and Dynamic Loads (DYLO) program which function similarly to parts of NASTRAN. Both SAP and DYLO are part of the IDEAS software system (ref. 3).

Table 4 gives the first nine modal frequencies for four configurations, namely, the IOC and growth PV and SD configurations. A typical primary mode shape for each is shown in figure 8. The frequencies and mode shapes of the IOC photovoltaic case were in general agreement with earlier results (ref. 1). That is, the mode shapes were dominated by array-bending modes, and the keel-bending modes had frequencies in the range of 0.2 to 0.25 Hz. The solar dynamic IOC has higher frequencies (attributable to the removal of the flexible arrays) than the photovoltaic IOC. The solar dynamic growth configuration has a much heavier mass and larger inertias and has lower frequencies than the photovoltaic IOC configuration. Also, for the SD growth configuration, the transverse boom bending mode takes precedence over the other bending modes of the structure as is illustrated in table 4. The boom-bending mode is also the primary bending for the photovoltaic growth configuration. It has masses similar to those for the solar dynamic growth configuration but has a much longer transverse boom. The frequencies of the transverse boom bending mode for the photovoltaic growth configuration are well below those for the shorter boom solar dynamic growth configuration, and they are also lower than the frequencies of the array bending modes of the IOC configuration.

Table 4. Modal Frequencies and Descriptions

FLEXIBLE MODE	FREQ.	DESCRIPTION	FREQ.	DESCRIPTION
		PV 75 kW		SD 75 kW
1	.14	Array Bend	.21	Keel Twist
2	15	Array Bend	.23	Keel Bend
3	16	Array Bend	.26	Keel Bend
4	.165	Array Bend	.45	Main Radiator Bend
5	20	Keel Bend	.49	Keel Bend
6	21	Keel Twist	.54	Keel Twist
7	25	Boom Twist	.56	Keel Bend
8	.34	Boom Twist	.65	Keel Bend
9	.44	Boom Twist	.66	Boom Bend

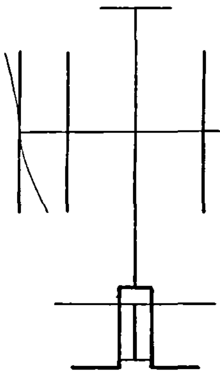
Max. Bend. Moment at Intersection = 10520 N-m
Max. Deflection at Power Boom End =.0082 m

Max. Bend. Moment at Intersection = 6390 N-m
Max. Deflection at Power Boom End =.0028 m

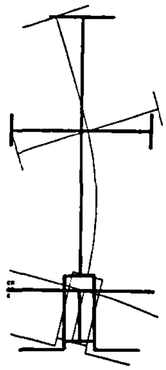
FLEXIBLE MODE	FREQ.	DESCRIPTION	FREQ.	DESCRIPTION
		PV 300 kW		SD 300 kW
1	.05	Boom Bend	.10	Keel Bend
2	06	Boom Bend	.16	Boom Bend
3	07	Boom Bend	.19	Keel Twist
4	.10	Boom Twist	.20	Keel Bend
5	.11	Boom Twist	.22	Keel Bend
6	.15	Array Bend	.34	Boom Bend
7	.15	Array Bend	.35	Boom Twist
8	.16	Array Bend	.35	Boom Twist
	.16	Array Bend	.45	Main Radiator Bend

Max Bend Moment at Intersection = 6400 N-m
Max. Deflection at Power Boom End = 016 m

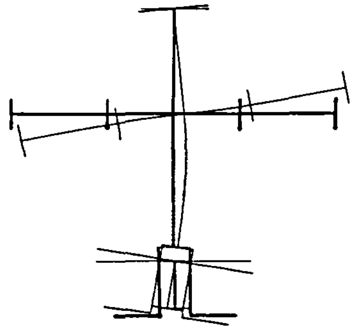
Max. Bend. Moment at Intersection = 20,600 N-m
Max. Deflection at Power Boom End = .011 m



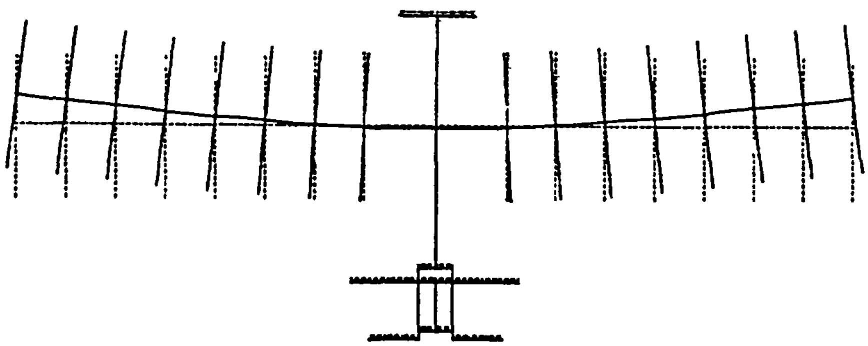
PV 75 kW
Array Bending



SD 75 kW
Keel Bending



SD 300 kW
Keel Bending



PV 300 kW
Boom Bending

Figure 8. Typical Primary Mode Shapes

The mode shapes and frequencies derived from SAP were used to calculate the loads and response of the structure at several points on the structure. The forcing function used in this analysis was an unsuccessful Shuttle docking, which has been identified as a worst-case load condition (ref. 7). For this analysis, the unsuccessful docking was simulated by applying the impulse normally imparted to the station during a routine docking. (The mass of the Shuttle was not included in the dynamic model mass.) The load (bending moment) at the intersection of the transverse boom and main keel, which, for the power boom should be the largest bending moment, is presented in table 4. The deflections at the end of the power boom for each power configuration are listed in table 4 for this load condition. These results indicate that the maximum bending moment calculated for any configuration is well within the design limit of 44000 N-m (35000 ft-lb) found in reference 1.

The relative magnitudes of these loads for the different configurations demonstrates two important characteristics of the structures. First, the bending moment for the photovoltaic 300 kW configuration is significantly smaller than that for the solar dynamic 300 kW configuration. Compared to the solar dynamic configuration, the large inertia of the photovoltaic configuration, due primarily to larger size, can more easily absorb the energy imparted to the station from the unsuccessful Shuttle-docking impulse. The larger deflections obtained for the photovoltaic growth configuration lower the strain energy along the boom and, consequently, reduce the bending moment.

The second characteristic relates to the 75 kW configurations. The solar dynamic configuration has a smaller bending moment at the keel/boom intersection than its photovoltaic counterpart. The inertias for the two configurations are relatively close and, therefore, are not a major factor in explaining differences in the bending moments. In this case, the lower frequencies of the photovoltaic configuration lead to larger bending moments.

The deflection at the end of the power boom caused by the unsuccessful docking impulse is larger for the photovoltaic growth than that for the solar dynamic growth (1.6 compared to 1.1 cm). This deflection should not be a problem for the photovoltaic concept because it has less strict pointing requirements. The solar dynamic concept, on the other hand, which requires pointing accuracies of about 0.1 degree, may be impacted by these deflections (the deflection, listed in table 4 for the SD growth configuration, results in a 0.025 degree pointing error), and more detailed pointing accuracy studies are required to assess this effect.

CONCLUSIONS

This study indicated that the major subsystem impacts associated with various Space Station power subsystem growth paths may be primarily due to: aerodynamic drag increase as a result of increasing panel or collector area, structural requirements as a result of mass and size increases, and solar dynamic power subsystem assembly and pointing requirements. The GN&C, Propulsion, Thermal, and S&MS subsystems are the Space Station subsystems most affected. Subsystem impacts have been discussed according to power subsystem characteristics and tabulated according to subsystem. Detailed analyses of the effects of aerodynamic drag and mass distribution of the "power tower" Space Station configuration have been presented and are documented in the appendices.

Many growth impacts discussed herein will be drastically changed as the Space Station design evolves. Nevertheless, conclusions about the impacts associated with the angular momentum of the solar dynamic rotating machinery, with the stringent pointing requirements, and with the assembly constraints will remain important design issues. The drag studies also are useful because they indicate trends in reboost and control requirements as functions of changes in Space Station mass and area.

The bending moments and vibration modes indicate the trends expected for selected photovoltaic and solar dynamic growth paths. The impact on the Structures and Mechanisms Subsystem may be a structural stiffness criteria for the IOC configuration to meet a specific growth case. This criteria will also apply to alpha and beta joints.

Other criteria may be placed on these joints and structure as well as various subsystems to allow for the utilization of waste heat associated with the solar dynamic concept. This option may be a viable alternative to ever increasing solar collector and radiator areas.

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APPENDIX A - IMPACTS LISTED BY SPACE STATION SUBSYSTEM

A1. GUIDANCE, NAVIGATION AND CONTROL

Item	Level	Impact	Scar
Power System Pointing	(1) Major	SDPS may have individual pointing control at each location with I/F to GN&C subsystem.	Capability to add to IOC GN&C subsystem the I/F for up to eight SDPS pointing units.
Drag Area	(1) Major	Growth PV & SD power systems increase the angular momentum control requirements of GN&C subsystem.	Capability to add additional CMG's. Worse case growth requirement is approximately 90,000 N-m-sec. (29 equivalent Skylab CMG's).
Rotating Machinery	(2) Nominal	SDPS rotating machinery increases the angular momentum control requirements of GN&C subsystem.	Capability to add additional CMG's. Insufficient detail on rotating machinery design available to predict angular momentum. Worse case growth estimate is less than two equivalent Skylab CMG's.
Structural Stiffness	(2) Nominal	Growth PV & SD power systems produce increased displacement and vibration of structural elements and may require active damping by GN&C subsystem.	Capability to add active damping control I/F to GN&C subsystem.

A1. GUIDANCE, NAVIGATION AND CONTROL (cont'd)

Item	Level	Impact	Scar
EMI/RFI	(2) Nominal	Growth PV & SD power systems will have new EMI/RFI signatures which may impact GN&C subsystem.	Provision for add-on filtering on IOC GN&C subsystem.
Power System Assembly	(3) Minor	Initial alignment of SDPS during assembly may require interface with GN&C subsystem.	Provision for I/F to provide SDPS alignment.
Radiator Requirements	(3) Minor	Growth SDPS radiator drag area increases the momentum control requirements of the GN&C subsystem.	Covered under Drag Area.
Reflected Energy	(3) Minor	Growth PV & SD power systems increase the possibility of reflected light into star trackers, or of blockage of FOV.	Provision for attachment of light shields or for star tracker relocation.
Contamination	(3) Minor	Increased reboost requirements for growth PV and SD power systems generate fuel by-products which may affect optical surfaces of GN&C subsystem or which may produce false targets for GN&C star trackers.	Protective shutters may be required for optical surfaces during periods of high levels of contamination.

A2. COMMUNICATIONS & TRACKING

Item	Level	Impact	Scar
Drag Area	(2) Nominal	Growth PV and SD power systems components present increased blockage for the C&T subsystem antennas.	Provision for antenna relocation or addition.
Radiator Requirements	(2) Nominal	Growth SDPS radiators present increased blockage for the C&T Subsystem antennas.	Provision for antenna relocation or addition.
Reflected Energy	(2) Nominal	SDPS collector reflections may result in nulls and sidelobes in C&T antenna patterns with variations of signal strength as a function of sun angle.	Provision for antenna relocation or addition. Increased ground antenna pattern testing for SDPS cases is implied.
EMI/RFI	(2) Nominal	Growth PV & SD power systems will have new EMI/RFI signatures which may impact C&T subsystem.	Provision for add-on filtering on IOC C&T subsystem.
Contamination	(3) Minor	Increased reboost requirements for growth PV & SD power systems generate increased fuel by-products which may cause rf breakdown of C&T subsystem rf fields.	None.

A3. INFORMATION & DATA MANAGEMENT SUBSYSTEM

Item	Level	Impact	Scar
Power System Pointing	(2) Nominal	SDPS status reporting and monitoring for collector pointing requires increased IDMS capability. Hybrid power system requires dual IDMS I/F.	Addition of SDPS/IDMS monitoring requirements to IOC or provision for IDMS I/F for add-on capability.
EMI/RFI	(2) Nominal	Growth PV & SD power systems will have new EMI/ RFI signatures which may impact IDMS.	Provision for add-on filtering on IOC IDMS.
Power System Assembly	(3) Minor	SDPS requires increased IDMS I/F for alignment procedures.	Covered under Power System Pointing.
Radiator Requirements	(3) Minor	SDPS radiators require status reporting and performance monitoring I/F to IDMS.	Provision for IDMS I/F for add-on capability to monitor SDPS radiator performance.
Reflected Energy	(3) Minor	Growth PV and SD power systems will require IDMS monitoring of reflected rf and light energy.	Provision for IDMS I/F for add-on capability to monitor reflected energy for growth systems.

A4. PROPULSION SUBSYSTEM

Item	Level	Impact	Scar
Power System Pointing	(1) Major	SDPS pointing back-up for failed Space Station control or failed SDPS individual pointing system may be required of the RCS.	Provision for SDPS/GN&C/RCS I/F for fine pointing back-up system.
Drag Area	(1) Major	Increased drag area for SD & PV growth cases increases RCS fuel needed for CMG desaturation control and fuel needed for reboost.	Provision on IOC for future add-on of propulsion subsystem fuel capacity.
Radiator Requirements	(2) Nominal	Increased drag area of SDPS radiators increases RCS fuel needed for CMG desaturation control and fuel needed for reboost.	Covered under Drag Area.
Thermal Utilization	(2) Nominal	Growth SDPS waste thermal heat utilization by propulsion subsystem.	Provsion on IOC for heating lines to supplement electrical heat for hydrazine lines and tanks, or provision for future add-on.
Rotating Machinery	(3) Minor	SDPS rotating machinery perturbations on control system increase RCS fuel requirements.	Covered under Drag Area.
Contamination	(3) Minor	Increased reboost and RCS control fuel requirements for growth SDPS and PVPS produce increased by-products which may impose tighter fuel impurity control and/or time of operation constraints.	None.

A5. ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

Item	Level	Impact	Scar
Thermal Utilization	(2) Nominal	Growth SDPS waste heat may become available for use in lieu of electrical heat.	IOC ECLSS design should not preclude the capability to accept waste heat when available.
Power System Pointing	(3) Minor	SDPS waste heat availability may be curtailed for small pointing errors or for streamline operation.	None.

A7. STRUCTURES AND MECHANISMS SUBSYSTEM

Item	Level	Impact	Scar
Structural Stiffness	(1) Major	Growth PV & SD power systems may cause increase structural loads.	Provisions for either worse case growth condition in IOC structural design or for adding stiffness to structure.
	(1) Major	Growth PV & SD power systems may induce vibration modes requiring active damping.	IOC structural design should not preclude the use of add-on active damping for growth cases.
Power System Pointing	(1) Major	Growth SDPS pointing accuracy requirement should not be limited by alpha and beta joint stiffness.	For SDPS configurations, require alpha- and beta-joints to be as stiff as adjoining structure.
Power System Assembly	(2) Nominal	SDPS may require on-orbit assembly rather than deployment.Use of MRMS may be required for first SDPS assembly.	None.
	(2) Nominal	Initial SDPS collector alignment may require structural attachment points for alignment fixtures.	If SDPS alignment fixtures are required, provision for structural attachment points.
Thermal Utilization	(2)Nominal	Use of growth SDPS waste heat requires rotary fluid joints and insulated fluid lines along structure.	Capability to add rotary fluid alpha- and beta-joints and provision for attaching thermal lines to structure.

A6. THERMAL CONTROL SUBSYSTEM

Item	Level	Impact	Scar
Thermal Utilization	(1) Major	Growth SDPS waste heat may be utilized by thermal subsystem in lieu of electrical power.	IOC thermal subsystem design to include provisions for future use of waste thermal heat.
Power System Pointing	(2) Nominal	Availability of SDPS waste heat (and electrical power) is sharply curtailed for pointing errors of more than a few tenths of a degree.	None.
Drag Area	(2) Nominal	Increased area of growth PV & SD power systems may result in occasional operational modes near streamline for extended periods. SDPS waste heat is curtailed.	None.
	(3)Minor	Increased area of growth PV & SD power systems may result in decreased FOV of cold space for thermal system radiators.	IOC Thermal System radiator area allowances for SDPS growth case, or design to include capability for future add-on.
Contamination	(2) Nominal	Contamination changes the thermal properties of radiators and other surfaces which may affect heat balance.	None.
Radiator Requirements	(3) Minor	Growth SDPS radiators may be in FOV of thermal system radiators.	Covered under Drag Area second item.
Reflected Energy	(3) Minor	When off-sun, SDPS collectors may direct light energy on thermal system radiators.	Covered under Drag Area second item.

A7. STRUCTURES & MECHANISMS SUBSYSTEM (cont'd)

Item	Level	Impact	Scar
Rotating Machinery	(3) Minor	Structural loads and vibration modes are induced by rotating machinery start-up, shut-down, and operation.	None.
	(3) Minor	Torsion is induced in structure separating counter-rotating machinery.	None.
Radiator Requirements	(3) Minor	Growth SDPS radiators require structural attachment and support.	Provision to attach and structurally support the worse case SDPS growth radiators.
Reflected Energy	(3) Minor	SDPS collectors slightly off sun can produce high thermal loads on receiver and support structure.	None. SDPS/S&MS design I/F requirement.
	(3) Minor	Unsafe regions for EVA	Provision for zone markings or barricade attachments on structure.
Contamination	(3) Minor	Increased reboost and RCS control fuel requirements for growth SDPS and PVPS may produce contamination on structural members that changes thermal properties and surface reaction rate to ozone.	None.

A8. PAYLOADS, MODULES AND STS

Item	Level	Impact	Scar
Power System Assembly	(2) Nominal	SDPS may require on-orbit assembly rather than deployment. May require use of SMRS and STS-based EVA.	None.
Power System Pointing	(3) Minor	SDPS initial alignment may require STS based EVA.	None.
Drag Area	(3) Minor	Increased reboost requirements for growth PVPS and SDPS will increase STS fuel resupply timelines.	None.
Rotating Machinery	(3) Minor	Angular momentum induced motions of Space Station must be considered during STS docking manuevers.	None. Depending upon the magnitude of the disturbance, SDPS movements may be inhibited during docking.
Structural Stiffness	(3) Minor	Growth PVPS and SDPS may induce vibrations modes affecting micro-gravity experiments.	None.
Radiator Requirements	(3) Minor	Growth SDPS radiators may restrict path available for STS docking manuevers.	None.
Reflected Energy	(3) Minor	RF energy reflected by power system collectors, panels or radiators may cause breakdown of unshielded low pressure gases in payloads.	Requirement that all low pressure gas containers are shielded from rf breakdown.

A8. PAYLOADS, MODULES AND STS (cont'd)

Item	Level	Impact	Scar
EMI/RFI	(3) Minor	Growth PVPS and SDPS will have new EMI/RFI signatures which may impact other systems in vicinity.	Payloads, Modules and STS systems designed for IOC EMI/RFI signatures may require additional filtering as power system evolves.
Contamination	(3) Minor	Increased reboost requirements for growth PVPS and SDPS generate increased fuel by-products which may impact payload expirements.	None.
Thermal Utilization	(3) Minor	Growth SDPS waste heat may be available for modules and for payload hanger utilization.	IOC module design should not preclude use of waste heat from growth SDPS.

A9. EVA, OMV AND OTV

Item	Level	Impact	Scar
Power System Assembly	(1) Major	SDPS may require on-orbit assembly and extensive EVA.	None.
Reflected Energy	(2) Nominal	SDPS collectors will have spatial regions where EVA is restricted due to thermal energy levels.	EVA restricted areas or requirement for fail-safe collector pointing techniques when EVA is in vicinity of collectors.
Power System Pointing	(3) Minor	SDPS initial alignment and operational adjustments to maintain pointing accuracy increases EVA timelines.	None.
Drag Area	(3) Minor	Increased reboost requirements for growth PVPS and SDPS may increase EVA fuel resupply timelines.	None.
Radiator Requirements	(3) Minor	Growth SDPS radiators may require on-orbit assembly and charging, increasing EVA timelines.	None.

A9. EVA, OMV and OTV (cont'd)

Item	Level	Impact	Scar
EMI/RFI	(3) Minor	Growth PVPS and SDPS will have new EMI/RFI signatures which may impact EVA, OMV, and OTV operations in vicinity of Space Station.	EVA, OMV, and OTV systems designed for IOC EMI/RFI signatures may require additional filtering as power system evolves.
Contamination	(3) Minor	Increased reboost requirements for growth PVPS and SDPS generate increased fuel by-products which may require more frequent EVA visor and/or suit cleaning or replacement.	None.
Thermal Utilization	(3) Minor	Growth SDPS waste heat utilization will increase EVA timelines for installation, charging and maintenance of thermal exchange systems.	None.

APPENDIX B - MASS PROPERTIES SUMMARY TABLE

CONFIGURATION	TOT MASS-KG	CENTER OF MASS-M X	Y	Z	SPACE STATION MOMENTS, PRODUCTS OF INERTIA-KG*M^2 IXX	IYY	IZZ	IXY	IXZ	IYZ
PV75	119863	.0	.0	56.2	1.04E+08	9.90E+07	1.02E+07	-2.89E+03	-8.72E+05	2.23E+04
PV75P	208408	-0.4	.0	43.9	2.99E+08	2.91E+08	1.45E+07	-1.82E+05	5.08E+05	-1.71E+06
PV300P	358896	-0.9	.0	54.4	7.13E+08	5.48E+08	1.78E+08	-1.73E+05	-4.85E+06	-1.53E+06
SD75	176351	0.1	.0	53.4	1.28E+08	1.19E+08	1.36E+07	-2 60E+03	-1.06E+06	1.43E+04
SD75P	206896	-0.4	0.1	42.5	3.15E+08	3.04E+08	1.79E+07	-1.84E+05	3.30E+05	-1.24E+06
SD300P	367056	-0.8	.0	53.2	6.57E+08	5.77E+08	9.30E+07	-1.55E+05	-5.61E+06	-1.47E+06
PV75+S	226623	5.0	.0	66.7	1.34E+08	1.44E+08	2.72E+07	-1.84E+03	1.28E+07	2.45E+04
PV75P+S	307168	3.4	.0	55.9	3.83E+08	3.93E+08	3.37E+07	-1.47E+05	2 76E+07	-1.68E+06
PV300P+S	405656	1.0	.0	63.7	8.49E+08	7.83E+08	2.00E+08	-1.50E+05	3 35E+07	-1.45E+06
SD75+S	253111	4.9	.0	64 9	1.65E+08	1.72E+08	3.07E+07	-2.42E+03	1.47E+07	1.47E+04
SD75P+S	313656	3.4	.0	54 8	4.07E+08	4.14E+08	3.71E+07	-2.34E+05	2.87E+07	-1.41E+06
SD300P+S	473816	1.8	.0	62.6	8.81E+08	7.42E+08	1.15E+08	-1.74E+05	3.39E+07	-1.54E+06

PROJECTED AREAS SUMMARY TABLE

APPENDIX C - PROJECTED AREAS SUMMARY TABLE

CONFIGURATION	SPACE STATION PROJECTED AREAS-M^2 MAIN BODY X	Y	Z	ARTICULATING COMPONENTS X	Y	Z	COMPLETE SPACE STATION BALLISTIC COEF.(M/CdA)
PV75	319	290	119	1980	175	334	29.1
PV75P	1549	901	479	1980	175	334	28.8
PV300P	1722	1084	467	7934	671	1268	28.6
SD75	320	299	120	577	252	380	59.2
SD75P	1543	901	477	577	252	380	41.8
SD300P	1710	1085	468	1848	741	1297	43.0
PV75+S	578	465	179	1980	175	334	48.8
PV75P+S	1000	1071	536	1980	175	334	40.8
PV300P+S	1943	1201	527	7934	671	1268	26.0
SD75+S	580	469	179	577	252	380	85.2
SD75P+S	1788	1078	532	577	252	380	56.9
SD300P+S	1936	1273	528	1848	741	1297	52.3

APPENDIX D - ATTITUDE CONTROL REQUIREMENTS: TRIM ANGLES, CONTROL TORQUES, ANGULAR MOMENTUM, NUMBER OF CMGS, AND ACS BACKUP FUEL

FLIGHT MODE: VERTICAL ARTICULATED

	CONFIGURATION	TEA	MAX.CONTROL TORQUE-NM			PEAK CYCLIC MOMENTUM-NMS		
		DEG	X	Y	Z	X	Y	Z
ALT.	PV75	8.9	0.1	49.3	0.2	319	37490	367
407 km	PV75P	3.3	8.7	44.4	0.3	9729	39270	16590
	PV300P	7.1	8.2	196.5	3.6	5297	157200	11710
	SD75	3.2	0.1	14.7	.0	157	13220	251
	SD75P	1.8	6.3	18.9	0.4	7178	20710	11970
	SD300P	3.0	7.5	66.5	0.2	8607	67980	14340
	PV75+S	1.7	0.1	58.4	0.2	334	44420	373
	PV75P+S	-0.9	8.2	56.6	0.7	9530	50820	15630
	PV300P+S	3.4	7.4	233.1	0.7	8457	179000	14190
	SD75+S	-3.5	0.1	17.0	0.2	167	15280	252
	SD75P+S	-2.4	7.1	24.1	-0.8	8551	26740	13630
	SD300P+S	-0.5	7.9	68.0	0.6	9356	65370	15080
ALT.	PV75	4.9	0.1	25.0	0.9	196	22220	274
463 km	PV75P	1.6	8.5	23.4	0.3	9716	23160	16490
	PV300P	3.9	7.7	100.1	1.1	7628	90310	13550
	SD75	1.9	0.1	9.6	.0	154	8742	247
	SD75P	0.9	6.1	12.0	0.3	7137	12940	11880
	SD300P	1.8	7.4	46.7	0.2	8599	48450	14250
	PV75+S	-2.4	0.1	29.3	0.1	214	26020	287
	PV75P+S	-2.7	8.0	29.5	0.7	9542	29780	15490
	PV300P+S	0.3	7.3	115.8	0.6	8493	103600	14060
	SD75+S	-4.9	0.1	11.0	.0	164	10150	248
	SD75P+S	-3.4	7.0	15.1	0.8	8515	16600	13530
	SD300P+S	-1.6	7.7	44.7	0.5	9338	42980	14970
ALT.	PV75	3.4	0.1	17.5	0.1	162	15980	246
500 km	PV75P	1.0	8.4	16.5	0.3	9740	16690	16390
	PV300P	2.7	7.5	69.6	0.6	8156	63930	14090
	SD75	1.4	0.1	7.6	.0	153	6950	245
	SD75P	0.5	6.0	9.4	0.3	7099	10040	11800
	SD300P	1.4	7.2	38.6	0.2	8568	40450	14160
	PV75+S	-3.8	0.1	20.5	0.1	181	18710	262
	PV75P+S	-3.3	7.8	20.6	0.7	9515	21300	15380
	PV300P+S	-0.8	7.1	79.9	0.5	8486	73470	13960
	SD75+S	-5.3	0.1	8.4	.0	162	7744	246
	SD75P+S	-3.8	6.9	11.6	0.7	8474	12510	13450
	SD300P+S	-2.1	7.6	35.3	0.5	9300	33860	14870
ALT.	PV75	2.2	0.1	10.8	.0	140	10180	228
555 km	PV75P	0.5	8.2	10.2	0.2	9677	10470	16230
	PV300P	1.8	7.3	42.5	0.3	8422	40060	14320
	SD75	1.0	0.1	5.7	.0	151	5382	242
	SD75P	0.3	5.9	6.8	0.2	7033	6989	11680
	SD300P	1.0	7.1	31.0	0.1	8502	33000	14020
	PV75+S	-5.1	0.1	12.6	.0	161	12010	245
	PV75P+S	-3.8	7.7	12.7	0.6	9446	13370	15210
	PV300P+S	-1.8	7.0	48.2	0.5	8445	45660	13820
	SD75+S	-5.7	0.1	6.3	.0	160	5931	243
	SD75P+S	-4.1	6.7	8.1	0.7	8398	8585	13310
	SD300P+S	-2.4	7.4	26.5	0.5	9224	25320	14710

APPENDIX D - ATTITUDE CONTROL REQUIREMENTS: TRIM ANGLES, CONTROL TORQUES, ANGULAR MOMENTUM, NUMBER OF CMGS, AND ACS BACKUP FUEL (cont'd)

FLIGHT MODE: VERTICAL ARTICULATED

	CONFIGURATION	CMGS	RCS LIN. IMPULSE-NS: X	Y	Z	FUEL(90DAYS)-KG
ALT. 407 km	PV75	6.0	34	6848	24	4346
	PV75P	7.1	2255	5926	31	5167
	PV300P	25.4	1658	19530	471	13630
	SD75	2.1	32	1798	1	1152
	SD75P	4.0	1622	2438	75	2601
	SD300P	11.3	1580	5989	22	4776
	PV75+S	7.2	35	8019	28	5085
	PV75P+S	8.7	2125	7452	139	6113
	PV300P+S	29.0	1587	22550	109	15260
	SD75+S	2.5	32	2041	3	1307
	SD75P+S	5.0	1846	3283	199	3353
	SD300P+S	10.9	1661	5773	121	4754
ALT. 463 km	PV75	3.6	31	3526	12	2218
	PV75P	4.8	2233	3102	47	3345
	PV300P	14.8	1643	10060	135	7356
	SD75	1.4	32	1170	0	747
	SD75P	3.1	1605	1536	68	1994
	SD300P	8.3	1565	4159	29	3576
	PV75+S	4.2	33	4102	15	2579
	PV75P+S	5.6	2097	3952	157	3857
	PV300P+S	16.9	1567	11580	115	8246
	SD75+S	1.6	32	1289	3	823
	SD75P+S	3.7	1828	2014	193	2508
	SD300P+S	7.5	1644	3813	128	3471
ALT. 500 km	PV75	2.6	31	2337	7	1464
	PV75P	4.1	2217	2123	52	2708
	PV300P	10.6	1631	6639	67	5140
	SD75	1.1	32	967	0	616
	SD75P	2.7	1593	1163	66	1740
	SD300P	7.0	1554	3475	32	3120
	PV75+S	3.0	32	2705	11	1694
	PV75P+S	4.5	2079	2702	162	3048
	PV300P+S	12.1	1554	7636	118	5739
	SD75+S	1.2	32	1046	2	666
	SD75P+S	3.3	1814	1502	190	2162
	SD300P+S	6.2	1632	3185	130	3049
ALT. 555 km	PV75	1.6	30	1388	4	866
	PV75P	3.5	2192	1328	56	2178
	PV300P	7.0	1613	3809	39	3327
	SD75	0.9	31	807	1	511
	SD75P	2.5	1574	899	64	1545
	SD300P	5.9	1536	2925	34	2738
	PV75+S	1.9	32	1583	7	988
	PV75P+S	3.6	2054	1663	166	2365
	PV300P+S	7.8	1535	4336	120	3649
	SD75+S	1.0	31	844	2	535
	SD75P+S	2.9	1793	1034	187	1836
	SD300P+S	5.0	1613	2691	131	2701

APPENDIX D - ATTITUDE CONTROL REQUIREMENTS: TRIM ANGLES, CONTROL TORQUES ANGULAR MOMENTUM, NUMBER OF CMGS, AND ACS BACKUP FUEL (cont'd)

FLIGHT MODE: VERTICAL LOCKED

	CONFIGURATION	TEA	MAX.CONTROL TORQUE-NM			PEAK CYCLIC MOMENTUM-NMS		
		DEG	X	Y	Z	X	Y	Z
ALT.	PV75	12.6	0.2	28.9	0.2	365	35800	369
407 km	PV75P	4.4	8.7	31.8	0.1	9607	39470	16590
	PV300P	9.8	7.7	123.6	0.2	8232	153400	14560
	SD75	3.8	0.1	9.0	.0	126	11160	219
	SD75P	2.0	6.3	15.1	0.3	7191	18710	12000
	SD300P	3.3	7.2	39.1	0.1	8110	48670	13870
	PV75+S	5.5	0.2	35.0	0.2	388	43480	370
	PV75P+S	0.2	8.2	41.1	0.4	9431	51000	15680
	PV300P+S	6.0	7.4	145.7	0.5	8213	180900	14010
	SD75+S	-3.0	0.1	10.6	.0	136	13180	219
	SD75P+S	-2.2	7.1	20.1	0.8	8566	24880	13660
	SD300P+S	-0.1	7.6	45.4	0.5	8851	56470	14600
ALT.	PV75	6.8	0.1	17.7	0.1	205	21880	257
463 km	PV75P	2.2	8.5	18.7	0.1	9707	23010	16500
	PV300P	5.3	7.6	74.4	0.2	8437	91780	14600
	SD75	2.2	0.1	5.4	.0	124	6691	217
	SD75P	1.0	6.1	9.0	0.3	7159	11130	11910
	SD300P	1.9	7.1	23.2	0.1	8129	28660	13770
	PV75+S	-0.4	0.1	20.9	0.1	222	25860	264
	PV75P+S	-2.1	8.0	24.2	0.5	9508	29900	15520
	PV300P+S	1.6	7.2	86.8	0.5	8356	107000	13960
	SD75+S	-4.5	0.1	6.3	0.1	133	7823	217
	SD75P+S	-3.3	7.0	11.9	0.7	8538	14750	13570
	SD300P+S	-1.4	7.4	27.1	0.5	8852	33470	14480
ALT.	PV75	4.6	0.1	12.6	0.1	157	15490	227
500 km	PV75P	1.4	8.4	13.2	0.2	9711	16070	16400
	PV300P	3.6	7.5	52.9	0.2	8500	64840	14570
	SD75	1.6	0.1	3.7	.0	123	4572	216
	SD75P	0.6	6.0	6.3	0.3	7123	7745	11830
	SD300P	1.4	7.0	16.6	0.1	8110	20390	13690
	PV75+S	-2.6	0.1	14.8	0.1	175	18080	238
	PV75P+S	-2.9	7.8	17.1	0.6	9498	20920	15400
	PV300P+S	.0	7.1	61.6	0.5	8393	75570	13900
	SD75+S	5.1	0.1	4.5	.0	132	5598	216
	SD75P+S	-3.7	6.9	8.4	0.7	8498	10310	13480
	SD300P+S	-1.9	7.3	19.3	0.5	8824	23780	14390
ALT.	PV75	2.8	0.1	7.5	.0	129	9070	212
555 km	PV75P	0.7	8.2	7.9	0.2	9670	9629	16240
	PV300P	2.2	7.3	31.9	0.2	8519	38640	14470
	SD75	1.1	0.1	2.3	.0	122	2856	214
	SD75P	0.3	5.9	3.9	0.2	7060	4709	11710
	SD300P	0.9	6.8	10.0	0.1	8052	12160	13550
	PV75+S	-4.5	0.1	8.9	.0	148	10750	227
	PV75P+S	-3.7	7.7	10.2	0.6	9444	12400	15230
	PV300P+S	-1.3	7.0	37.0	0.5	8389	44840	13780
	SD75+S	-5.6	0.1	2.6	.0	131	3212	214
	SD75P+S	-4.0	6.7	5.0	0.7	8424	5970	13340
	SD300P+S	-2.3	7.2	11.7	0.5	8757	14200	14240

APPENDIX D - ATTITUDE CONTROL REQUIREMENTS: TRIM ANGLES, CONTROL TORQUES, ANGULAR MOMENTUM, NUMBER OF CMGS, AND ACS BACKUP FUEL (cont'd)

FLIGHT MODE: VERTICAL LOCKED

	CONFIGURATION	CMGS	RCS LIN. IMPULSE-NS: X	Y	Z	FUEL (90DAYS)-KG
ALT. 407 km	PV75P	7.1	2247	5737	17	5034
	PV300P	24.9	1643	15980	41	11120
	SD75	1.8	30	1646	1	1055
	SD75P	3.8	1624	2746	69	2793
	SD300P	8.3	1544	5075	12	4172
	PV75+S	7.0	38	6322	44	4029
	PV75P+S	8.7	2123	7439	92	6074
	PV300P+S	29.3	1582	18830	79	12890
	SD75+S	2.1	30	1941	4	1242
	SD75P+S	4.8	1849	3655	194	3585
	SD300P+S	9.5	1626	5880	108	4790
ALT. 463 km	PV75	3.5	33	3156	19	1994
	PV75P	4.8	2230	3354	24	3486
	PV300P	15.1	1637	9550	23	6967
	SD75	1.1	30	965	0	618
	SD75P	2.9	1607	1600	66	2034
	SD300P	5.3	1531	2993	26	2828
	PV75+S	4.2	33	3737	23	2358
	PV75P+S	5.6	2098	4341	134	4085
	PV300P+S	17.5	1566	11150	100	7964
	SD75+S	1.3	30	1144	3	731
	SD75P+S	3.5	1830	2135	190	2583
	SD300P+S	6.1	1609	3475	119	3234
ALT. 500 km	PV75	2.5	31	2239	12	1407
	PV75P	4.0	2215	3359	38	2843
	PV300P	10.8	1629	6752	22	5180
	SD75	0.7	29	683	0	440
	SD75P	2.6	1595	1127	64	1717
	SD300P	4.2	1521	2116	31	2261
	PV75+S	2.9	32	2638	16	1656
	PV75P+S	4.5	2080	3052	148	3255
	PV300P+S	12.5	1554	7853	108	5866
	SD75+S	0.9	29	806	2	517
	SD75P+S	3.1	1817	1502	188	2162
	SD300P+S	4.7	1598	2458	123	2577
ALT. 555 km	PV75	1.5	30	1347	6	843
	PV75P	3.4	2191	1401	50	2219
	PV300P	6.8	1612	4048	31	3467
	SD75	0.5	29	407	1	266
	SD75P	2.3	1576	671	63	1407
	SD300P	3.2	1504	1272	35	1713
	PV75+S	1.7	32	1573	9	983
	PV75P+S	3.5	2054	1815	159	2454
	PV300P+S	7.7	1535	4707	114	3872
	SD75+S	0.5	29	486	2	315
	SD75P+S	2.7	1796	900	186	1755
	SD300P+S	3.5	1580	1477	126	1939

APPENDIX E - ALTITUDE MAINTENANCE FUEL REQUIREMENTS

FLIGHT MODE: VERTICAL ARTICULATED

	CONFIGURATION	RCS LIN. IMPULSE-NS;	FUEL(90DAYS)-KG
ALT.	PV75	2929	2132
407 km	PV75P	5017	3339
	PV300P	12430	8794
	SD75	1545	1026
	SD75P	3588	2328
	SD300P	6128	4058
	PV75+S	3383	2194
	PV75P+S	5426	3468
	PV300P+S	12860	8569
	SD75+S	1981	1324
	SD75P+S	4024	2639
	SD300P+S	6544	4151
ALT.	PV75	1237	835
463 km	PV75P	2106	1346
	PV300P	5242	3480
	SD75	648	416
	SD75P	1507	951
	SD300P	2550	1635
	PV75+S	1425	921
	PV75P+S	2294	1492
	PV300P+S	5402	3375
	SD75+S	833	562
	SD75P+S	1698	1119
	SD300P+S	2764	1767
ALT.	PV75	715	467
500 km	PV75P	1216	763
	PV300P	3029	1957
	SD75	373	236
	SD75P	870	541
	SD300P	1453	918
	PV75+S	825	542
	PV75P+S	1329	866
	PV300P+S	3125	1954
	SD75+S	481	324
	SD75P+S	983	646
	SD300P+S	1601	1022
ALT.	PV75	325	205
555 km	PV75P	553	340
	PV300P	1377	864
	SD75	169	105
	SD75P	395	242
	SD300P	635	394
	PV75+S	377	250
	PV75P+S	607	394
	PV300P+S	1424	894
	SD75+S	218	146
	SD75P+S	447	292
	SD300P+S	730	464

APPENDIX E - ALTITUDE MAINTENANCE FUEL REQUIREMENTS (cont'd)

FLIGHT MODE: VERTICAL LOCKED

	CONFIGURATION	RCS LIN. IMPULSE-NS;	FUEL(90DAYS)-KG
ALT. 407 km	PV75	3803	2927
	PV75P	5930	4018
	PV300P	16060	11850
	SD75	1539	1032
	SD75P	3565	2323
	SD300P	6058	4031
	PV75+S	4295	2964
	PV75P+S	6291	3971
	PV300P+S	16550	11500
	SD75+S	1963	1300
	SD75P+S	3998	2613
	SD300P+S	6299	3971
ALT. 463 km	PV75	1626	1130
	PV75P	2489	1606
	PV300P	6816	4629
	SD75	640	413
	SD75P	1494	944
	SD300P	2529	1624
	PV75+S	1794	1123
	PV75P+S	2669	1720
	PV300P+S	6952	4443
	SD75+S	834	560
	SD75P+S	1694	1114
	SD300P+S	2683	1710
ALT. 500 km	PV75	941	627
	PV75P	1437	907
	PV300P	3943	2585
	SD75	369	234
	SD75P	863	538
	SD300P	1458	921
	PV75+S	1043	672
	PV75P+S	1547	1003
	PV300P+S	4006	2471
	SD75+S	484	325
	SD75P+S	982	645
	SD300P+S	1558	993
ALT. 555 km	PV75	428	274
	PV75P	654	403
	PV300P	1795	1136
	SD75	167	104
	SD75P	393	240
	SD300P	663	410
	PV75+S	477	313
	PV75P+S	706	458
	PV300P+S	1833	1142
	SD75+S	221	148
	SD75P+S	484	292
	SD300P+S	713	452

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-87667		

4. Title and Subtitle
System Impacts of Solar Dynamic and Growth Power Systems on Space Station

5. Report Date
July 1986

6. Performing Organization Code
506-49-31-01

7. Author(s)
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8. Performing Organization Report No.

10. Work Unit No.

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, VA 23665-5225

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, DC 20546-0001

14. Sponsoring Agency Code

15. Supplementary Notes
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16. Abstract

Concepts for the 1990's Space Station envision an initial operational capability with electrical power output requirements of approximately 75 kW and growth power requirements in the range of 300 kW over a period of a few years. Photovoltaic and solar dynamic power generation techniques are contenders for supplying this power to the Space Station. A study was performed to identify growth power subsystem impacts on other Space Station subsystems. Subsystem interactions that might suggest early design changes for Space Station were emphasized. Quantitative analyses of the effects of power subsystem mass and projected area on Space Station controllability and reboost requirements were conducted for a range of growth station configurations. Impacts on Space Station structural dynamics as a function of power subsystem growth were also considered.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Space Station Space Power Systems Trades	Unclassified - Unlimited Subject Category 15

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	48	A03

*For sale by the National Technical Information Service, Springfield, Virginia 22161

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