NASA Contractor Report 3395

Satellite Power Systems (SPS) Concept Definition Study (Exhibit D)

Volume IV - Operations Analyses

G. M. Hanley

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FOREWORD

This is Volume IV - *Operations Analyses*, of the SPS Concept Definition Study final report as submitted by Rockwell International through the Space Operations and Satellite Systems Division. All work was completed in response to the NASA/MSFC Contract NAS8-32475, Exhibit D and Amendment Number 1.

The SPS final report will provide the NASA with additional information on the selection of a viable SPS concept and will furnish a basis for subsequent technology advancement and verification activities. Other volumes of the final report are listed as follows:

Volume	Title
I	Executive Summary
II	Systems/Subsystems Analyses
III	Transportation Analyses
V	Systems Engineering/Integration Analyses
VI	Cost and Programmatics
VII	Systems/Subsystems Requirements Data Book

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GLOSSARY

A	Ampere
Å	Angstrom
ac	Alternating current
ACSS	Attitude control and stationkeeping system
AMO	Air mass zero
ARDS	Attitude reference determination system
$\overline{B}$	Billions of dollars
B_eO	Beryllium oxide (Berlox)
BCD	Binary coded decimal
BCU	Bus control units
BOL	Beginning of life
BT	Battery tie contactor
°C	Degree centigrade
C_e	Cesium
cm	Centimeter
CMD	Command
COTV	Cargo orbital transfer vehicle
CPU	Central processing unit
CR	Concentration ratio
CR_E	Effective concentration ratio
CVD	Controlled vapor deposit
D/A	Digital to analog
dB	Decibel
dc	Direct current
DOE	Department of Energy
DVM	Digital voltmeter

EBS	Electron beam semiconductor
E_g	Bandgap energy
EMI	Electromagnetic interference
EOL	End of life
EOTV	Electric orbital transfer vehicle
EVA	Extra-vehicular activity
f	Frequency
°F	Degree Fahrenheit
FEP	Adhesive material
FET	Field-effect transistor
FOC	Final operational capability
f_p	Pilot frequency
f_r	Reference signal frequency
f_T	Transmitted frequency
G	Giga- (10^9)
G	Gear, switch
GaAlAs	Gallium aluminum arsenide
GaAs	Gallium arsenide
GEO	Geosynchronous, equatorial orbit
GHz	Gigahertz
GPS	Global Positioning System
GRS	Ground receiving station
GW	Gigawatt
HLLV	Heavy-lift launch vehicle
HPWB	Half-power-point beamwidth
HV	High voltage
Hz	Hertz
IB	Interface bus
IBM	International Business Machines Corp.
IMCS	Information management and control system
IMS	Information management system (see IMCS)

IOC	Initial operations capability
IOP	In-orbit plane
IOTV	Inter-orbit transfer vehicle
IUS	Inter-orbit utility stage
k	Kilo (10^3)
K	Potassium
°K	Degree Kelvin
km	Kilometer (1000 meters)
kN	Kilonewton
KSC	Kennedy Space Flight Center
kV	Kilovolts
LED	Light-emitting diode
LEO	Low earth orbit
LH_2	Liquid hydrogen
LOX	Liquid oxygen
LPE	Liquid phase epitaxal
LRB	Liquid rocket booster
LRU	Line replaceable unit
LSST	Large space structures technology
m	Meter
M	Mega- (10^6)
MBG	Multi-bandgap
MC-ABES	Multi-cycle airbreathing engine system
MeV	Millions of electron volts
μp	Microprocessor
MPCA	Master phase reference control amplifier
MPTS	Microwave power transmission system
MSFC	Marshall Space Flight Center
MTBF	Mean time between failure
MTTF	Mean time to failure
MW	Megawatt
MW	Microwave

MW_e	Megawatt—electrical
MWM	Manned work modules
MW_T	Megawatt—thermal
M_x	Disturbance torque along X-axis
N	Newton
NaK	Sodium-potassium
NASA	National Aeronautics and Space Administration
N-S	North-South
O&M	Operations and maintenance
OTV	Orbit transfer vehicle
PDS	Power distribution system
PLV	Personnel launch vehicle
PM	Personnel module
POP	Perpendicular to orbit plane
POTV	Personnel orbital transfer vehicle
psi	Pounds per square inch
RAC	Remote acquisition and control
R&D	Research and development
R&T	Research and technology
RCA	Radio Corporation of America
RCI	Replacement cost investment
RCR	Resonant cavity radiator
RCS	Reaction control system
RF	Radio frequency
RFI	Radio frequency interference
RTE	Real-time evaluation
S/A	Solar array
SCB	Space construction base
SG	Switch gear
Si	Silicon

SIT	Static induction transistor
SM	Sub-multiplexer
SOC	Space Operations Center
SPS	Satellite Power Systems
SRB	Solid rocket booster
STS	Space Transportation System
T	Temperature
TBD	To be determined
T&E	Test and evaluation
TFU	Theoretical first unit
TT&C	Telemetry, tracking, and communications
TWT	Traveling wave tubes
UI	Utility interface
V	Volt
VHF	Very high frequency
VSWR	Voltage standing wave ratio
VTO	Vertical take-off
W	Watt
Wh	Watt-hour
X,Y,Z	Coordinate axes of satellite

Symbols

ε	Error signals
λ	Wavelength of frequency f (Hertz)
μ	Micro-
η	Efficiency
ϕ	Phase
ϕ	Coordinate axis angle—Phi
θ	Coordinate axis (angle)—Theta

1.0 INTRODUCTION

The current study effort entailed, in part, a more detailed definition of solid state devices for conversion from dc to RF on the satellite, primarily to improve reliability and reduce or eliminate maintenance requirements. Utilizing the coplanar, end-mounted antenna defined in Exhibit C as a baseline, various configuration trades were performed to select a preferred solid state concept. The increase in efficiency that could be realized by use of multi-bandgap solar cells, either with klystron or solid state antenna also was evaluated. Additionally, new satellite configurations were developed to exploit the sandwich antenna concept wherein solar cells are located on one side of the antenna panel and solid state dc/RF converters on the other side. These concepts entailed various primary and secondary reflector arrangements for directing solar energy to the solar cell side of the antenna with higher concentration ratios than utilized on the coplanar configurations. The concepts developed bore little resemblance to previous configurations and generated a requirement for a specialized satellite construction base (SCB) specifically tailored to the selected concept.

The operations analysis effort during the current study was concentrated on the solid state satellite. The scope of the analyses included development of a satellite construction scenario, a concept for the SCB, a top level satellite construction operation, construction timelines and crew sizes, mass flows to orbit, and a satellite maintenance scenario. Additionally, the list of materials required for satellite construction identified in Exhibit C was updated to identify significant differences relevant to the solid state satellite concept.

A special study involving feasible means of decommissioning satellites at the end of their design life was conducted. The implications of orbital change were defined and alternative uses of the satellite in lieu of disposal by orbital change identified.

2.0 SOLID-STATE SANDWICH CONCEPT SATELLITE OPERATIONS

2.1 CONCEPT CONSTRUCTABILITY RANKING

Six solid state satellite concepts were evaluated for constructability. Five of these concepts are shown in Figure 2.1-1 and described briefly herein.

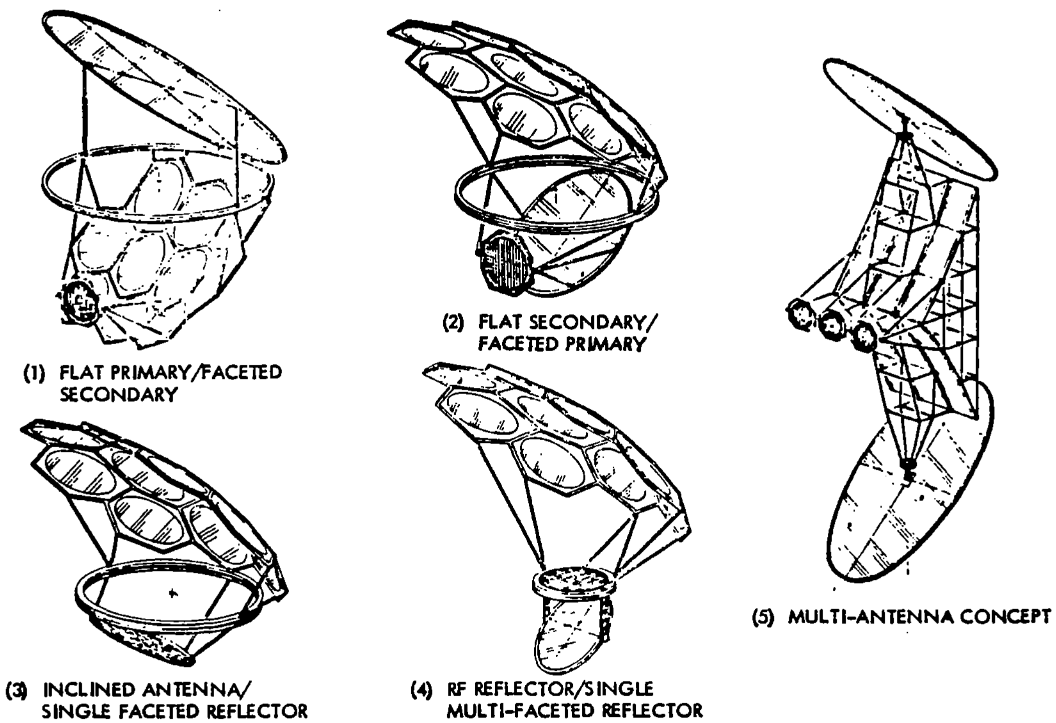


Figure 2.1-1. Alternative Solid State Sandwich Concepts

Concept Number 1 uses a large optical flat as a coleostat to track and reflect solar rays onto a ten-mirror secondary which in turn concentrates the solar energy on the integrated solar cell/RF transmitting assembly. The flat mirror assembly is hinge mounted on a rotary ring. The two cable actuated strut assemblies adjust the reflector to track the annual ±23.5 solar declination, while the ring tracks the daily rotation of the sun relative to the earth-pointing antenna. The ten optical flats (membrane mirrors) forming the secondary mirror assembly are oriented tangent to a paraboloid of revolution and are attached to the frame structure by catenary cables. This concept has an effective concentration ratio (CR_E) of 6.

In this concept (Number 2), ten mirrors comprise the primary reflector, which directs the solar rays to a flat secondary mirror and thence to the antenna. The primary mirrors rotate on a rotary ring to track the daily rotation of the sun relative to the earth-pointing antenna. Link actuators adjust the primary system to compensate for the sun's declination change. This concept also has a CR_E of 6.

Concept Number 3 consists of a ten mirror primary, a rotary joint, and an electrically scanned MW antenna/solar cell assembly. The rotary joint and link actuators provide for sun tracking.

In Concept Number 4, with a CR_E of 7.2, a ten-mirror assembly is mounted on the primary side of the rotary joint, while the antenna is fix-mounted to the secondary side of the joint. A flat screen RF reflector is pivot mounted to the secondary side of the rotary joint to permit latitude pointing of the RF beam. The rotary joint tracks the apparent daily rotation of the sun, while the primary mirror tracks the sun's declination motion.

Concept Number 5 consists of a symmetrical dual flat mirror, primary reflectors mounted on small rotary pivots, tower attached to back-to-back secondary mirror systems. Each of three integrated, earth pointing antennas receive solar energy from two sets of secondary mirrors. The axes of the rotary joints are in line and parallel to the earth N-S equatorial plane. Daily and annual sun tracking is accomplished by the rotary and pivot joints respectively. A CR_E of 3.4 is produced by this configuration.

A more detailed description of these five concepts is contained in Volume II, Systems/Subsystems Analyses, of the Final Report. Concept Number 6, the recommended concept, is described in Section 2.2.3 of this volume.

Concept Numbers 1 through 6 were qualitatively evaluated for constructability. The general configuration of these concepts differ markedly from the Rockwell coplanar configuration and would require substantial modification to construction scenarios previously developed. The large rotary joints as well as the large reflectors featured in some of the concepts will require special consideration in developing construction techniques and procedures. An advantage of the recommended concept is the absence of rotary joints and extremely large reflectors as compared to Concept Number 1, for example.

Each of the concepts generates its own peculiar problems relative to construction operations. However, construction of any concept appears feasible and the differences in construction complexity were not significant enough to override selection on the basis of other technical aspects.

2.2 SELECTED CONFIGURATION

2.2.1 OVERALL CONSTRUCTION SCENARIO

The overall scenario leading to establishment of satellite construction support facilities and to satellite construction is shown in Figure 2.2-1. Initial operations entail use of the growth shuttle and the shuttle derived HLLV for transporting men and material to LEO for the precursor phase of the program. Subsequently, during the 30 year satellite construction phase, the new generation HLLV will become the primary transportation element for delivering construction mass to LEO.

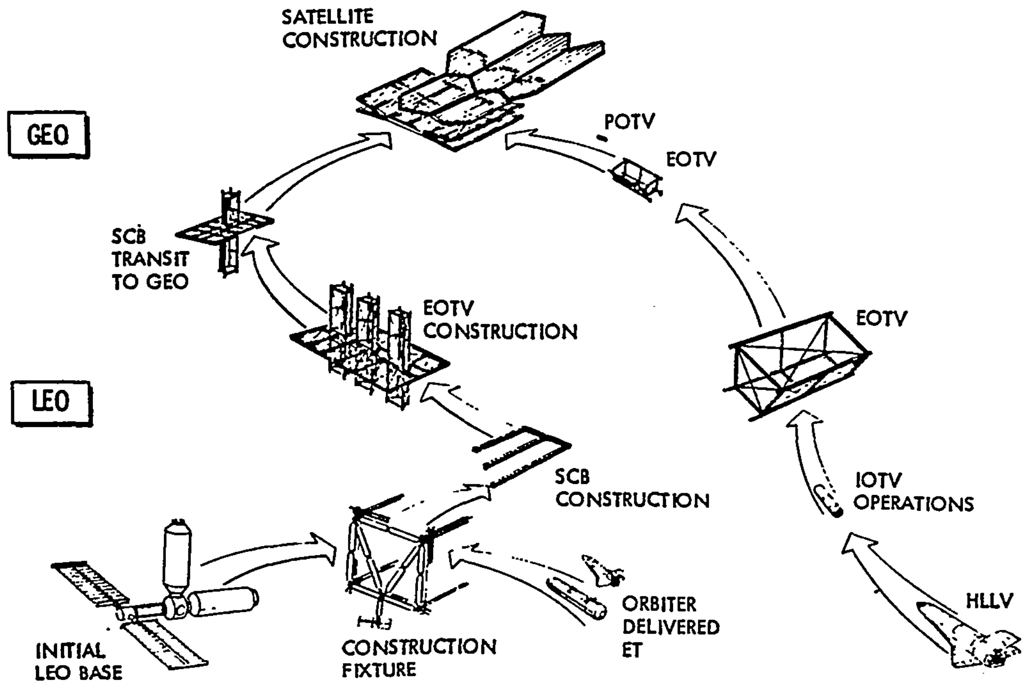


Figure 2.2-1. Overall Satellite Construction Scenario Solid State Concept

The initial step in satellite precursor operations is establishment of a LEO base as shown in the lower left of the figure. The facility consists of crew habitat modules, crew support modules, a LEO operations control and staging module and a power module. A permanent crew of 30 has been established to provide LEO support operations. These include supervisory activity for transfer of up and down payloads between the HLLV and EOTV's, mating of crew modules and POTV stages, and maintenance of the EOTV's (primary changeout of thruster grids and argon propellant tanks). The base required for this size crew consists of one crew habitat and one crew support module of the same configuration as the modules used for the GEO base. Figure 2.2-2 shows more detail of the module configurations. While direct transfer of crew and equipment between the HLLV and the EOTV's is planned, multiple docking ports and excess subsystems capability and power are provided for emergency staging support. If more detailed downstream analyses indicate a need for increasing the crew size, the modular design can accommodate additional modules as required. All modules are compatible with the payload weight and volume capability of both the HLLV and the shuttle derived HLLV.

When the LEO base is fully operational mobile beam fabricators capable of producing the 100 m quad beams of the SCB are assembled (see Section 2.2.2 for a description of the SCB). In the Exhibit C study, the precursor concept entailed use of expended shuttle external tanks (ET's) which were mated by adapters to form the framework of tri-beam fabricators. Figure 2.2-1 shows an ET configuration for SCB quad beam fabricators. Because of the larger size of the SCB beams, use of ET's as the basis of the structure may not be as attractive; the beam machines are larger, more ET's would be required,

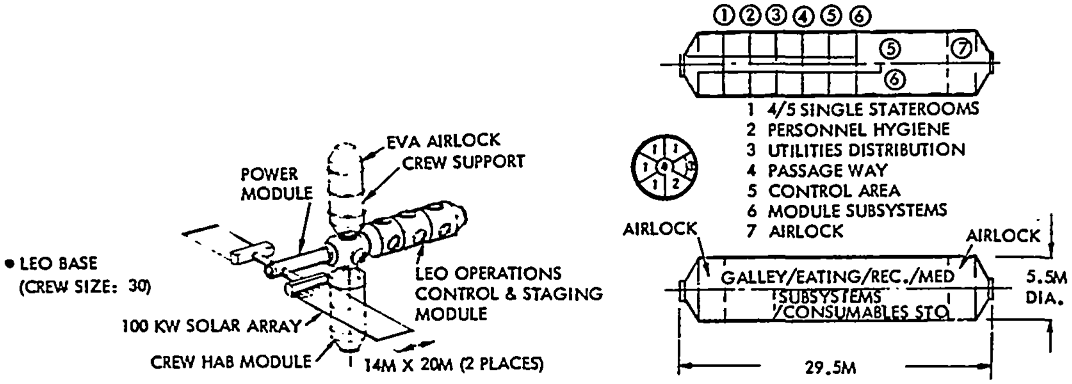


Figure 2.2-2. LEO Base Concept

and considerable structure would have to be added at each corner. As an alternate approach, some of the concepts developed in Rockwell's Space Construction System Analysis Study (MSC contract NAS9-15718) appear to be adaptable to constructing the beam fabricators utilizing beam machines.

The overall concept specifies construction of the SCB in LEO. Although more propellant is required for stationkeeping in LEO than in GEO, the complex operations attendant to installation of SCB special features are anticipated to require considerable EVA, which is more restricted by environment in GEO than in LEO.

The center section of the dual SCB, measuring 2300×4500 m and 200 m deep, is first constructed. Four beam fabricating facilities start at one corner and proceed to construct double 100 m quad beams 90° apart which comprise part of the outer frame. Two additional beam facilities are connected to the frame when the point of the middle 4500 m beam is reached and proceed to construct this beam. Upon completion of the SCB center portion, the outer panel rotation mechanisms are installed; the outer panels are then fabricated as above.

Initially the SCB construction effort is supported by the LEO base (and the SOC, if in operation and in the vicinity). As soon as sufficient structure of the SCB has been completed to accommodate a personnel base, crew habitat and crew support modules similar to those comprising the LEO base will be installed. This base ultimately will support the satellite construction crew.

An initial fleet of six EOTV's will be required to support the early portion of the satellite construction program. It is planned to utilize the SCB for EOTV construction. Since the EOTV is fabricated from 2 m beams, tri-beam fabricators equipped with 2 m beam machines must be constructed and utilized. After the initial fleet of EOTV's is complete, the fabricators will be translated to a parking area until such time as additional or replacement EOTV's are required. Figure 2.2-3 illustrates the construction concept. Up to six EOTV's can be constructed simultaneously.

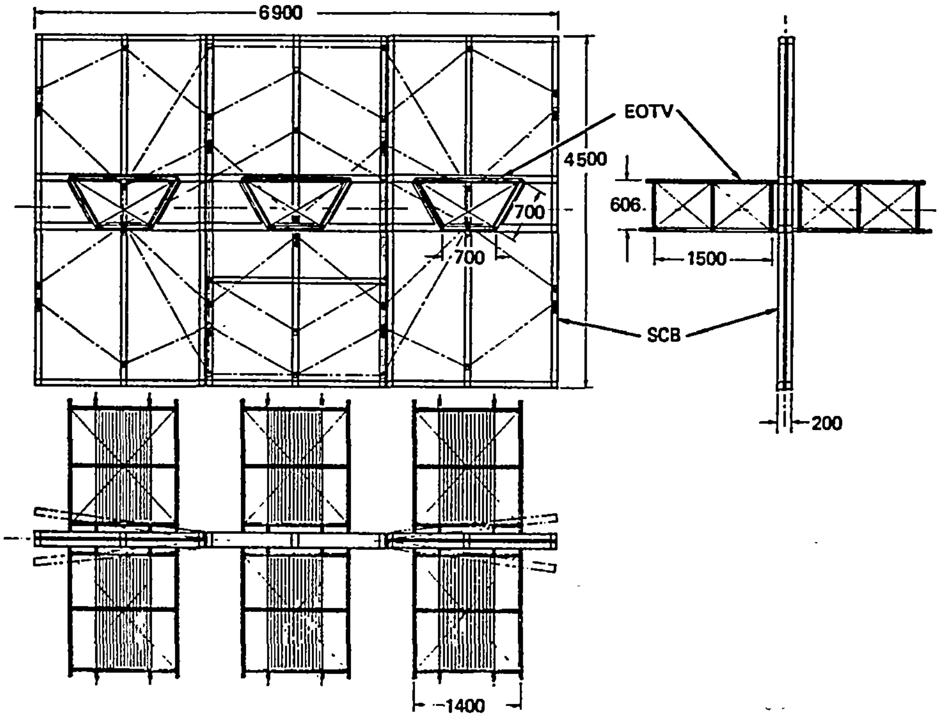


Figure 2.2-3. SCB/EOTV Fabrication
Solid State Concept

The last few EOTV's to be constructed will remain attached to the SCB to provide thrust and attitude control during transit to GEO. Figure 2.2-4 illustrates the concept. The mass of the dual satellite is estimated to be 14.82 M̄ kg. The nominal EOTV payload for the LEO-GEO transit is 6.86 M̄ kg. Determination of the optimum number of EOTV's to be employed for this maneuver requires additional trade studies. Up to six EOTV's, utilizing only the thruster pods on the unattached ends, would provide excess payload capacity and shorter trip time. By decreasing the number of EOTV's to four (or two as illustrated) and augmenting the outboard (from the SCB) thrusters and propellant, the transit still could be accomplished. Upon reaching GEO, the EOTV's are detached and satellite construction commences, with logistics support as shown in the right portion of Figure 2.2-1.

The primary time constraint to the precursor operations is that the SCB must be in GEO and operational commencing the year 2000 in accordance with the current SPS schedule. This constraint influences the overall program approach as related to GBED, orbital demonstration models, LEO base establishment, transportation system development, and SCB construction.

2.2.2 SATELLITE CONSTRUCTION BASE (SCB)

The basic SCB is utilized to produce a single satellite. Two SCB's, attached back-to-back and operating in parallel are required to support construction of the dual satellite configuration. Since the SCB's are identical, a single version is described herein.

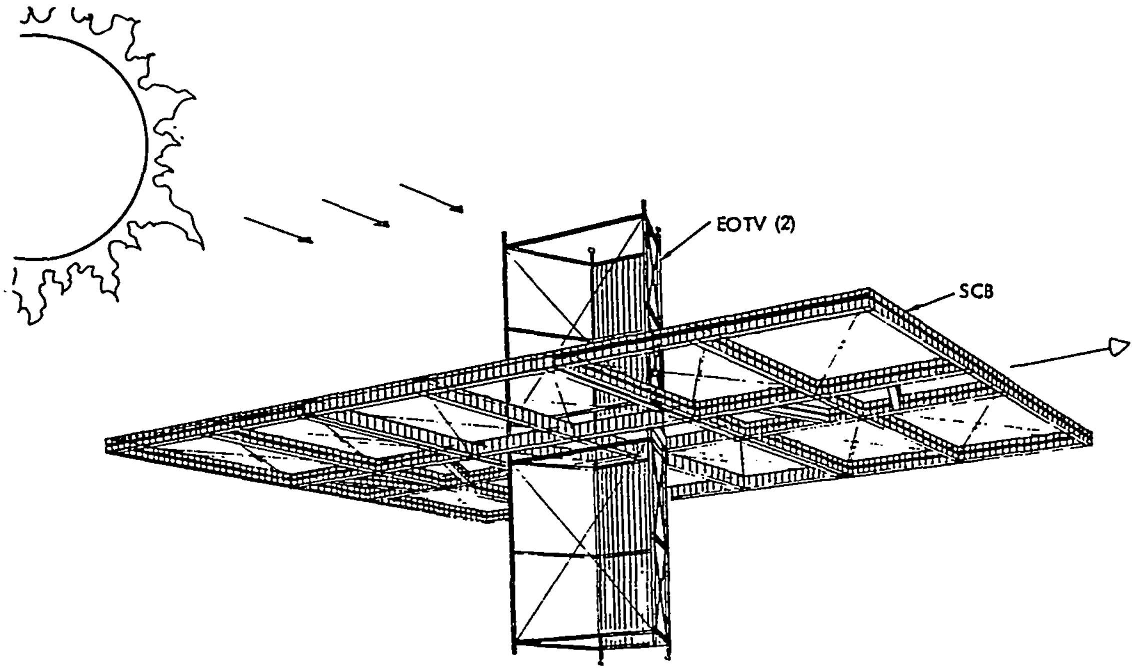


Figure 2.2-4. EOTV/SCB Transfer Configuration
Solid State Concept

The SCB (Figure 2.2-5) is 6,900 by 4,500 meters and is 100 meters deep. The side sections, 2,300 meters wide, are capable of angular rotation to accommodate the satellite reflector intersecting angles. The primary structure consists of square composite beams, 100 meters on a side, built up from 4 meter tri-beams produced by beam machines. The structure contains the construction fixtures, equipment, and base supply facilities. The seven equally spaced beams along the 4,500 meter axis plus decking as required provide the support and tracks for the translatable and rotatable beam fabricating facilities.

The major construction equipment elements include the beam fabricating facilities, deployment equipment for reflector strips, and the facilities for assembling and installing the antenna RF/solar cell modules.

The beam fabricators contain eight beam machines; four for longitudinals and four for cross beams. The beam machines can be translated within the fabricators to accommodate the different sized and shaped beams of which the satellite is comprised. A total of 20 beam fabricating facilities is required to support construction, since some of the operations are conducted in parallel. These fabricators can be translated along the 4,500 meter axis and also can be rotated.

The satellite reflecting surfaces are packaged in rolls 25 meters wide; sufficient material is in each roll to reach across the major axis of the reflector frame without splicing. Each roll is mounted on a spindle type of dispenser from which the 25 meter wide strip is deployed. About 250 dispensers, located as indicated in Figure 2.2-5, are required, since construction of the first three surfaces of the primary mirror requires simultaneously deployment of that many reflector rolls. The end of each roll is secured to the completed

Table 2.2-1. SCB Mass Summary (10^6 kg)

ITEM	MASS
STRUCTURE AND MECHANISMS	2.3819
REFLECTOR INSTALLATION FACILITIES	0.1512
SATELLITE BEAM FABRICATORS	0.2000
RF FACILITIES	1.0356
BASE FACILITIES AND POWER	1.8220
EOTV 50 M TRI-BEAM FABRICATORS	0.0600
MANNED MANIPULATOR MODULES	0.2400
LOGISTICS VEHICLES	0.0360
	5.9267
25% GROWTH	1.4817
SINGLE SCB TOTAL	7.4084
TOTAL MASS FOR DUAL SCB — 14.82×10^6 kg	

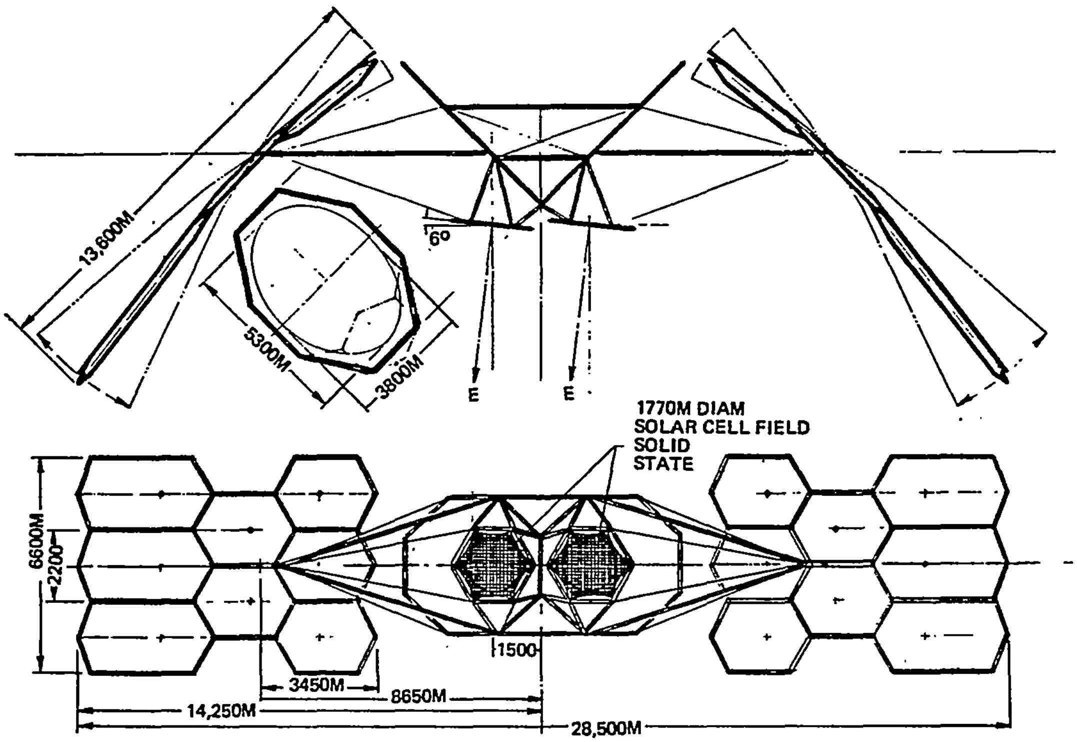


Figure 2.2-7. Solid State Sandwich Satellite Concept

shape. This arrangement provides certain advantages over a single satellite in that solar pressure moments are reduced and ACSS propellant requirements are less for the dual configuration than for maintaining two separate satellites on station.

Each of the two satellites comprising the dual concept has eight primary reflectors, or mirrors, arranged as shown in the figures. These mirrors collect

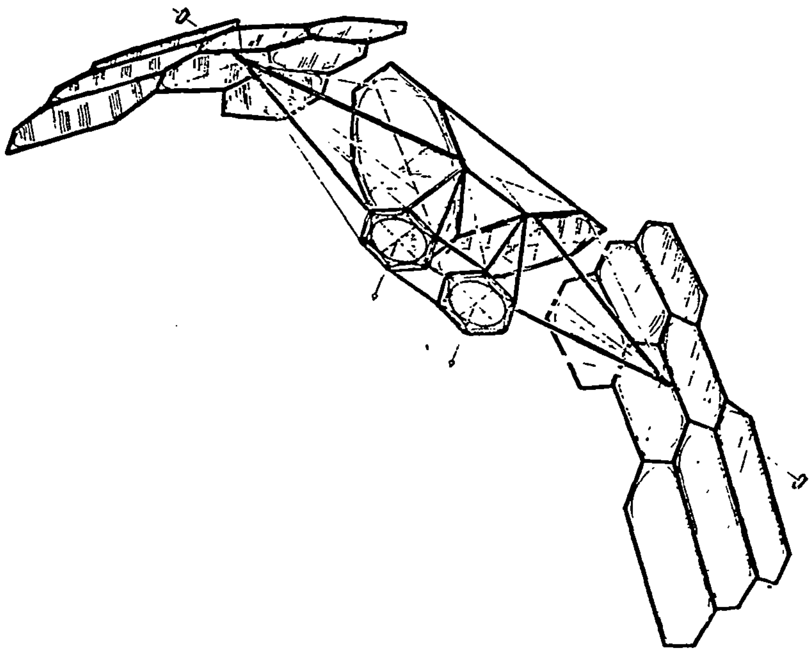


Figure 2.2-8. Solid State Point Design Satellite Concept (Perspective)

the energy from the sun and focus it on the secondary reflector, providing a geometric concentration ratio of 7.7 and an effective concentration ratio of 5.3. The primary mirror planes are tangent to a paraboloid of revolution that has the desired focal length to the solar cell surface (Figure 2.2-9). The primary mirrors are suspended on a frame attached to a rotatable joint as shown to permit adjustment for the seasonal variations of the sun. The reflecting surface of all reflectors consists of aluminized kapton attached to the frame by catenaries which maintain the proper degree of tension.

The secondary reflector is an octagonal frame arrangement (Figure 2.2-8) which is rigid with respect to the antenna and which transmits the solar energy received from the primary reflectors to the solar cells mounted on the face of the antenna. The antenna itself consists of a hexagonal frame with tension web cabling which provides the support for the solid state panels. Solar cells are mounted on the sun side of the panels and the solid state devices utilized for transmission on the earth pointing side. For a more detailed description of the antenna panel design see Volume II, Section 2.0.

The satellite mass summary is contained in Table 2.2-2.

Satellite Construction Concept

Satellite Construction Base (SCB) concepts and construction procedures applicable to the Rockwell reference concept were developed during the prior constractual effort and reported in Volume V of the Final Report, Exhibit C.

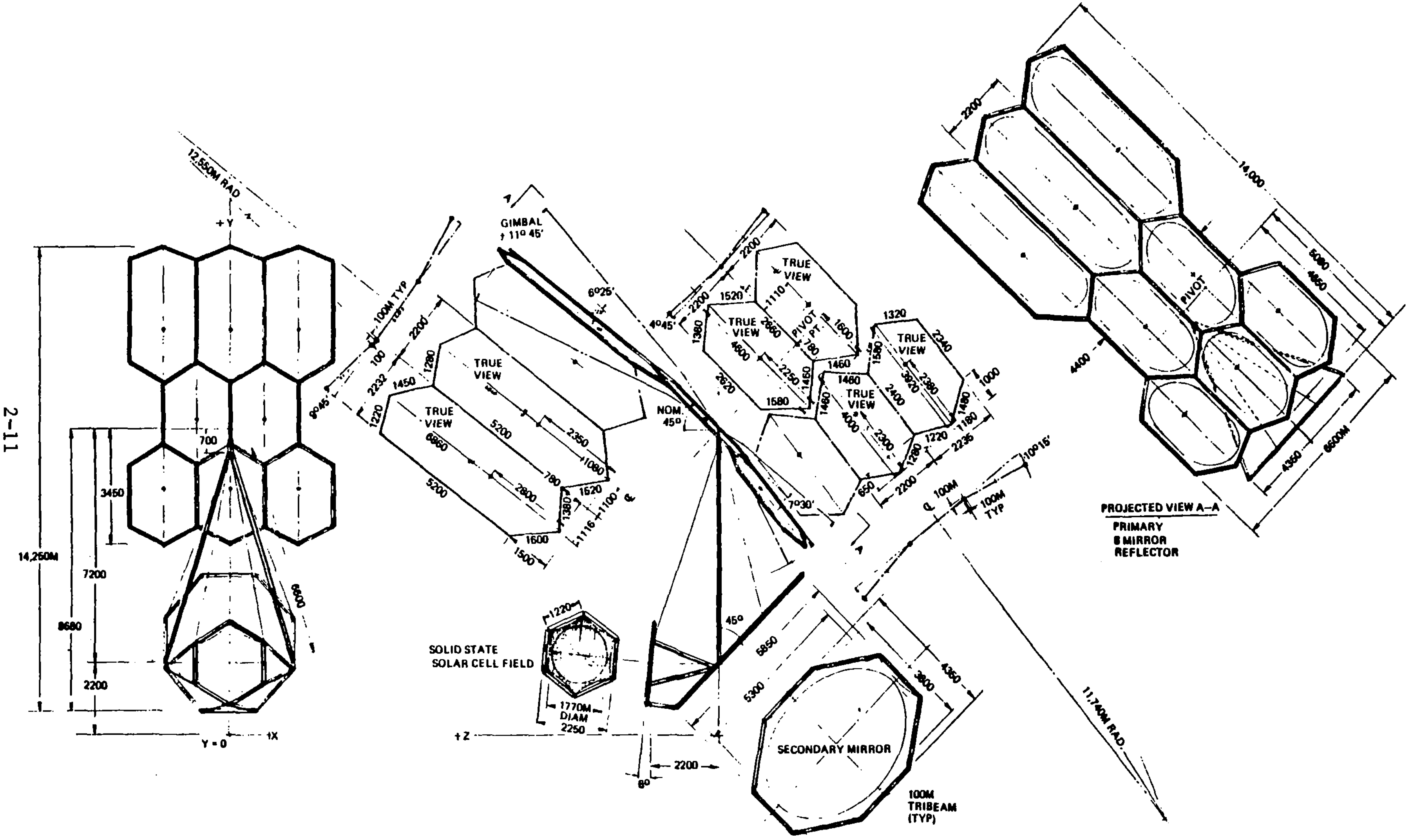


Figure 2.2-9. Solid State Point Design Satellite Concept
(Mirror Detail)

Table 2.2-2. Dual Solid State Satellite Mass Summary (10^6 kg)

ITEM	MASS
ENERGY CONVERSION	
STRUCTURE AND MECHANISMS	3.539
CONCENTRATOR	2.075
AUXILIARY SOLAR PANEL	0.076
POWER DISTRIBUTION AND CONTROL	0.015
INFORMATION MANAGEMENT AND CONTROL	0.033
ATTITUDE CONTROL	0.103
SUBTOTAL	5.841
POWER TRANSMISSION	
STRUCTURE AND MECHANISMS	1.165
SUBARRAY	8.821
ANTENNA CONTROL ELECTRONICS	0.340
INFORMATION MANAGEMENT AND CONTROL	0.256
SUBTOTAL	10.582
TOTAL (DRY)	16.423
GROWTH (25%)	4.106
TOTAL WITH GROWTH	20.529 × 10^6 kg

The solid state satellite concept developed under the current contract bear little resemblance to the reference concept. Construction of this concept requires a satellite construction fixture of an entirely different configuration than the SCB of Exhibit C. However, maximum utilization of previously developed techniques and procedures has been made. For example, tri-beam or double tri-beam fabricating facilities equipped with the required number of beam machines similar to those described in previous reports will be used for primary structure fabrication. Installation of reflector rolls can be accomplished either by mobile facilities traversing cables across the reflector frame or by securing the leading reflector edge to a previously completed beam and deploying the reflector from rolls as the beam advances during the course of structural fabrication. The latter concept also was developed in earlier reports. The use of construction support equipment, e.g., manned manipulator modules (cherry pickers) such as were hypothesized for construction of the reference concept, is still applicable.

The program buildup for the Rockwell reference concept specified the construction of two satellites per year, with a total of sixty satellites producing 5 GW each. Because of the smaller output of the solid state satellite, 250 single satellites or 125 dual satellites will be required to produce the same amount of power. Assuming the same 30 year construction program as the reference concept, an average of 8 single satellites or 4 dual satellites must be produced initially, with the rate subsequently increased to 5 per year. Since construction of 8-10 satellites per year with a single SCB does not appear realistic, two satellite construction fixtures will be required to support this production rate. The general concept for constructing either a single or a dual satellite is the same; however, two construction fixtures operating in parallel are necessary for simultaneous fabrication of the two satellites comprising the dual configuration. In the following sections the scenarios for constructing a single satellite is developed, followed by overall procedures required to adopt the process to the dual configuration.

Single Solid State Satellite

The configuration of the reflector construction/deployment cradle, hereafter referred to as the Satellite Construction Base (SCB) for the initial phase of the construction is shown in the left portion of Figure 2.2-10. A description of the SCB appears in Section 2.2.2. The two outermost sections of the SCB have been translated upwards to conform to the angles formed by the intersections of the thre primary reflectors designated as set 1.

The first step in the construction process is to fabricate and join the crossbeams which make up the end legs of the set 1 hexagonal frames. The lower left portion of the figure shows the location on the SCB and the construction sequence for this operation. Following this step, the forward beam fabrication facilities are retracted and positioned for the next operation in which they will be used. The facilities for fabricating the longitudinal members of set 1 are then positioned and secured to the crossmember intersections. At this point, the reflector catenaries are secured to the trailing edges of the first crossmember set and the leading edge of the reflector rolls are attached to the catenaries. As the construction of the longitudinal members progresses, the reflectors are payed out from dispensers by the advancement of the crossmembers as shown in Step 2 of the figure. (As indicated earlier, an alternative concept entails use of mobile cable-riding facilities which traverse the face of the reflector.) During the roll deployment process, automatic equipments secure the edge of one strip to the edge of the ajoining strip to form a continuous reflecting surface. The side catenaries also are installed and the outermost reflector strips attached to the catenaries as the beams advance. The ACSS thruster pods, located at the apex of the middle hexagon, are installed before the first set of crossmembers advances past the SCB. These pods may be used as necessary to assist in subsequent rotations.

Upon completion of the longitudinal members, they are attached to the second set of crossmembers, closing the hexagons, and the trailing edges of the reflectors secured to the catenaries. This completes the fabrication of mirror set 1 as shown in the upper left portion of Figure 2.2-11.

Prior to start of mirror set 2, the longitudinal beam fabricators are repositioned and the gimbal towers prepared for the rotation maneuver. The SCB is then rotated 6°25' about the towers as shown in the lower left of the figure. The SCB ACSS, augmented as required by the set 1 thruster pods, is utilized for the rotation. Upon completion of the rotation, 3 longitudinals are attached to set 1 crossmember intersections and construction of mirror set 2 proceeds as described above for set 1.

Before the completed set 2 clears the SCB, the basic fitting for the "A" frame structure about which the primary mirrors will rotate is installed.

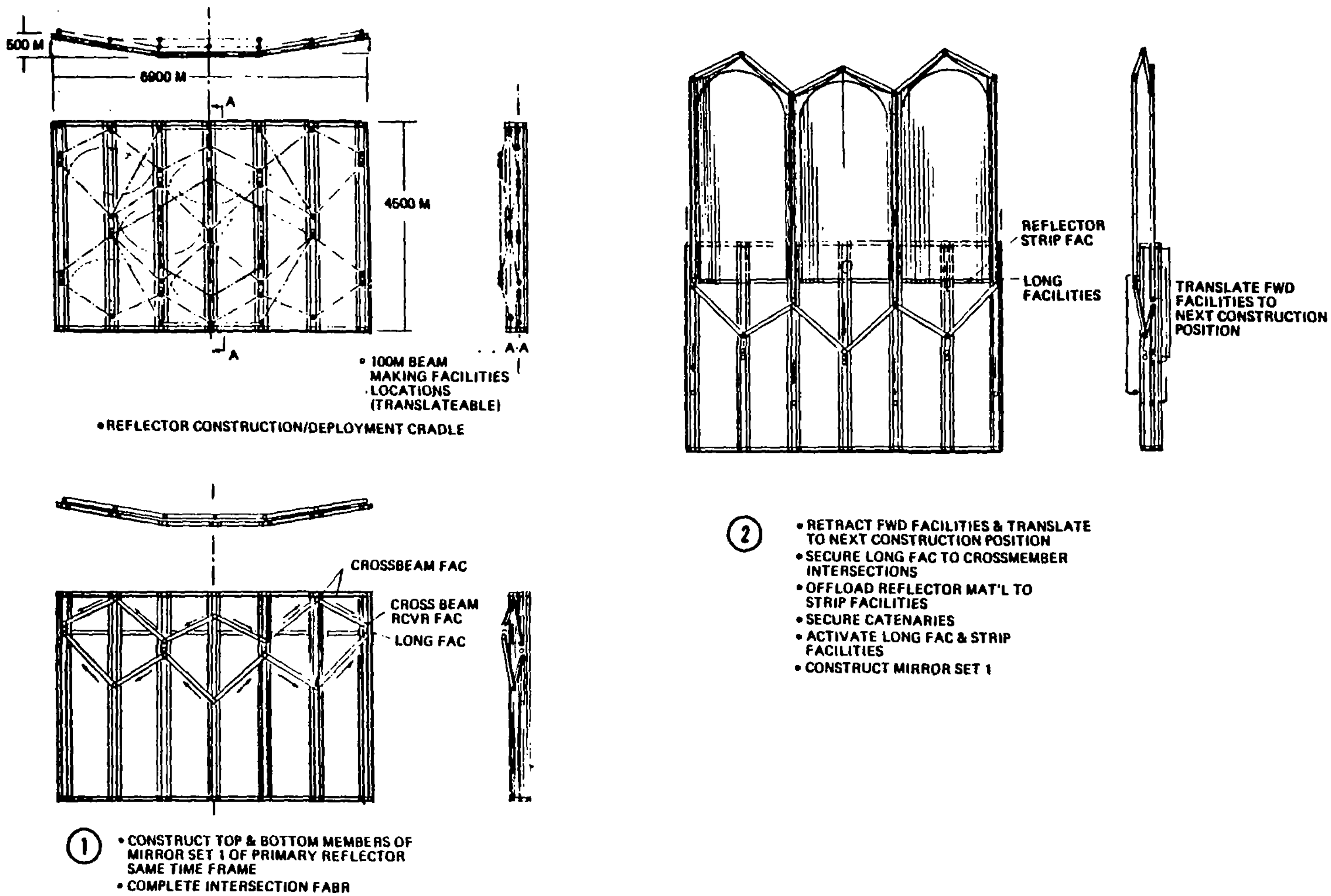


Figure 2.2-10. Satellite Construction Sequence (Mirror Set 1)

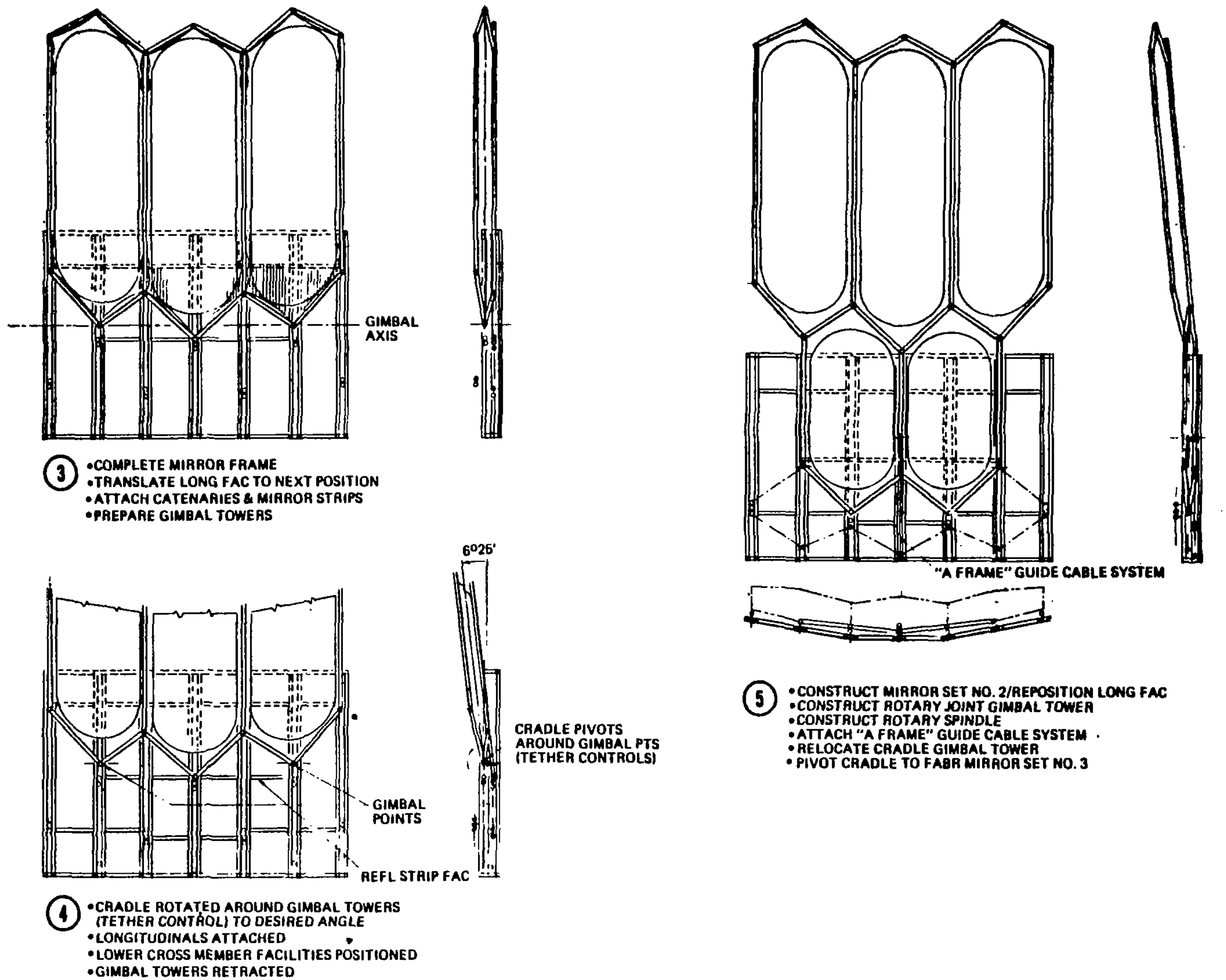


Figure 2.2-11. Satellite Construction Sequence (Mirror Set 2)

This fitting essentially is an extension from the mirror beam structure that ultimately will provide a rotating capability and provision for attaching the "A" frame beams. The fitting consists of a tower attached to a spindle housing for "A" frame interface. The "A" frame guide cable system supports are installed at this time. The SCB is then rotated about the gimbal towers to be in the proper position for fabricating mirror set 3, which is accomplished in the same manner as described for set 1. Figure 2.2-12 (left side) shows the completed primary mirror system.

The SCB must now be reconfigured for the next step in the overall operation. The side panels are translated as shown in view A-A of the figure to form a plane surface. The SCB is then translated 4100 meters with respect to the completed primary mirrors, locked in position, the "A" frame support cables installed, and the beam fabrication to be used in constructing with "A" frame members positioned. The cables are then utilized for a minor SCB rotation.

The right portion of Figure 2.2-12 shows the almost completed "A" frame. Initially the side members of the frame are constructed as shown by the lines across the base of the "A" frame. The spindle housing previously referred to is constructed around the center guide cable and then connected to the partially completed frame beams. As the fabrication of the beams progresses, the spindle housing forming the apex of the frame advances on the cable until it reaches and is attached to the tower which was installed previously.

Referring to Figure 2.2-13, completion of the "A" frame will extend the SCB to the proper position relative to the primary mirrors. The SCB is then rotated 45° around the "A" frame base by using the cable system and the facilities are repositioned. ACSS is available for augmentation as required. This maneuver places the SCB in position for fabricating and installing the antenna frame, and fabricating the secondary reflector.

After SCB rotation the antenna frame is fabricated as shown in the left portion of Figure 2.2-14. Prior to this operation, the stabilizing cable system is moved from the center to the sides of the SCB. Following antenna frame construction gimbal fittings are installed, the catenaries and tension web cables strung, and the antenna support structure partially fabricated and attached to the gimbal fittings. A set of stabilization cables is then rigged as shown in the right side of the figure. Completion of the antenna support structure beams, combined with exercise of the antenna support cables, provides a force which causes the antenna to translate upwards from the SCB as shown in Figure 2.2-15. When the support structure beams are completed, the antenna will be in correct position relative to the secondary reflector. Once the antenna is in place, installation of the solid state modules commences. While this operation, described later in this section, is underway, the secondary reflector framework is fabricated (Figures 2.2-16 and 2.2-17) and the reflector surfaces installed as indicated in the figure, following the same general procedures utilized in constructing the primary mirrors. This operation completes the satellite, which is then checked out and placed in commission. The SCB is separated and proceeds to the next satellite location, starting the construction process enroute.

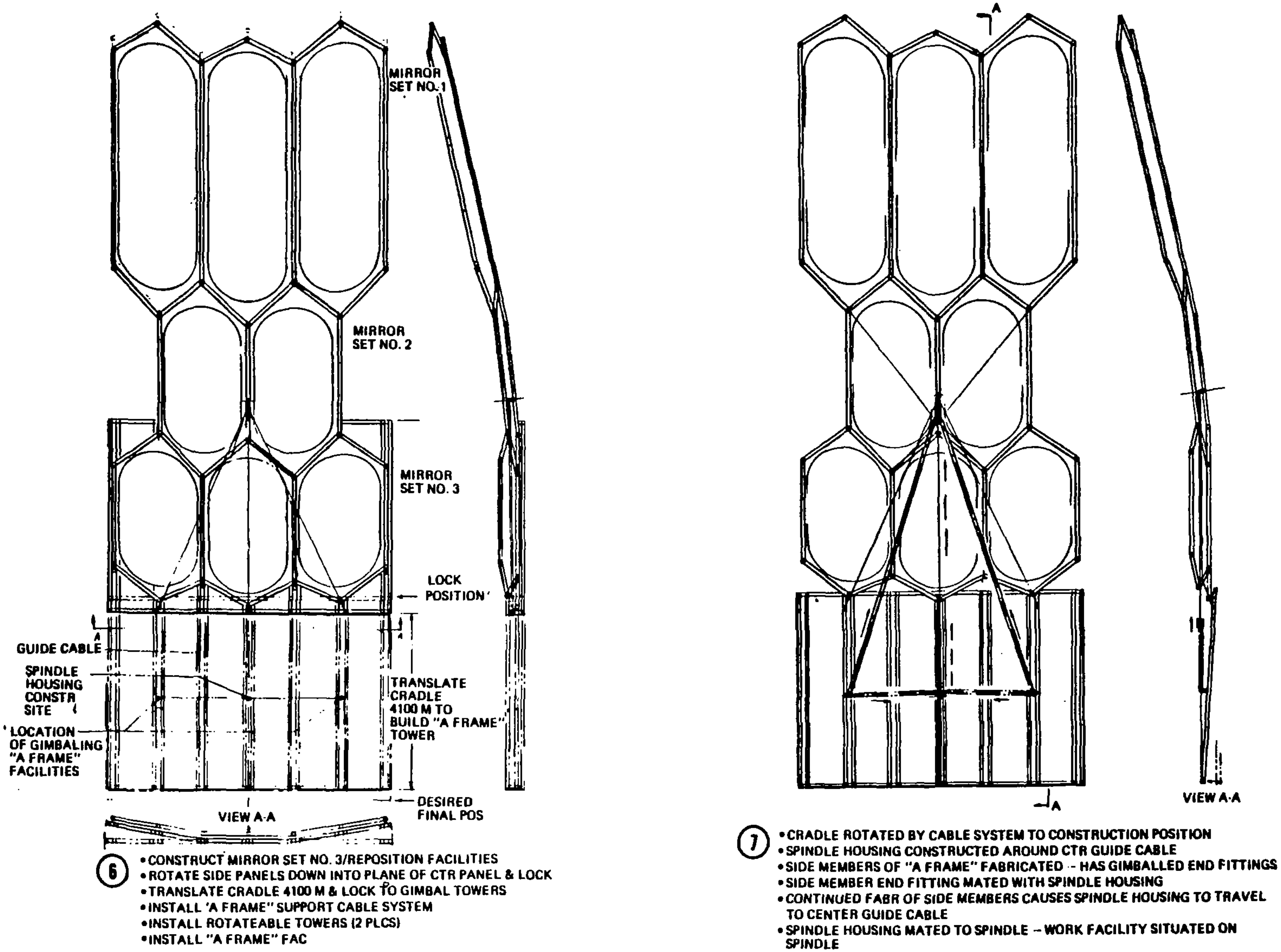


Figure 2.2-12. Satellite Construction Sequence
(Mirror Set 3 and Mirror "A Frame")

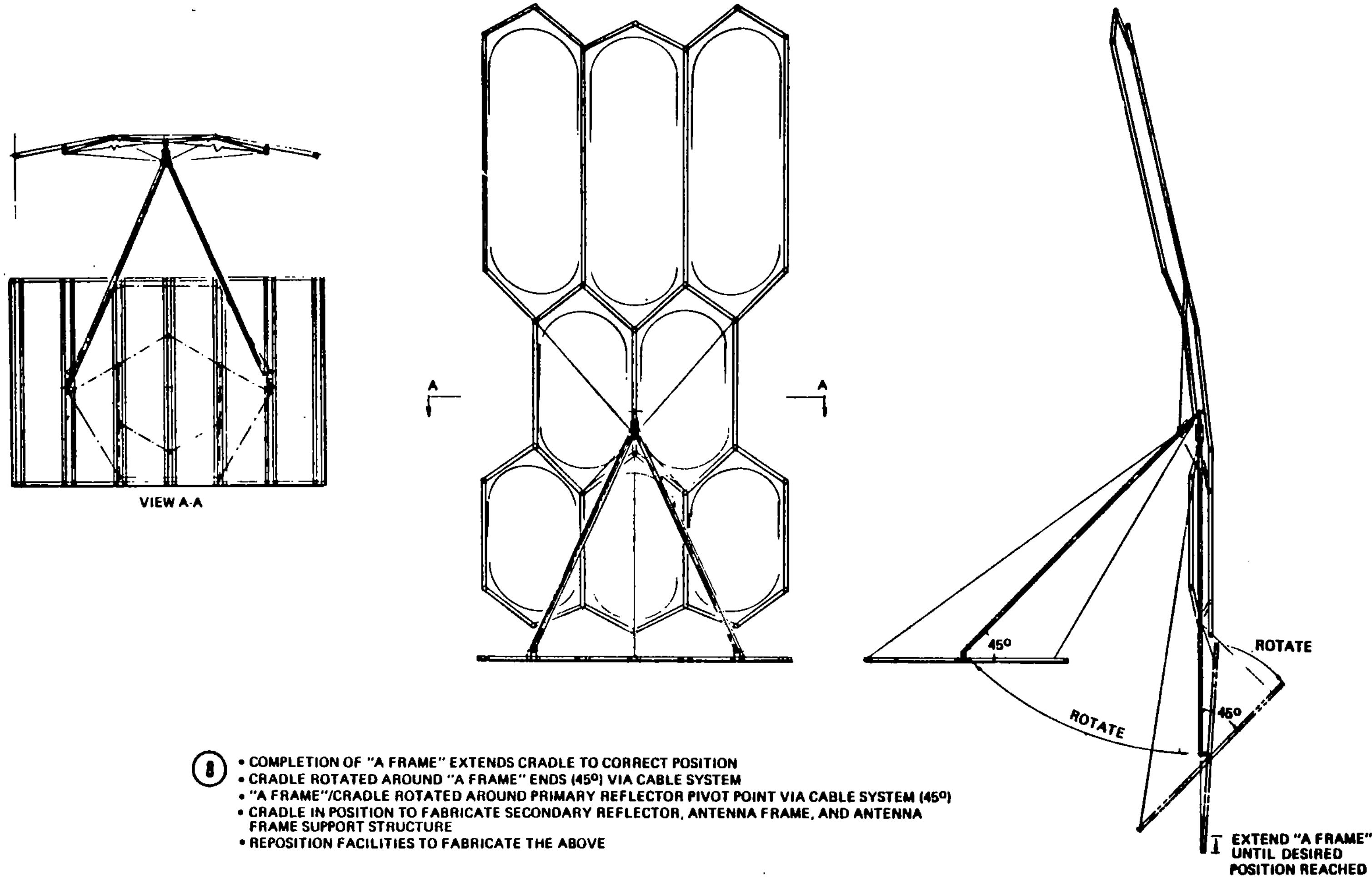
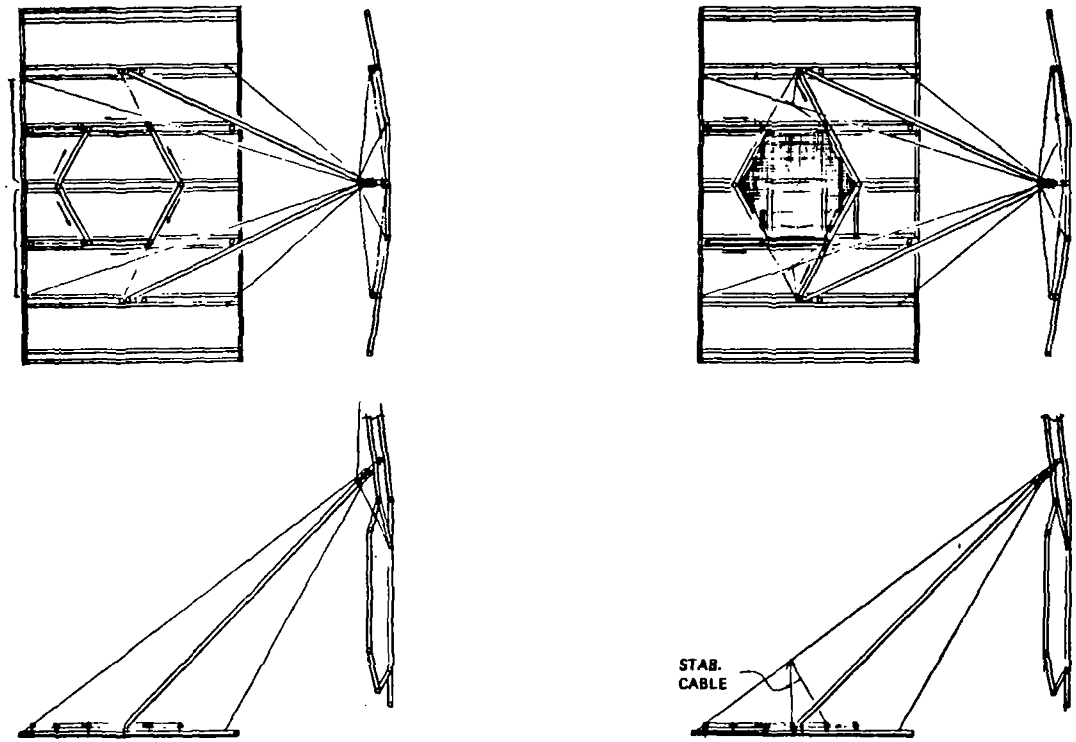


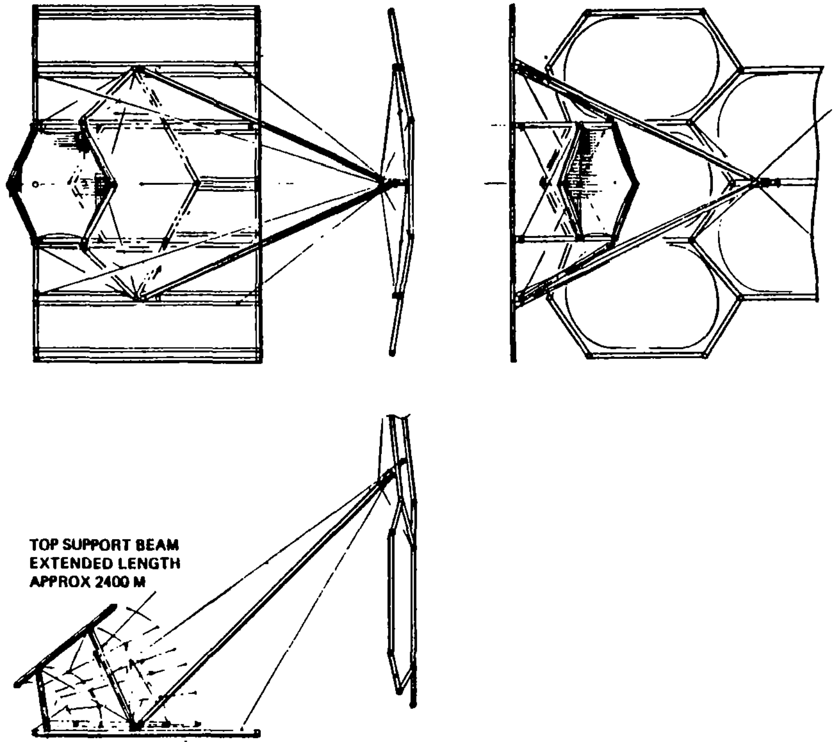
Figure 2.2-13. Satellite Construction Sequence ("A Frame" Completion and Cradle Rotation)



(9)
- MOVE FWD STABILIZING CABLE SYSTEM FROM CENTER TO SIDES
- FABR ANTENNA HEX FRAME
- INSTALL GIMBAL FITTINGS (8 PLCS)

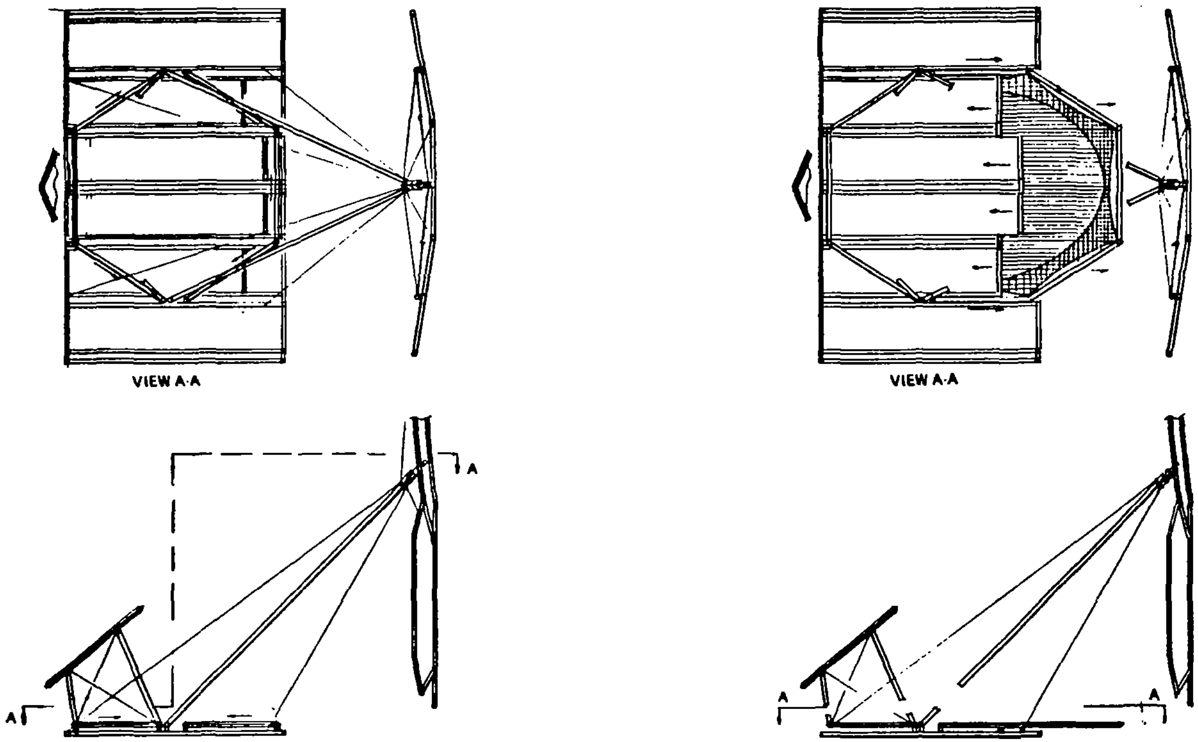
(10)
- INSTALL ANTENNA CABLE/PLATFORM (50 M DEEP) SOLID ST MOD FAC
- INSTALL ANTENNA CATENARY/CABLE NETWORK 30 M GRID
- USING ABOVE – STRUCTURE & INSTALL/MAINT TOOLS COMPLETED
- FABR ANTENNA SUPPORT STRUCTURE
- ATTACH SUPPORT STRUCTURE TO GIMBAL FITTINGS
- STAB CABLES ATTACHED

Figure 2.2-14. Satellite Construction Sequence
(Antenna Fabrication)



(11)
- ANT HEX FRAME ROTATED INTO POSITION
  - THE FABR OF TOP SUPPORT BEAMS FROM LENGTH 1200 M TO FINAL LENGTH ~ 2400 CAUSES ANT HEX FRAME & LWR SUPPORT BEAMS TO ROTATE AROUND FWD GIMBAL FIXTURES
- ANT ROTATION INITIATED BY SUPPORT STAB CABLES ATTACHED TO "A FRAME" STAB CABLE SYSTEM
- SUPPORT STAB CABLES DEPLOYED INTO POSITION WITH ROTATION OF HEX FRAME

Figure 2.2-15. Satellite Construction Sequence (Antenna Installation)



(12)
- ANTENNA HEX FRAME SUPPORT STRUCTURE STAB CABLES INSTALLED AND TENSIONED
- BEGIN UNLOADING OF SOLID STATE MODULES TO ANT CABLE/PLATFORMS
- BEGIN FABR & INSTALLATION OF SOLID STATE ELEMENTS TO ANTENNA CABLE GRIDWORK
- FABR SECONDARY MIRROR END MEMBERS
- FABR & INSTALL INTERSECTION STRUCTURE
- REFL STRIP DEPLOYMENT PLATFORMS IN PLACE & LOADED

(13)
- ATTACH CATENARYS TO REFL FRAME INTERSECTIONS
- FABR LONG BEAMS/DEPLOY REFL STRIPS
- COMPLETE ATTACHMENT OF SUPPORT MEMBERS TO REFL STRUCTURE
- COMPLETE CLOSEOUT OF LONG BEAMS TO FWD CROSS MEMBERS
- DEPLOY REFL STRIP PLATFORM TOWARD FWD END OF SECONDARY MIRROR

Figure 2.2-16. Satellite Construction Sequence (Secondary Mirror)

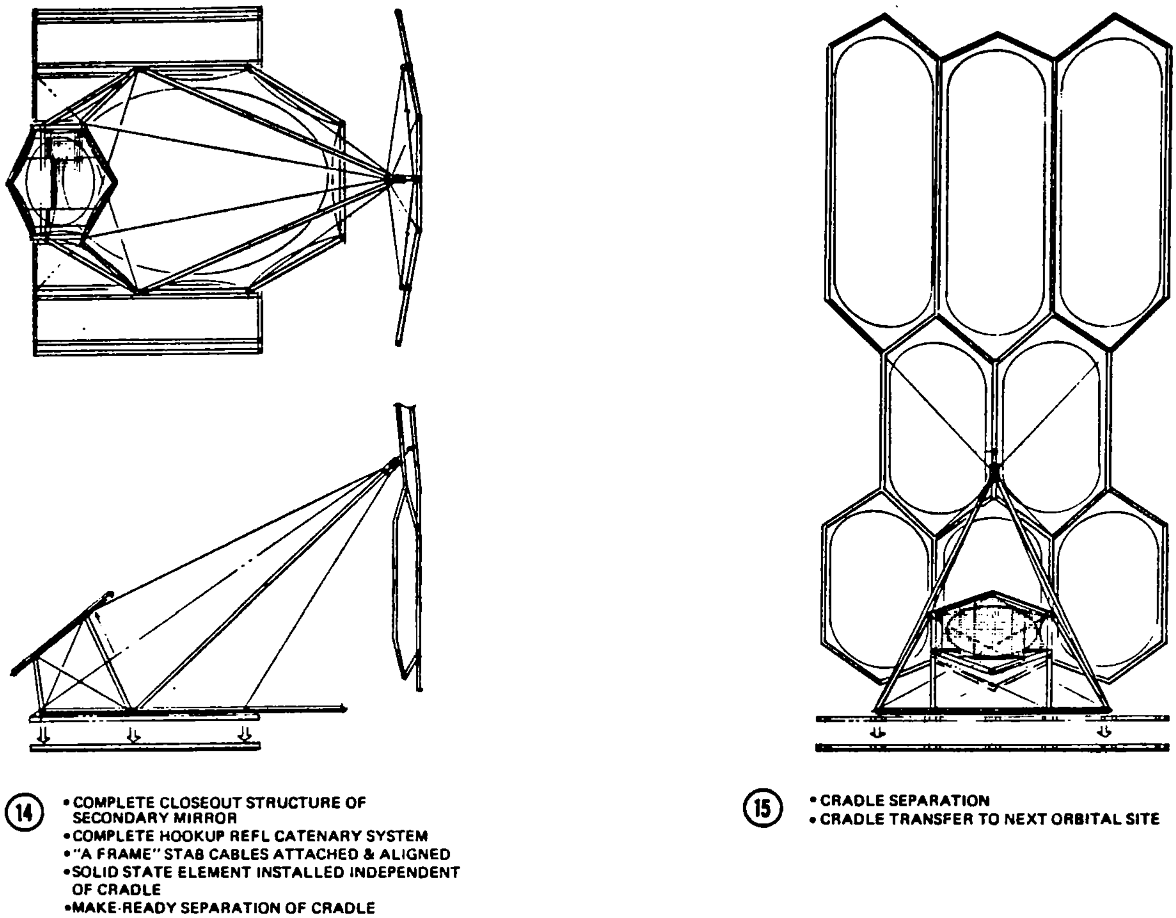


Figure 2.2-17. Satellite Construction Sequence
(Secondary Mirror Complete)

<u>Dual Solid State Satellite</u>

Construction of this satellite configuration, shown in Figures 2.2-7 and 2.2-8, requires the use of two SCB's, mounted back-to-back as a single unit. Each SCB initially constructs a separate primary mirror assembly, following the procedures described in the proceding section. Since the tandem SCB's cannot rotate with respect to each other, each completed mirror set is rotated to attain the proper angle for construction of the next set. Figure 2.2-18 illustrates the tandem SCB's which have completed three primary mirror assemblies and have attached the partially completed "A" frames and support cable system. The "A" frame members are then completed and the primary mirrors rotated with respect to the SCB to achieve the desired angular displacement. As shown in Figure 2.2-19, the left "A" frame is completed first and the rotation effected by utilizing the cable system to obtain the configuration shown in the right portion of the figure. The right mirror assembly is then rotated in a similar manner, resulting in the arrangement illustrated in Figure 2.2-20.

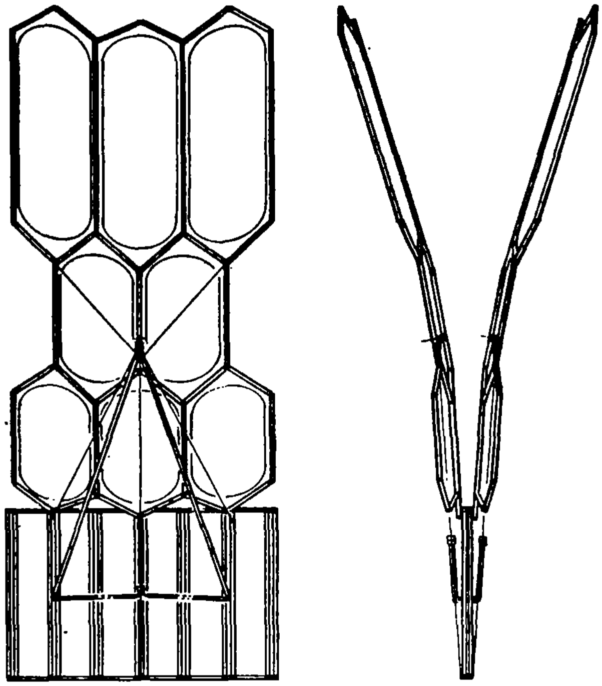


Figure 2.2-18. Dual Satellite Construction Sequence
(Primary Mirrors Complete)

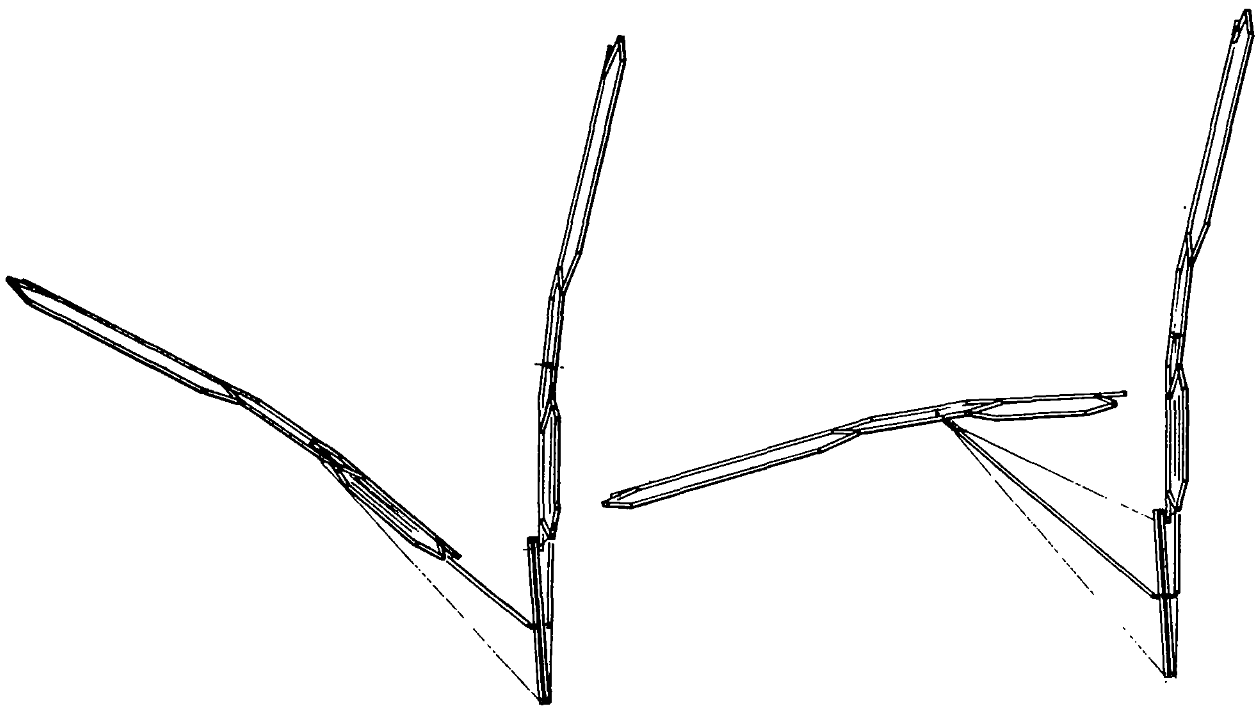


Figure 2.2-19. Dual Satellite Construction Sequence
(Primary Mirror Rotation)

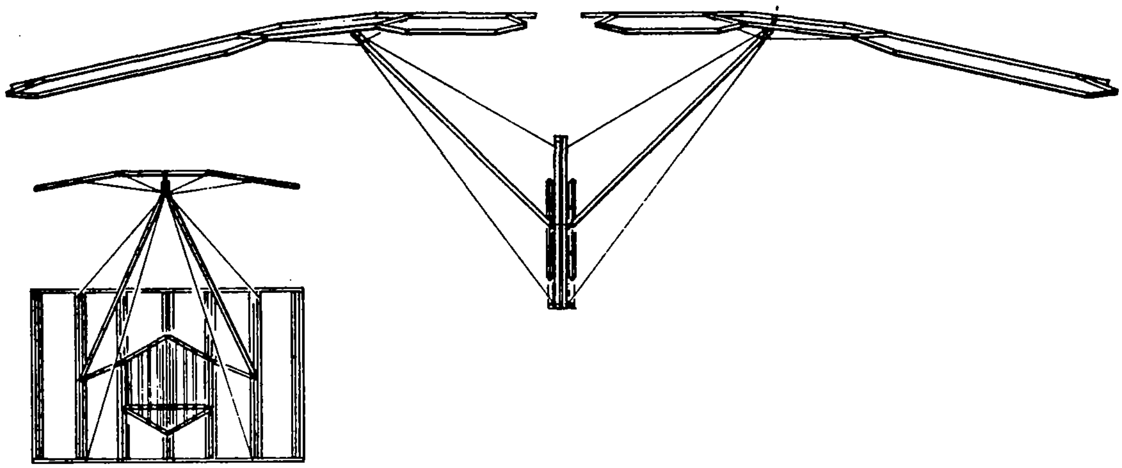


Figure 2.2-20. Dual Satellite Construction Sequence
(Antenna Frame Fabrication)

After the rotation operation has been completed, the antenna frame is fabricated and the tension web cabling installed as shown in the left of the figure. The mobile antenna assembly and installation facilities, described in the next section, are then mounted on their cable system. The antenna is now ready for final positioning, accomplished as described earlier by a combination of beam building extension and cabling. In Figure 2.2-21, the antennas have been rotated and are in their final position with respect to the SCB. The antennas are mounted at slightly different angles with respect to the reflectors (see Figure 2.2-7) because of the ground receiving station locations; each antenna transmits to a dedicated antenna. Installation of antenna panel assemblies then proceeds.

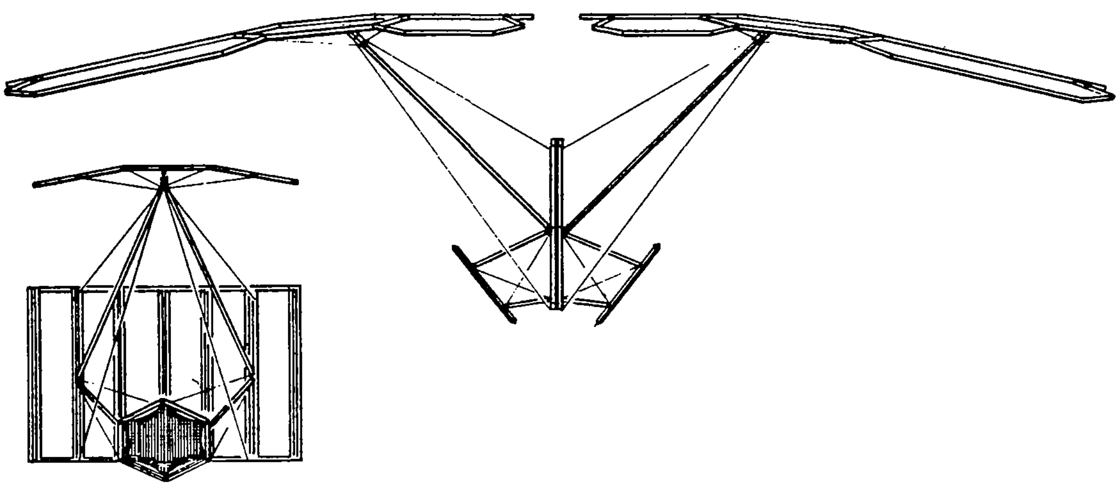


Figure 2.2-21. Dual Satellite Construction Sequence
(Antenna Rotation Complete)

While the panels are being installed on the antenna, the secondary reflectors are constructed, following procedures described for a single satellite in the preceding section. At the left of Figure 2.2-22, the antenna panel installation facilities are shown progressing across the face of the antenna. The partially constructed secondary reflector is shown on the face of the SCB. The upper right illustration of the figure shows the position of the completed reflectors relative to the SCB.

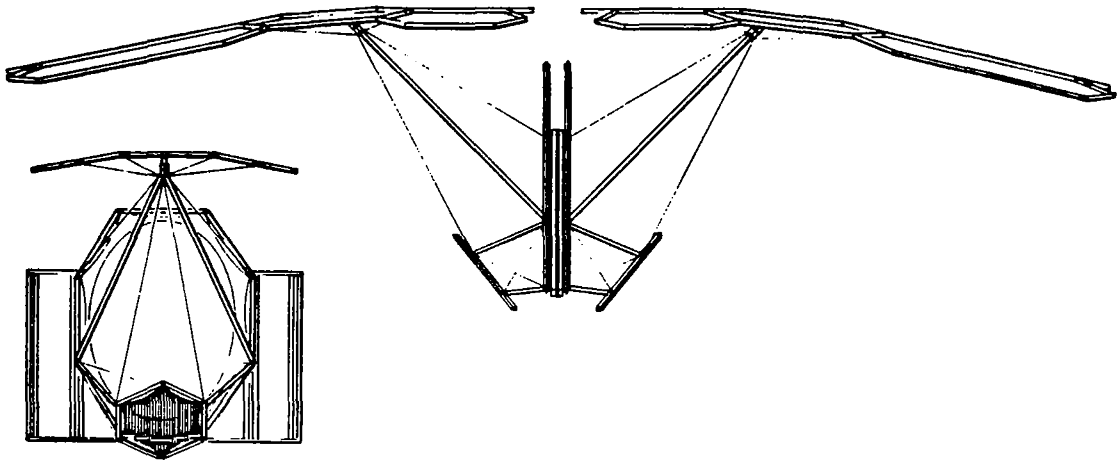


Figure 2.2-22. Dual Satellite Construction Sequence (Secondary Mirror Fabrication)

The next step in the operation is construction of the beams which secure the two satellites together. As the beams progress, a cable system, augmented by beam advance and by RCS as required, is utilized to rotate the secondary reflectors towards their final position. This operation has commenced in the upper half of Figure 2.2-23. One reflector has been detached from the SCB and rotated, while the other reflector is still secured to the SCB. When the beams have been completed, the final configuration (lower part of figure) will have been achieved. Incident to the operation, the SCB has been translated upwards with respect to the reflector; after completion, it is translated further as shown in the upper portion of Figure 2.2-24. Following satellite checkout, the mobile panel facilities are transferred from the antennas to the SCB (lower part of figure), and the SCB separated; it then proceeds to the site of the next satellite construction operation, commencing fabrication en-route.

Antenna RF Installation

The overall antenna structure and tension web installation takes place after completion of the primary mirror assembly as noted in the preceding sections. The tension web itself consists of a network of composite cabling secured to the catenaries at each leg of the hexagon. The cables are spaced at 30 meter intervals to form an arrangement as illustrated in Figure 2.2-25.

The current solid state design concept specifies a 30x30 meter mechanical module as the size of the element to be installed on the antenna. These modules are comprised of 5x5 meter segments which are compatible with HLLV payload

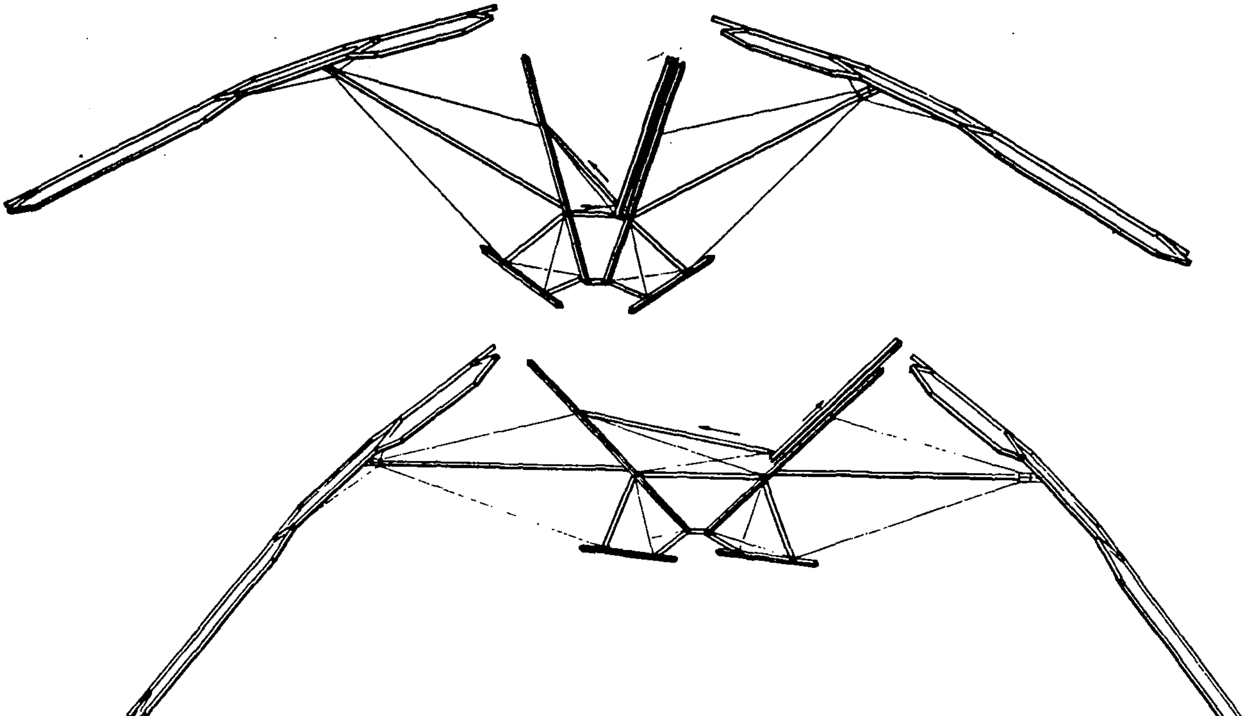


Figure 2.2-23. Dual Satellite Construction Sequence
(Connecting Beam Fabrication and Final Rotation)

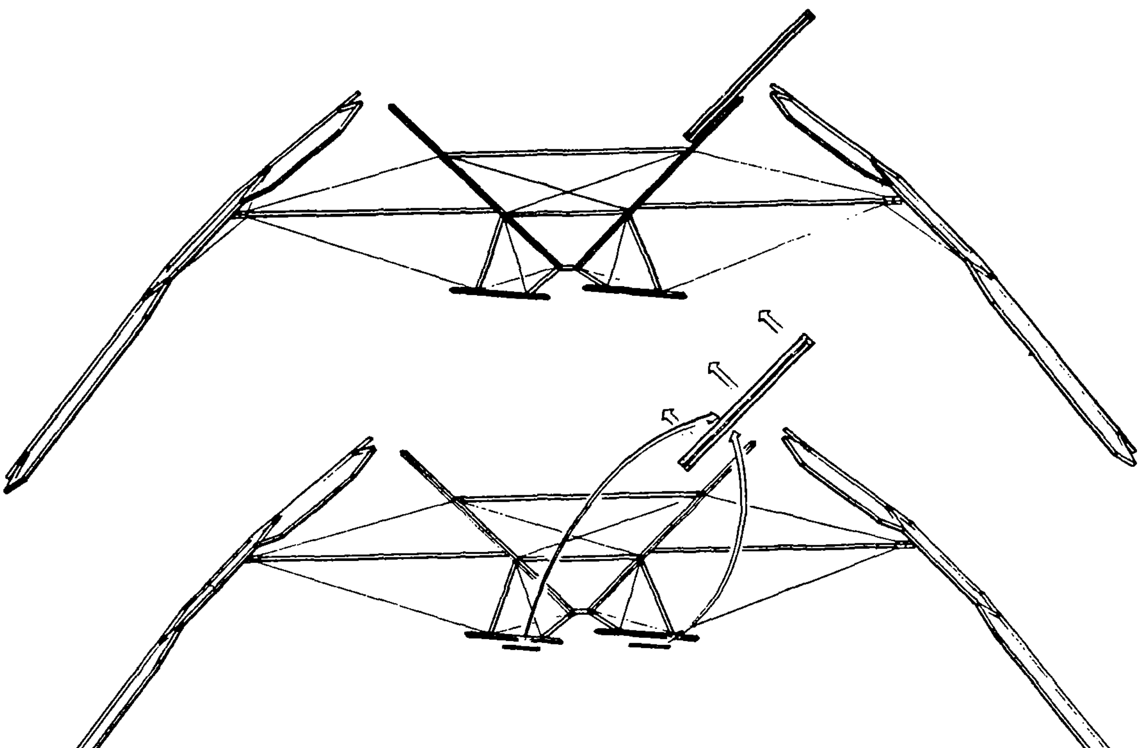


Figure 2.2-24. Dual Satellite Completion
(Cradle Translation and Separation)

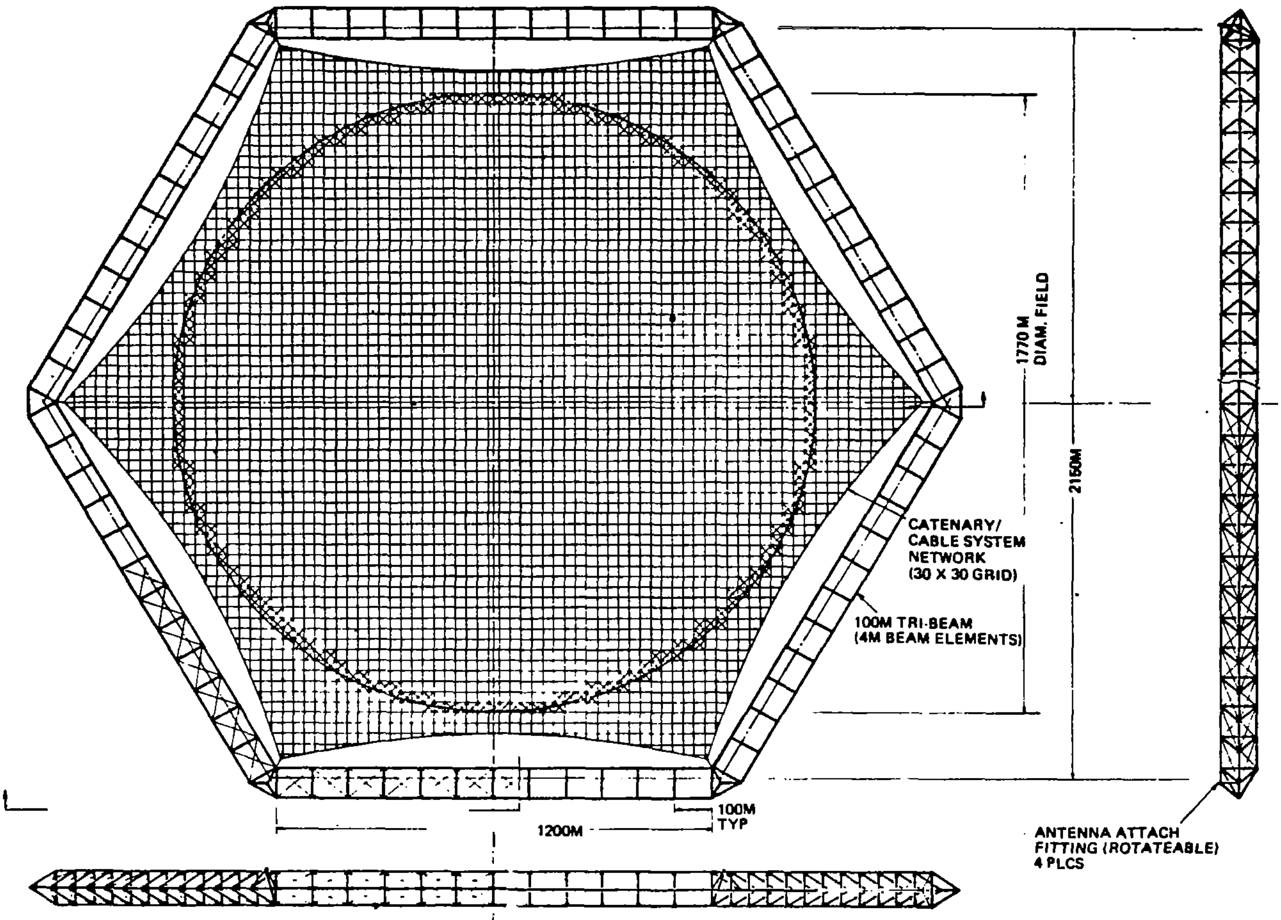


Figure 2.2-25. Tension Web Hex-Frame Antenna
Solid State Modules

constraints. The concepts described herein reflect these dimensions. The results of additional studies of the solid state sandwich concept may result in minor dimensional changes; the concepts presented can be accommodated to reflect any such changes.

A total of 2800 30x30 meter modules are required to fill the 1770 meter antenna aperture. Since each module contains 36 elements measuring 5x5 meters, a total of over 100,000 elements must be assembled into the larger modules. Assembly and installation of these modules becomes one of the pacing items in the 90 day construction schedule allocated for each satellite, particularly since a number of construction operations, i.e., primary mirrors, must be completed before work starts on the antenna.

Because of the geometry and construction sequence of the dual satellite, assembly and installation of the antenna mechanical modules, or panels, must be accomplished by mobile facilities which are based on the SCB when not in use. There are fourteen of these facilities; seven for each of the two antennas on the dual satellite, all of which are interchangeable. As shown in Figure 2.2-26,

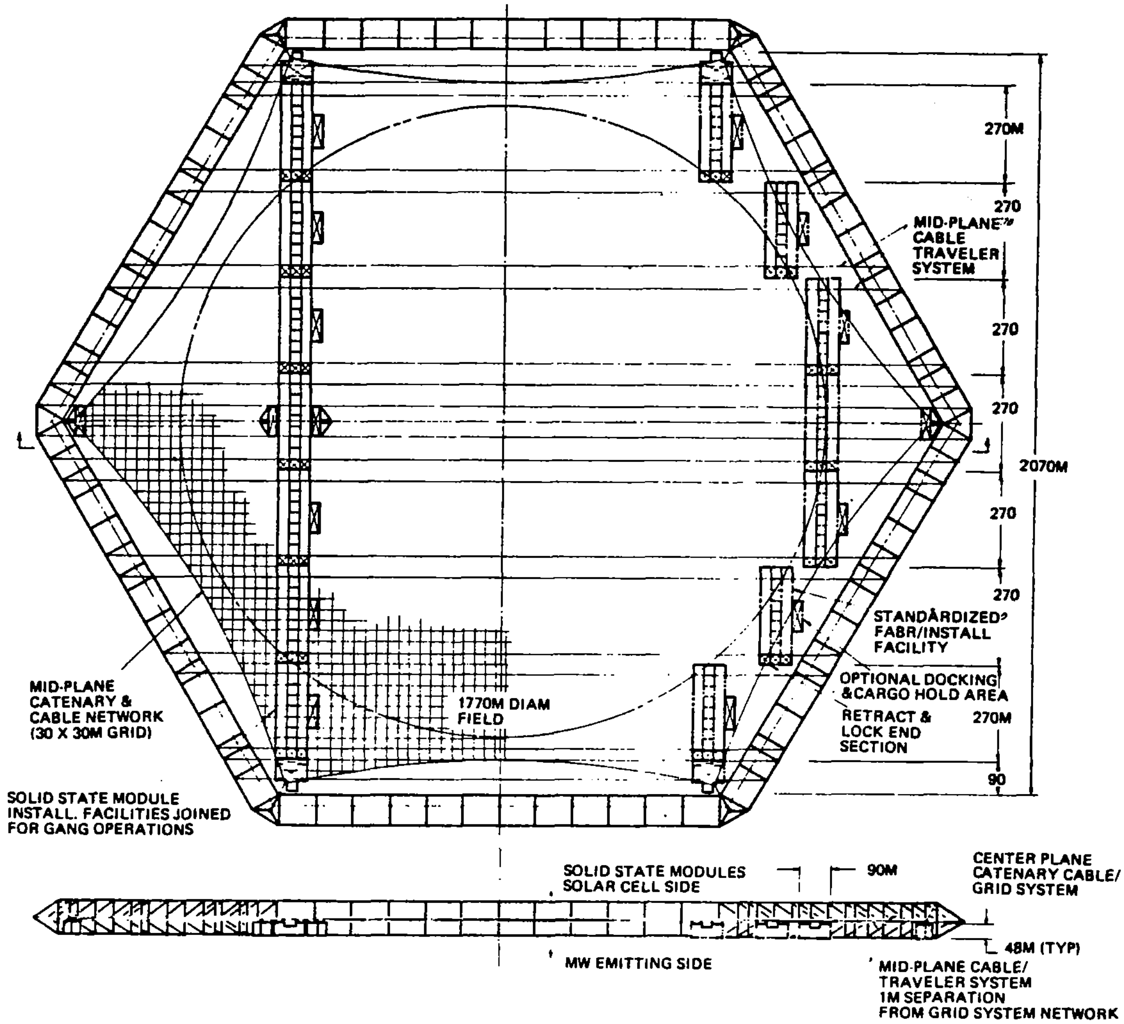


Figure 2.2-26. Solid State Module Assembly/Installation Facility Concept—Standardized Cable Walking Platforms

each facility can operate independently or be attached to other facilities for gang operation. More details of the facility are contained in Figure 2.2-27. The facilities, designed to ride special cables, contain provisions for receiving the 5x5 meter panels, assembling them, and installing them. They are assembled on a rotatable table as indicated at the lower left of the figure. After assembly, each half of the table swings downward and the module is translated on tracks to the tension web for installation.

Upon completion of the antenna and installation of the tension web (Figure 2.2-14), the panel facilities are moved into their initial position as shown in the right part of Figure 2.2-26. After panel installation has been completed on the right segment of the aperture circle, the facilities may either be ganged or operate independently until the left segment is reached. After the installation has been completed, the facilities are returned to their parking position on the SCB and the support cables shifted. These cables otherwide would create shadows on the face of the antenna solar array.

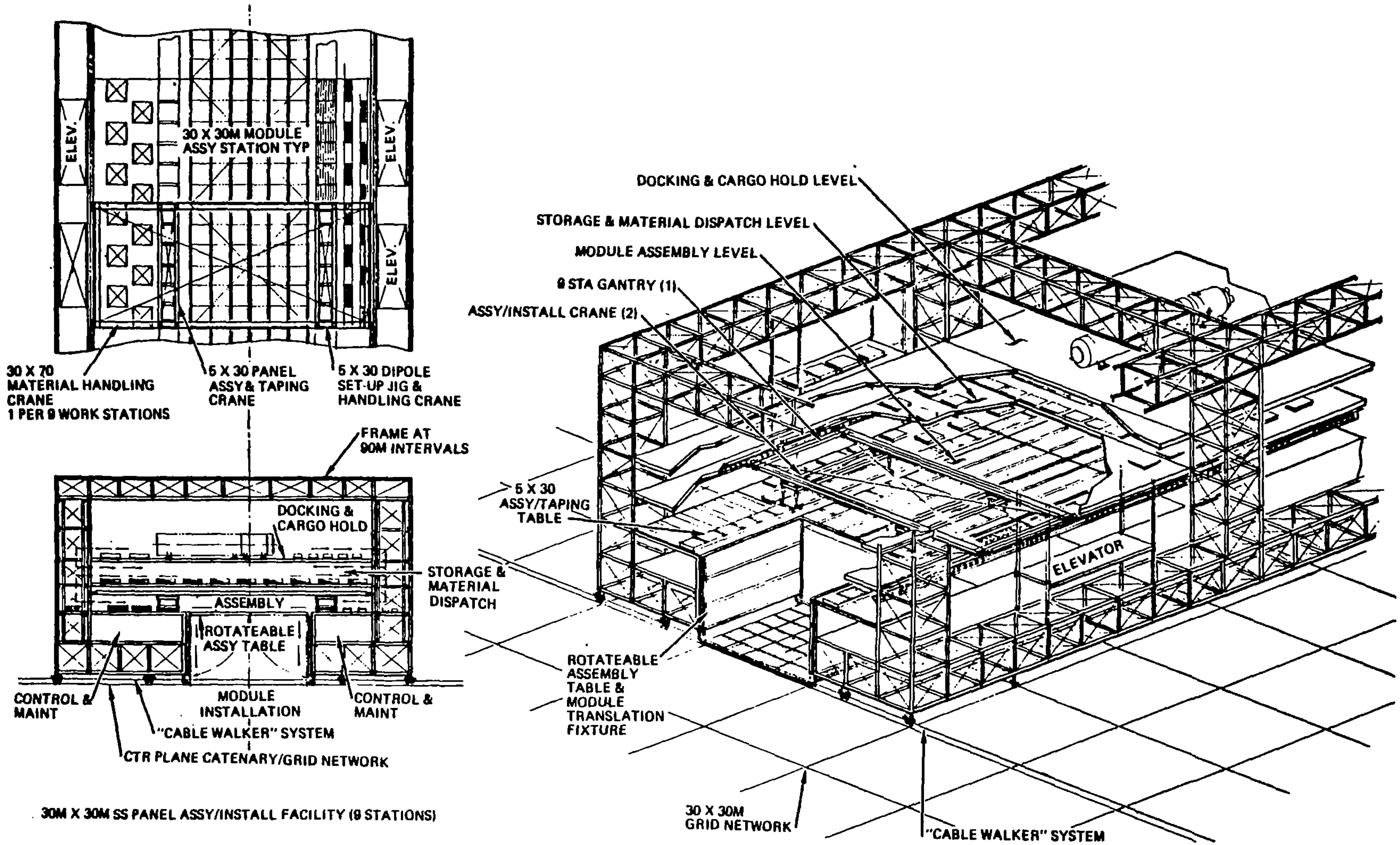
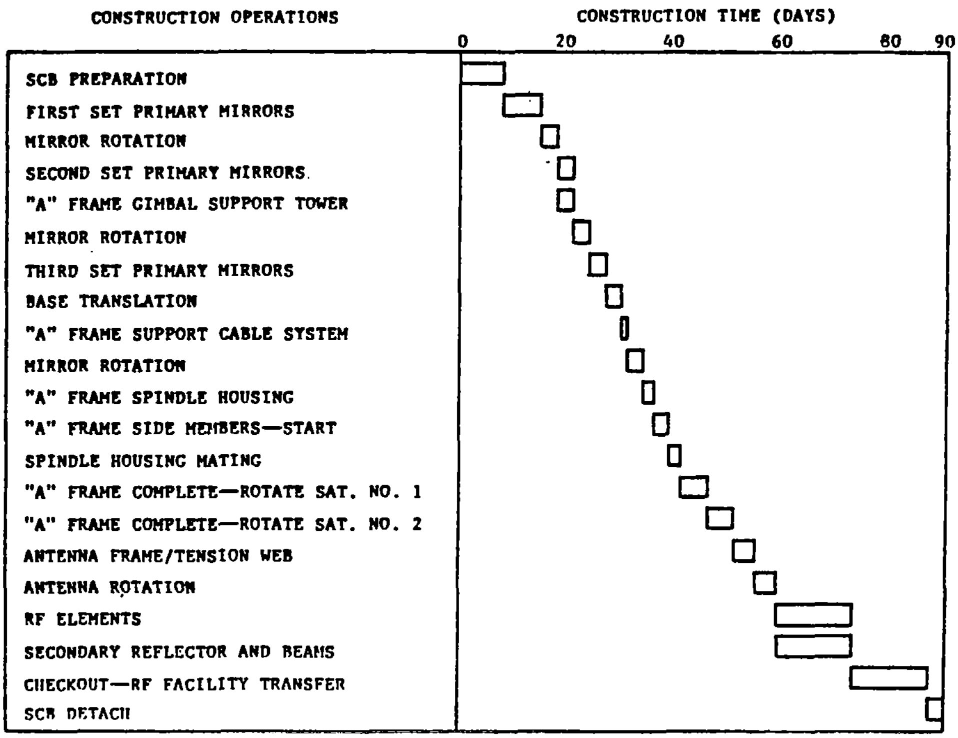


Figure 2.2-27. Solid State Module Assembly/Installation
—Facility General Arrangement

Construction Schedule and Crew Size Schedule

As indicated previously, 125 dual satellites will be required to produce the same amount of power as the 60 coplanar satellites. For a 30 year construction period, 4 dual satellites must be constructed during the first part of the program with a subsequent increase to 5 per year. A timeline reflecting 4 satellites per year, or a nominal 90 days per satellite is shown in Table 2.2-3. In allocating time for the various operations, a beam machine rate of 1 meter/minute was assumed. Additionally, a 40% factor was added; 20% for joints, but not less than 8 hours, 10% for machine downtime and servicing, and 10% for reflector operations. Three days were estimated for each reflector rotation, since detailed procedures have not been developed. The assembly and installation of the antenna panels has been allocated 2 weeks; 12 days for assembly and installation and 2 days for the incremental movements of the facilities across the face of the antenna.

Table 2.2-3. Dual Satellite Construction Timeline



Crew Size

Crew size estimates for satellite configuration cintained in Table 2.2-4 are based on a top level evaluation of the functions to be performed within the schedule constraints shown in Table 2.2-3. Further analyses which identify specific procedures in more detail probably will result in modifications to these numbers; however, they are considered to be sufficiently accurate for overall planning at this stage in the program.

Table 2.2-4. Crew Size (Dual SCB)

	DAYS		
	0—59	59—73	73—90
CONSTRUCTION CREW			
STRUCTURES AND REFLECTORS	88	40	—
ANTENNA RF ASSY/INSTALLATION	—	48	—
CONSTRUCTION SUPPORT	40	40	50
MAINTENANCE	44	44	56
BASE MANAGEMENT	24	24	24
CREW SUPPORT	30	30	30
CHECKOUT	—	—	40
TOTAL SHIFT CREW	226	226	200
*TOTAL CREW (4 SHIFTS)	904	904	800
TOTAL CREW ON BOARD	904	904	800

*BASED ON 8 HR SHIFTS, 3 SHIFTS/DAY, 8 DAY WORK CYCLE (6 ON, 4 OFF), AND 4 SHIFT CREWS

2.2.4 MAINTENANCE AND REPAIR SCENARIO

The maintenance concept developed for the SPS satellite defined in Exhibit C, April 1979, entailed stationing of a maintenance crew at each satellite on a full time basis. The large number of klystrons utilized for each satellite antenna together with the expected klystron life of ten years or less, plus anticipated maintenance activities in support of the PDS, rotary joint, etc., would be expected to generate a requirement for maintenance operations sufficient to justify this permanent, satellite maintenance base. The solid state satellite concept, (Figure 2.2-8) which substitutes solid state amplifiers for klystrons, will reflect a substantial increase in expected antenna reliability. Given a successful post-assembly checkout, the antenna (solar cells and solid state devices) is expected to operate unmaintained for a 30 year period with minimum degradation. Therefore, the current maintenance scenario does not include replacement or repair of antenna panel modules as either a scheduled or unscheduled operation. It is recognized that further development of the high power solid state amplifiers and accumulation of test data may dictate a change in this policy to allow for periodic maintenance. In any event, the characteristics and configuration of the solid state satellite concept should require substantially less maintenance than its klystron-equipped counterpart. For this reason, maintenance personnel will not be based at each satellite, but instead will be stationed at one of the two satellite construction fixtures and will also be utilized to maintain construction fixture equipment when not involved in satellite maintenance operations.

Spares Requirements

Table 2.2-5 contains an estimate of the annual spares required for each dual satellite configuration. The solar cell spares are for the special arrays which provide power for remotely located electric ion thrusters. It can be seen that the propellants for attitude control and stationkeeping comprise the

Table 2.2-5. Annual Spares Requirements for Each Satellite

ELEMENT	DATA BASE MASS FOR COMPLETE SATELLITE	EST. SPARES REQMTS (%)	SPARES MASS ($kg \times 10^{-6}$)
• MECHANISMS	0.027	1.5	0.004
• PWR DIST. & CONDI-TIONING	0.015	2.0	NEG
• INFORMATION MGMT & CONTROL	0.289	1.0	0.002
• ATT. CONT. HDWR.	0.103	2.0	0.002*
• SOLID-STATE ANT. DEV.	8.821	NO SPARES	—
• SOLAR CELLS	0.076	2.5	0.002
• ATT. CONT. ELECTRONICS	0.340	1.0	0.003
			0.013
		+25% GROWTH	0.016

ATT. CONT. PROPELLANT/YR =	0.164
10% FOR TANKAGE	0.016
	0.180×10^6 kg
SPARES	0.016
TOTAL	0.196×10^6 kg

*PRIMARILY THRUSTER GRIDS @ 4 kg/GRID.

bulk of the mass and must be replenished yearly, regardless of other maintenance requirements. The remainder of the equipment listed in the table was estimated as a percentage of the subsystem mass, since the design detail required for a more precise evaluation is not now available. An exception is thruster grids which must be replaced periodically; however, the number of thrusters and weight involved, (4 kg/grid) constitute a relatively unsignificant percentage of the overall mass.

Operations

The annual maintenance mass for each satellite is transported to LEO via HLLV's and then to the satellite construction fixture in GEO by EOTV's. Because of the close proximity of the two construction fixtures to each other, one fixture would be designated as the maintenance control center for storing and dispensing the supplies. However, the maintenance crews should be somewhat equally divided between the two fixtures for more efficient utilization in other tasks when not engaged in a maintenance sortie.

Because of the number of satellites which eventually will be operational, it will be necessary to establish a maintenance control center on one of the satellite construction fixtures which will remain in operation as long as satellites are still in commission. The center will store data received from the information management and control systems of each operating satellite, either by direct reception, up-date link from the ground, or a combination of both in order to maintain a satellite "health" status relevant to hardware anamolies. Prior to planning a maintenance sortie to one or more satellites, satellite data would be evaluated to determine the type and number of necessary spares and maintenance support equipment/tool requirements; e.g., free flying manned work module or cherry picker as shown in Figure 2.2-28, special removal/installation tools, etc. This is in addition to ACSS propellant replenishment which is scheduled on an annual basis.

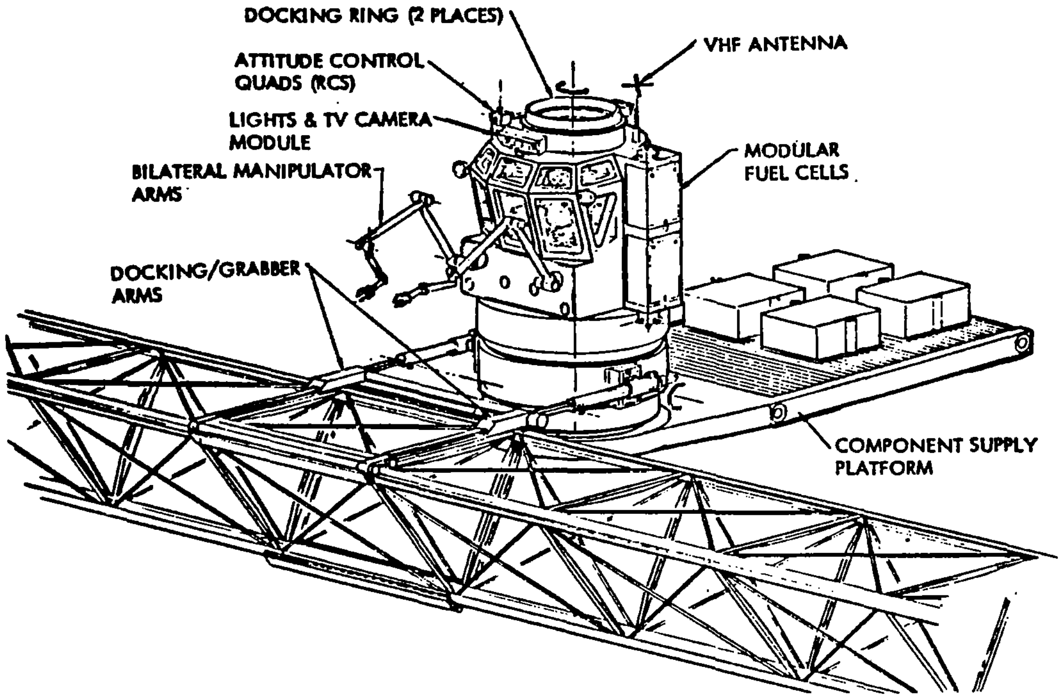


Figure 2.2-28. Manned Work Module
Free Flying or Stationary

Following maintenance data analysis and loading of the IOTV with the ACSS cryogenic propellant tanks and other equipment, the IOTV would proceed to the satellite to be maintained. A crew module providing habitat for the maintenance crew would be carried in a separate IOTV. After rendezvous with the satellite, a number of dockings at the various RCS locations would be accomplished, where, under human remote control, the full propellant tanks would be inserted by quick disconnects into the propellant manifold, and the partially empty tanks removed for ultimate return to earth. Concurrently, other required maintenance operations would be conducted as required. All manned activities would utilize protected modules; no EVA is planned except in case of an emergency.

The size of the maintenance crew will vary, depending on the scope of required activities and the distance to the satellite, which could result in utilization of multiple shifts. For overall planning purposes an average crew size of 30 men has been postulated. It has been assumed that one dual satellite configuration can be serviced per sortie from the base, and that each crew will visit four dual satellites during their 90 day orbital tour.

The requirement for a protected environment and the probable need for mobile cherry pickers at each satellite during maintenance operations generates the ingredients for an operational and cost trade study. A possible approach is to station selected habitat and maintenance modules at each satellite on a permanent basis, to be activated as required during the maintenance visit.

This concept reduces the propellant needed to transit between the base and the satellites because of reduced mass, but increases the material cost because of duplication of facilities and equipment. Moreover, any required maintaining of the equipment can be accomplished more effectively at a central location. No definition conclusions regarding the preferred approach have been reached; the alternative concepts should be the subject of further study.

2.2.5 MASS FLOWS AND TRAFFIC MODEL

Mass flows for both satellite construction and maintenance are contained in Table 2.2-6. A satellite mass of 20.78×10^6 kg was used as a baseline. This includes an allowance for SCB spares as per note (A) of the table.

The satellite construction schedule is shown in the left portion of the table. One year has been made available for construction of the first satellite. The rate then increases to four a year or 90 days per satellite. This rate is increased to five satellites per year for the last four years in order to satisfy the overall requirement of 125 satellites.

Approximately 250,000 kg of spares will be required for satellite maintenance on an annual basis. This includes propellant and associated tankage for the satellite attitude control and stationkeeping system. A breakdown of the spares is contained in Table 2.2-5 of the preceding section. Combining the mass requirements of the satellite construction material, SCB spares and satellite spares with the construction schedule and applying the ten percent packaging allowance provides the basis for determining yearly EOTV flights from LEO to GEO in accordance with the payload capacity defined in Note (C) of the table, and for determining yearly HLLV flights required to support the mass flow based on a payload capacity of 227,000 kg.

Satellite construction and maintenance crews must be rotated every 90 days. The portion of the table entitled "Personnel Mass" summarizes the annual POTV flights to GEO [see Notes (D), (E), and (F) of the table], and the HLLV flights required to transport personnel, their consumables, the POTV crew module, and the POTV chemical stages to LEO from the launch site.

On-orbit propellants are required for POTV's and IOTV's. Since the POTV's are refueled in GEO for the GEO-LEO return trip and since a portion of the IOTV's operate exclusively in GEO, propellant for these operations must be transported to GEO via EOTV's. The overall on-orbit propellant requirements, including that required for EOTV flights, are contained in the table, together with the HLLV flights required to deliver the propellant to LEO.

The columns at the right of the table summarize annual and total flights for all vehicles required to support the 30 year satellite construction program. Operational requirements for precursor and EOTV fleet buildup have been added at the bottom of these columns. Establishment of the LEO base and construction of the SCB are supported by the shuttle derived HLLV, since the large HLLV will not be available in that time frame. After the SCB has been completed, an initial fleet of EOTV's will be constructed in LEO, using the SCB as a fabrication fixture. Availability of the HLLV has been assumed for support of this operation.

Table 2.2-6. Mass Flows and Traffic Model, Dual Solid-State Satellite

(Sheet 1 of 4)

PROGRAM YEAR	CALENDAR YEAR	SATELLITE CONSTRUCTION SCHEDULE: PER YEAR	SATELLITE CONSTRUCTION SCHEDULE: SATELLITES OPERATIONAL AT YEAR'S END	CONSTRUCTION TIME PER SATELLITE (DAYS)	(A)* TOTAL CONSTRUCTION MASS TO GEOSYNCH EACH YEAR (INCL. 25% GROWTH)	NO. COMPLETED SATELLITE YEARS AT YEAR'S END	(B)* EOTV-DELIVERED MAINTENANCE MASS DURING YEAR	TOTAL YEARLY MASS TO ORBIT (CONSTRUCTION + MAINTENANCE)	EOTV DELIVERY REQMTS PER YEAR (CONSTRUCTION + MAINTENANCE + 10% PACKAGING)	(C)* EOTV FLIGHTS	(C)* HLLV FLIGHTS: SCHEDULED EOTV PAYLOAD MASS	(C)* HLLV FLIGHTS: HLLV FLIGHTS
1	2000	1	1	360	20.78	0	0	20.78	22.86	3	20.58	91
2	2001	4	5	90	83.12	2.5	0.625	83.75	92.13	13	89.18	393
3	2002	4	9			6.5	1.625	84.74	93.21	14	96.04	423
4	2003	4	13			10.5	2.625	85.75	94.33	14	96.04	423
5	2004	4	17			14.5	3.625	86.74	95.41	14	96.04	423
6	2005	4	21			18.5	4.625	87.75	96.53	14	96.04	423
7	2006	4	25			22.5	5.625	88.74	97.61	14	96.04	423
8	2007	4	29			26.5	6.625	89.75	98.73	14	96.04	423
9	2008	4	33			30.5	7.625	90.74	99.81	15	102.90	453
10	2009	4	37			34.5	8.625	91.75	100.93	15	102.90	453
11	2010	4	41			38.5	9.625	92.74	102.01	15	102.90	453
12	2011	4	45			42.5	10.625	93.75	103.13	15	102.90	453
13	2012	4	49			46.5	11.625	94.74	104.21	15	102.90	453
14	2013	4	53			50.5	12.625	95.75	105.33	15	102.90	453
15	2014	4	57			54.5	13.625	96.74	106.41	16	109.76	484
16	2015	4	61			58.5	14.625	97.75	107.53	16	109.76	484
17	2016	4	65			62.5	15.625	98.74	108.61	16	109.76	484
18	2017	4	69			66.5	16.625	99.75	109.73	16	109.76	484
19	2018	4	73			70.5	17.625	100.74	110.81	16	109.76	484
20	2019	4	77			74.5	18.625	101.75	111.93	16	109.76	484
21	2020	4	81			78.5	19.625	102.74	113.01	16	109.76	484
22	2021	4	85			82.5	20.625	103.75	114.13	17	116.62	514
23	2022	4	89			86.5	21.625	104.74	115.21	17	116.62	514
24	2023	4	93			90.5	22.625	105.75	116.33	17	116.62	514
25	2024	4	97			94.5	23.625	106.74	117.41	17	116.62	514
26	2025	4	101			98.5	24.625	107.75	118.53	17	116.62	514
27	2026	4	105	90	83.12	102.5	25.625	108.74	119.61	17	116.62	514
28	2027	5	110	72	103.9	107.0	26.725	109.80	120.78	18	123.48	544
29	2028	5	115	72	103.9	112.0	28.000	111.12	122.23	18	123.48	544
30	2029	5	120	72	103.9	117.0	29.250	112.37	123.61	18	123.48	544
31	2030	5	125	72	103.9	122.0	30.500	113.62	124.98	18	123.48	544
		125			2598	1823	455.750	2,970.06	3,267.08	476	3265.4	14,388

**See Sheet 3 of 4*

Table 2.2-6. Mass Flows and Traffic Model, Dual Solid-State Satellite

(Sheet 2 of 4)

		PERSONNEL MASS							CREW CONSUMABLES (F) *							
		CONSTR. CREW	(D) * MAINT. CREW	LEO BASE					SATELLITE CONSTRUCTION CREW			SATELLITE MAINTENANCE CREW			LEO BASE CREW	
PROGRAM YEAR	CALENDAR YEAR	CREW ROTATION EACH 90 DAYS (900 MEN)	MAINT. CREW ROTATIONS EACH 90 DAYS/SAT. YR (24 MEN/CREW)	CREW ROTATION EACH 90 DAYS (30 MEN)	TOTAL PERSONNEL (CONSTR. + MAINT. + LEO BASE) ROTATED TO LEO EACH 90 DAYS	TOTAL PERSONNEL (CONSTR. + MAINT.) ROTATED TO GEO EACH 90 DAYS	HLLV FLIGHTS TO LEO (54,000 KG/60-MAN POTV)	POTV FLIGHTS TO GEO @ 60 MEN/FLIGHT	CREW CONSUMABLES @ 0.352x10^6 KG/CREW ROTATION	EOTV FLIGHTS	HLLV FLIGHTS	CREW CONSUMABLES @ 0.009x10^6 KG/CREW ROTATION	EOTV FLIGHTS	HLLV FLIGHTS	CREW CONSUMABLES @ 0.01175x10^6 KG/CREW ROTATION	HLLV FLIGHTS
1	2000	4	0	4	930	900	14.3	60	1.41	0.21	6.2	0	0	0	0.05	0.22
2	2001	↓	1	↓	954	924	14.7	62	↓	↓	↓	0.038	↑	0.2	↓	↓
3	2002		1		954	924	14.7	62				0.038		0.2		
4	2003		1		954	924	14.7	62				0.038		0.2		
5	2004		1		954	924	14.7	62				0.038		0.2		
6	2005		2		978	948	15.0	63				0.075		0.3		
7	2006		2		978	948	15.0	63				0.075		0.3		
8	2007		2		978	948	15.0	63				0.075		0.3		
9	2008		2		978	948	15.0	63				0.075		0.3		
10	2009		3		1,002	972	15.5	65				0.113		0.5		
11	2010		3		1,002	972	15.5	65				0.113		0.5		
12	2011		3		1,002	972	15.5	65				0.113		0.5		
13	2012		3		1,002	972	15.5	65				0.113		0.5		
14	2013		4		1,026	996	15.7	66				0.150		0.7		
15	2014		4		1,026	996	15.7	66				0.150	NEGLIGIBLE	0.7		
16	2015		4		1,026	996	15.7	66				0.150		0.7		
17	2016		4		1,026	996	15.7	66				0.150		0.7		
18	2017		5		1,050	1,020	16.2	68				0.188		0.8		
19	2018		5		1,050	1,020	16.2	68				0.188		0.8		
20	2019		5		1,050	1,020	16.2	68				0.188		0.8		
21	2020		5		1,050	1,020	16.2	68				0.188		0.8		
22	2021		6		1,074	1,044	16.7	70				0.226		1.0		
23	2022		6		1,074	1,044	16.7	70				0.226		1.0		
24	2023		6		1,074	1,044	16.7	70				0.226		1.0		
25	2024		6		1,074	1,044	16.7	70				0.226		1.0		
26	2025		7		1,098	1,068	16.9	71				0.263		1.2		
27	2026		7		1,098	1,068	16.9	71				0.263		1.2		
28	2027		7		1,098	1,068	16.9	71				0.263		1.2		
29	2028		7		1,098	1,068	16.9	71				0.263		1.2		
30	2029	↓	8	↓	1,122	1,092	17.4	73	↓	↓	↓	0.301	↓	1.3	↓	↓
31	2030	4	8	4	1,122	1,092	17.4	73	1.41	0.21	6.2	0.301	0	1.3	0.05	0.22
		124	128	124	31,902	30,972	492	2066	43.7	6.4	192	4.814	0	21	1.55	6.8

*See Sheet 4 of 4

Table 2.2-6. Mass Flows and Traffic Model, Dual Solid-State Satellite

(Sheet 3 of 4)

PROGRAM YEAR	CALENDAR YEAR	TOTAL EOTV FLIGHTS, CONSUMABLES	TOTAL HLLV FLIGHTS, CONSUMABLES	ON-ORBIT PROPELLANTS: (E)* POTV PROPELLANT, GEO-LEO, 35,475 KG/TRIP	EOTV FLIGHTS FOR POTV PROPELLANT, GEO-LEO	HLLV FLIGHTS FOR TOTAL POTV PROPELLANT	IOTV FLIGHTS IN LEO (CONSTR. + MAINT.)	PROPELLANT TO LEO (0.00033 KG/IOTV FLT)	IOTV FLIGHTS IN GEO (CONSTR. + MAINT.)	PROPELLANT TO GEO (0.00033 KG/IOTV FLT)	HLLV FLIGHTS—IOTV PROPELLANT TO LEO	EOTV FLIGHTS, IOTV PROPELLANT	EOTV PROPELLANT (933,900 KG ROUND TRIP, INCL. 10% TANKAGE)	HLLV FLIGHTS FOR EOTV PROPELLANT	SUMMARY: TOTAL POTV FLIGHTS	TOTAL IOTV FLIGHTS	TOTAL EOTV FLIGHTS	TOTAL HLLV FLIGHTS	GROWTH SHUTTLE	SHUTTLE-DERIVED HLLV
1	2000	0.21	6.4	2.12	0.3	18	153	0.05	153	0.05	0.2	>0.1	5.23	23	60	306	5.4	152.7		
2	2001		6.6	2.20	0.3	18	497	0.16	497	0.16	0.7		14.57	64.2	62	997	15.4	496.5		
3	2002		6.6	2.20	0.3	18	531	0.18	531	0.18	0.8		15.50	68.3	62	1,062	16.4	530.6		
4	2003		6.6	2.20	0.3	18	531	0.18	531	0.18	0.8		15.50	68.3	62	1,062	16.4	530.6		
5	2004		6.6	2.20	0.3	18	531	0.18	531	0.18	0.8		15.50	68.3	62	1,062	16.4	530.6		
6	2005		6.7	2.23	0.3	19	532	0.18	532	0.18	0.8		15.50	68.3	63	1,064	16.4	532.0		
7	2006		6.7	2.23	0.3	19	532	0.18	532	0.18	0.8		15.50	68.3	63	1,064	16.4	532.0		
8	2007		6.7	2.23	0.3	19	532	0.18	532	0.18	0.8		15.50	68.3	63	1,064	16.4	532.0		
9	2008		6.7	2.23	0.3	19	566	0.19	566	0.19	0.8		16.44	72.4	63	1,132	17.4	566.1		
10	2009		6.9	2.31	0.3	19	567	0.19	567	0.19	0.8		16.44	72.4	65	1,134	17.4	566.8		
11	2010		6.9	2.31	0.3	19	567	0.19	567	0.19	0.8		16.44	72.4	65	1,134	17.4	566.8		
12	2011		6.9	2.31	0.3	19	567	0.19	567	0.19	0.8		16.44	72.4	65	1,134	17.4	566.8		
13	2012		6.9	2.31	0.3	19	567	0.19	567	0.19	0.8		16.44	72.4	65	1,134	17.4	566.8		
14	2013		7.1	2.34	0.3	20	568	0.19	568	0.19	0.8		16.44	72.4	66	1,136	17.4	568.2		
15	2014		7.1	2.34	0.3	20	603	0.20	603	0.20	0.9		17.37	76.5	66	1,206	18.4	603.3		
16	2015		7.1	2.34	0.3	20	603	0.20	603	0.20	0.9		17.37	76.5	66	1,206	18.4	603.3		
17	2016		7.1	2.34	0.3	20	603	0.20	603	0.20	0.9		17.37	76.5	66	1,206	18.4	603.3		
18	2017		7.2	2.41	0.4	20	604	0.20	604	0.20	0.9		17.46	76.9	68	1,208	18.5	604.3		
19	2018		7.2	2.41	0.4	20	604	0.20	604	0.20	0.9		17.46	76.9	68	1,208	18.5	604.3		
20	2019		7.2	2.41	0.4	20	604	0.20	604	0.20	0.9		17.46	76.9	68	1,208	18.5	604.3		
21	2020		7.2	2.41	0.4	20	604	0.20	604	0.20	0.9		17.46	76.9	68	1,208	18.5	604.3		
22	2021		7.4	2.48	0.4	21	640	0.21	640	0.21	0.9		18.40	81.1	70	1,280	19.5	640.2		
23	2022		7.4	2.48	0.4	21	640	0.21	640	0.21	0.9		18.40	81.1	70	1,280	19.5	640.2		
24	2023		7.4	2.48	0.4	21	640	0.21	640	0.21	0.9		18.40	81.1	70	1,280	19.5	640.2		
25	2024		7.4	2.48	0.4	21	640	0.21	640	0.21	0.9		18.40	81.1	70	1,280	19.5	640.2		
26	2025		7.6	2.52	0.4	21	641	0.21	641	0.21	0.9		18.40	81.1	71	1,282	19.5	640.6		
27	2026		7.6	2.52	0.4	21	641	0.21	641	0.21	0.9		18.40	81.1	71	1,282	19.5	640.6		
28	2027		7.6	2.52	0.4	21	675	0.22	675	0.22	0.9		19.33	85.2	71	1,350	20.5	674.7		
29	2028		7.6	2.52	0.4	21	675	0.22	675	0.22	0.9		19.33	85.2	71	1,350	20.5	674.7		
30	2029		7.7	2.59	0.4	22	676	0.22	676	0.22	0.9		19.33	85.2	73	1,352	20.5	676.3		
31	2030	0.21	7.7	2.59	0.4	22	676	0.22	676	0.22	0.9	>0.1	19.33	85.2	73	1,352	20.5	676.3		
		6.4	266	73.26	10.7	614	18,010	6.0	18,010	6.0	26	1.0	521.1	2296	2066	36,020	493	18,010		
									PRECURSOR											
									LEO BASE (FIVE MODULES)											5
									SCB MASS (14.82×10^6 KG)											148
									6 EOTV's PLUS PROP. (9.65×10^6 KG)									43		
									12 CREW ROTATIONS @ 360/CREW										72	
									CREW CONSUMABLES (1.69×10^6 KG)											16
									TOTAL						2066	36,020	493	18,053	72	169

*See Sheet 4 of 4

Table 2.2-6. Mass Flows and Traffic Model,
Dual Solid-State Satellite

(Sheet 4 of 4)

NOTES:

(A) SATELLITE MASS, 16.42 + 25% GROWTH = 20.53
SCB SPARES, 0.200×10^6 + 25% GROWTH = 0.25
20.78×10^6 KG, TOTAL DELIVERED MASS FOR CONSTRUCTION OF EACH DUAL SATELLITE

(B) SATELLITE MAINTENANCE MASS (SPARES + RCS PROPELLANTS) INCL. 25% SPARES GROWTH } 0.25×10^6 KG PER SATELLITE YEAR

(C) EOTV PAYLOAD CAPACITY = 6.86×10^6 KG
HLLV PAYLOAD CAPACITY = 0.227×10^6 KG

(D) ONE 24-MAN CREW, SCB BASED, VISITS 4 DUAL SATELLITES IN 90 DAYS.

(E) 67,720 KG PROPELLANT (INCL. TANKAGE) DELIVERED TO LEO VIA HLLV FOR EACH POTV ROUND TRIP.

35,475 KG PROPELLANT DELIVERED TO GEO FOR ONE POTV GEO-LEO TRANSFER.

(F) 391.6 KG (INCL. 10% PACKAGING) PER CREWMAN ROTATION (30 DAYS).

Since the EOTV's are life limited, a 10 year life being postulated, additional EOTV's will be constructed in GEO at various times during the 30 year program. HLLV and EOTV flights to support this construction have been included but not time phased, since the number of flights required is small compared to the traffic model supporting satellite construction.

The SPS HLLV requirements identified in the table are based on mass to be carried to LEO versus the HLLV payload weight. The HLLV payload bay has an ideal packing density of 85.6 kg/cubic meter, derived by dividing the volume into the maximum cargo weight. With the exception of the antenna panels, satellite construction materials exceed this density. The 5x5x0.045 meter panels are very light, resulting in a density of 40 kg/cubic meter. However, the addition of POTV stages, and propellants and EOTV propellants required to support construction of one satellite offsets the low density of the panels and results in the overall payloads being weight limited.

It is noted that the total traffic requirements contained in the summary are not exact because of the rounding off process utilized in constructing the table. However, the accuracy is considered to be within 1% and should be sufficient for long range planning.

2.3 RESOURCES UPDATE

Volume V to the Final Report (Exhibit C) identified materials required to produce the Rockwell coplanar satellite and indicated a number of potential problem areas relative to material requirements versus availability. These included cobalt, gallium, gold, kapton, sapphire, silver, teflon, and tungsten.

A similar materials evaluation has been conducted on the dual solid state satellite described in Section 2.2 of this volume. Table 2.3-1 identifies the materials requirements for one satellite; Table 2.3-2 compares these requirements with the data developed for the Rockwell coplanar satellite, Exhibit C. In the two left columns, materials for one satellite of each configuration are identified. It can be seen that beryllium oxide is the only material uniquely required for the solid state satellite versus the reference concept. The only other materials which are required in greater amounts for the solid state concept are gallium, the ingredients of composite materials (graphite, fiberglass and resin) and kapton.

Referring to Table 2.3-2 the mass of the reference satellite is about 33×10^6 kg, including twenty-five percent growth. The power output of this satellite at the utility interface is approximately 5 GW, resulting in a total output of 300 GW for the projected 60 satellites. The solid state concept produces about 2.4 GW and 125 satellites are required to equal the desired 300 GW total output. Therefore, an annual average production rate of 4 satellites per year is necessary as compared to the reference concept rate of 2 satellites per year. When the individual satellite materials mass is adjusted to reflect the annual production rates as indicated in the two right columns of Table 2.3-2, greater quantities of several additional materials are required for the solid state satellite. These include aluminum and tin.

Table 2.3-1. Dual Solid State Sandwich Configuration
($\times 10^6$ kg)

MATERIAL	STRUCT/ MECH	CONCEN- TRATORS	MISC. SOLAR PANELS	POWER DISTR.	SUBARRAYS & ELEC.	MAINT.	MISC. OTHER S/S	TOTAL
BERYLLIUM OXIDE					1.312			1.312
ALUMINUM	3.295	0.026	145 kg	0.015	2.560	0.670	0.320	6.886
COBALT							0.001	0.001
ARSENIC			0.005		0.090			0.095
COPPER			0.005	0.002	0.092		0.010	0.109
GALLIUM			0.005		0.507		0.010	0.522
GLASS FIBER	0.287				5.513			5.800
GOLD			0.018		0.318		0.001	0.337
GRAPHITE	0.576							0.576
IRON							0.016	0.016
KAPTON		2.568	0.014		0.235			2.817
NICKEL							0.001	0.001
PLASTIC				0.001			0.001	0.002
RESIN	1.052							1.052
SAPPHIRE			0.030		0.521		0.100	0.651
SELENIUM			0.38 kg		6.6 kg			(6.98 kg)
SILVER			0.002	13 kg	0.033		0.010	0.045
STEEL				0.001				0.001
TEFLON			0.010		0.176		0.020	0.206
TIN			0.005		0.094			0.099
TITANIUM				60 kg				(60 kg)
ZINC			0.12 kg		(2.1 kg)			(2.22 kg)
TOTAL (INCL. 25% GROWTH)	5.210	2.594	0.095	0.019	11.451	0.670	0.490	20.529

Of the materials listed as potential problem areas, only gallium and kapton are required in greater annual quantities for the solid state version. Data developed in Volume V of Exhibit C (Alcoa Study), indicate that potential 1995 gallium production capability in the United States is about 2.6 times the requirements of one reference satellite. The satellite production rate and the greater usage of gallium for the solid state concept indicate a need for greatly increased production. Relative to kapton raw materials currently are available but production facilities would have to be expanded to meet the SPS demand.

Table 2.3-2. Summary Comparison of Materials Requirements ($\times 10^6$ kg)

MATERIAL	(5 GW) REF. SATELLITE (EXHIBIT C)	(2.4 GW) DUAL SOLID-STATE	ANNUAL REQUIREMENTS REF. SATELLITE (2 = 10 GW)	ANNUAL REQUIREMENTS SOLID-STATE SAT. (4 = 9.7 GW)
BERYLLIUM OXIDE	-	1.312	-	5.248
ALUMINUM	8.965	6.886	17.930	27.544
COBALT	0.212	0.001	0.424	0.004
ARSENIC	0.465	0.095	0.930	0.380
COPPER	3.865	0.109	7.730	0.436
GALLIUM	0.432	0.522	0.864	2.088
GLASS FIBER	0.178	5.800	0.356	23.200
GOLD	1.640	0.337	3.280	1.348
GRAPHITE	0.357	0.576	0.714	2.304
IRON	0.515	0.016	1.030	0.064
KAPTON	2.502	2.817	5.004	11.268
NICKEL	1.141	0.001	2.282	0.004
PLASTIC	0.681	0.002	1.362	0.008
RESIN	0.653	1.052	1.306	4.208
SAPPHIRE	2.700	0.651	5.400	2.604
SELENIUM	(34 kg)	(7 kg)	(68 kg)	(28 kg)
SILVER	0.178	0.045	0.356	0.180
STEEL	1.196	0.001	2.392	0.004
TEFLON	0.915	0.206	1.830	0.824
TIN	0.188	0.099	0.376	0.396
TITANIUM	0.028	(60 kg)	0.056	(240 kg)
ZINC	(11 kg)	(2.22 kg)	(22 kg)	(8.88 kg)
SUBTOTAL	26.700	20.529	53.400	82.116
OTHER (ACS, THERMAL)	6.318	-	12.636	-
TOTAL (INCL. 25% GROWTH)	33.018	20.529	66.036	82.116

3.0 SATELLITE DECOMMISSIONING

3.1 INTRODUCTION

The SPS satellite design life, with maintenance, is 30 years. Therefore, in assessing various approaches to satellite decommissioning, it has been assumed that the selected approach would be implemented at the end of the design life. Options include satellite disposal by orbital change, cannibalization, alternative uses, or continued operations, with or without technological updating. These options are summarized in Table 3.1-1. The selected option will reflect feasibility and cost effectiveness, and will be influenced by the development status of other power generation techniques such as fusion. These options are discussed in the following sections together with scenarios for the more attractive concepts.

Table 3.1-1. Possible Options

OPTION	REMARKS
ABANDON IN GEO	UNACCEPTABLE
EARTH REENTRY	POLITICALLY UNACCEPTABLE, LARGE ΔV REQUIRED
LUNAR IMPACT	PROBABLY UNACCEPTABLE BUT SMALL ΔV
SOLAR ORBIT	FEASIBLE, MODEST ΔV BUT LONG BURN TIME
CONTINUED USE AS SPS SATELLITE	FEASIBLE, SUBJECT TO MAINTENANCE COST TRENDS, DEGRADATION, AND ALTERNATE POWER SOURCE DEVELOPMENT
CANNIBALIZATION	CAN BE ACCOMPLISHED TO LIMITED EXTENT,.BUT SATELLITE DISPOSAL PROBLEM REMAINS
ALTERNATE USE	FEASIBLE WITH MODIFICATIONS—PROBABLY WOULD NOT UTILIZE ENTIRE FLEET

While the scope of this task includes only the satellite, implications of other SPS elements ultimately should be considered, specifically rectennas, utility interfaces, and consumer requirements. Unless the decommissioned satellites are to be upgraded or replaced by newer, power transmitting satellites, there will remain many receiver sites occupying considerable acreage which cannot be used effectively for other purposes unless leveled. Where rectennas are in close proximity to an adjoining country, it may be feasible to lease a rectenna and satellite to that country for power augmentation. Regarding consumer requirements, it is assumed that if a decision to decommission satellites as power transmitters is made, alternate sources of power will be available to fill the void.

3.2 OPTIONS

3.2.1 SATELLITE DISPOSAL

Assuming that decommissioning satellites and leaving the total satellite population unattended and uncontrolled in geosynchronous orbit is not acceptable, disposal methods include providing sufficient ΔV for earth reentry or for attainment of a more remote orbit with respect to earth. In view of Skylab publicity it would appear that earth reentry is not politically acceptable for vehicles of such large size, moreover, the ΔV requirements are considerably larger than for some other orbital changes. Therefore, earth reentry will not be considered further.

Other potential disposal concepts which utilize orbital change include escape from the solar system, impact with the sun, or a solar orbit. The most economical approach in terms of ΔV requirements is a solar orbit. A circular orbit of 0.86 AU's can be attained from GEO with a relatively modest ΔV; this orbit, which is very stable and is well removed from the vicinity of earth, was selected for further evaluation.

Cannibalization of certain components prior to disposal, if deemed cost-effective and feasible, could be accomplished providing sufficient solar array area and the associated power distribution for ion thruster power requirements remain.

3.2.2 SATELLITE LIFE EXTENSION

The 30 year satellite design life assumes a solar array degradation of about 4% over that period. If this estimate, which is based on a combination of laboratory results and engineering judgement, is valid, the arrays theoretically could produce about 96% of beginning-of-life power at the end of 30 years. This would be reduced somewhat by reflector degradation, anticipated to be about 8.5%, but the amount of power generated would still be substantial.

A decision to extend the satellite end-of-life, considering the reduced power output, would be based primarily on cost. After the satellite has been in operation for 10-15 years, the cost of maintenance and maintenance trends will have been established. Additionally, solar array and reflector degradation characteristics will have been determined through operational data. If effective power output has decreased beyond projected values and/or if actual maintenance costs are considerably greater than those projected, life extension may not be cost effective. If, on the other hand, maintenance costs and degradation factors have been reasonably well projected, extension may be worthwhile. In any case, the development status of fusion or other forms of power production which do not depend on unrenewable sources and which may not make an SPS program extension advantageous must be considered. Summarizing, selection of this extension option does not appear feasible until the SPS program has been in operation for at least 10-15 years.

3.2.3 ALTERNATIVE USES

Various utilization concepts can be hypothesized for an SPS satellite which is no longer required for its original purposes. These include such things as military, staging bases, space industrialization (which probably can be accomplished more economically in low earth orbit), and communications. If end-of-life (30 years) power level predictions are reasonably valid, sufficient power for supporting these activities would still be available. Installation of specialized equipment and facilities for a specific application is feasible; however, the satellite probably is oversized for the requirement and the cost of maintenance and stationkeeping propellant must be considered. In any event, alternate uses of satellites for such requirements as can be identified at this time would entail utilization of only a relatively small portion of the satellite fleet, which will number 60 to 125, depending on the configuration. Therefore, regardless of the intended alternate uses, it would appear that a substantial number of the total population would exceed the demand and would have to be disposed of in other ways.

3.2.4 MATERIAL RECLAMATION

The primary elements of the Rockwell Reference Concept satellite include GaAs solar blankets, aluminized kapton reflectors, aluminum power feeders, slip rings, electric/electronic modules (switch gears, etc.), attitude control propulsion and tankage, antenna RF modules, miscellaneous wiring, and crew habitat. With the exception of components which have been replaced in connection with maintenance activities the bulk of satellite equipment will have been exposed to 30 years of operation at the satellite end-of-life. Much of it will have been rendered obsolete, or at least obsolescent by technological advances. The value of component retrieval for future use (after refurbishment) therefore does not appear to be cost-effective. Accepting this, there remains the possibility of removal and shipment to earth of other satellite elements such as solar blankets, etc., where certain expensive ingredients could be removed and reused. The operations attendant to detaching and packaging long ($\approx$700 meters) solar blanket strips, aluminum feeders, slip ring segments, or 30×30 meter mechanical modules (solid state sandwich antenna) could be most complicated and time-consuming. While the required operations and support equipments have not been analyzed, the monetary gains which would be realized by removing and transporting these materials to earth for subsequent reclamation of expensive ingredients appears questionable. Removal and return of large modules such as propellant tanks and crew habitats may be cost-effective, since the installation design philosophy should provide for removal with minimum effort. Additionally, modularized support equipment such as manned manipulator modules and free-flying support vehicles would be candidates for salvage.

Summarizing, reclamation of crew modules, free-flying support vehicles, tankage, etc., seems to be feasible. The value of salvaging other portions of the satellite in order to reclaim specific materials appears very questionable. A detailed study which considers the ultimate composition of the satellite, the criticality in the mid 2000's of specific materials which may be candidates for reclamation, transportation costs, and the cost of operations attendant to removal and packaging of salvagable material is essential before a final decision can be made.

3.3 SELECTED SATELLITE DECOMMISSIONING CONCEPTS

Continued use of SPS satellites past 30 years is a viable option, but as indicated earlier, a decision to extend the life must consider maintenance costs, output degradation trends, technological upgrading, and the state of development of other power generation systems which do not utilize unrenewable sources. It does not appear practicable to make a decision at this time on a course of action which would be implemented about the year 2030 at the earliest, when the first satellites would approach or reach the end of their design life. Continued use, therefore, should be considered an open issue and potential option.

Accepting the assumption that SPS satellites will not be left unattended in geosynchronous orbit and that alternate use will be limited to a few satellites, disposal by orbital change has been selected as a potential concept. Other acceptable concepts include partial salvage of certain satellite materials and alternate use. In each of these concepts, disposal by orbital maneuvers of the bulk of the satellite fleet is inherent.

3.3.1 DISPOSAL

Transfer of a satellite from geosynchronous orbit to a 0.86 AU solar orbit requires a modest ΔV as compared to escape from the solar system or impact with the sun. Lunar impact requires even less ΔV, but has not been explored further because of potential political repercussions. The basic ΔV for attaining the 0.86 AU solar orbit has been calculated to be 3073 meters/sec (10,084 ft/sec), consisting of an initial escape maneuver requiring 1815 meters/sec (5955 ft/sec) and a circularization maneuver requiring 1258 meters/sec (4129 ft/sec). However, because of the low thrust levels characteristic of electric ion thrusters, a factor of 25% has been added to the initial burn, resulting in a total ΔV of 3527 meters/sec (11,573 ft/sec).

For a 13,000 second specific impulse (argon propellant), a mass ratio of 1.028 is obtained, which determines the propellant mass for a given satellite mass. This relationship is shown in Figure 3.3-1 for varying spacecraft masses. For the Rockwell reference concept of approximately 33 $\bar{M}$ kg dry weight, the required propellant is 924,000 kg. The solid state dual satellite concept, reflecting a mass of 20.53 $\bar{M}$ kg dry weight, requires only 570,000 kg of propellant for the same series of maneuvers.

Studies currently are being conducted to evaluate the effect of utilizing hydrogen instead of argon as a propellant. If a change to hydrogen is effected, a specific impulse of 28,000 seconds is feasible, resulting in a decrease of the mass ratio to 1.013. This reduces the required propellant by over 50%.

The thrust of one of the satellite electric thrusters is 13.02 Newtons or 2.93 pounds. If 32 thrusters were available for the ΔV maneuvers, an acceleration of 4×10^{-5} ft/sec^2 would be produced, resulting in a total burn time (escape plus circularization) of about 9.2 years. Increasing the number of thrusters decreases the burn time accordingly. Figure 3.3-2 shows this relationship.

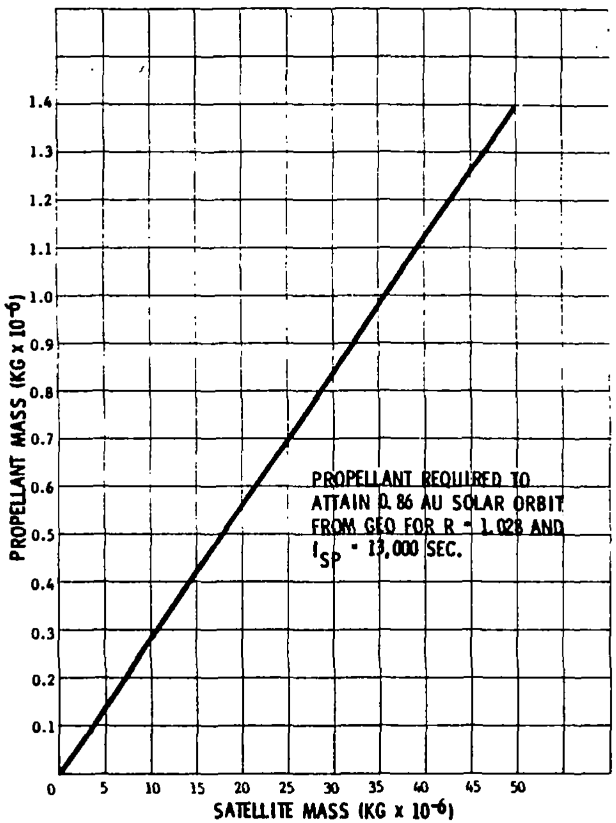


Figure 3.3-1. Propellant versus Mass Attain Solar Orbit

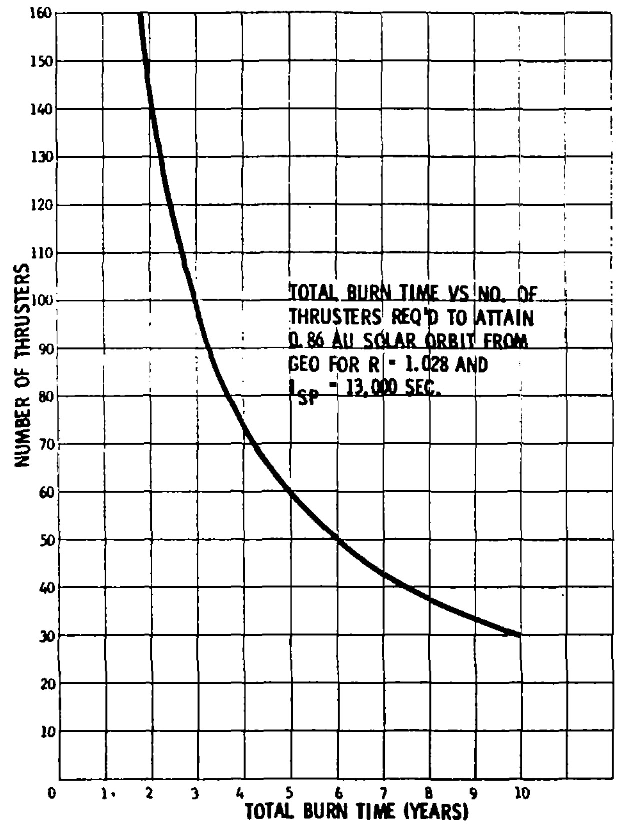


Figure 3.3-2. Burn Time as a Function on Total Thrusters

It can be seen that increasing the total number of thrusters past about 120-140 results in a relatively small decrease in burn time. Therefore, thruster banks totaling 128 thrusters have been postulated for the satellite disposal maneuvers. This requires a total burn time of 2.3 years, which should be obtainable by the year 2030 with improvements in thruster grids and by operating at low current densities. Since current satellite configurations have fewer numbers of thrusters, additional thrusters will have to be installed prior to implementation of the first burn. The use of hydrogen (assuming the same total thrust) has negligible effect on burn time but enhances thruster grid life. (Chemical propulsion has not been considered for these maneuvers since for an I_{sp} of 450 seconds, the mass ratio, R, would result in propellant requirements exceeding the weight of the satellite.)

The required propellant will vary, depending on the satellite mass, but could be as high as 924,000 kg of argon for the Rockwell Reference Concept. Since the current EOTV tanks are sized for approximately 170,000 kg, six EOTV tanks would be more than ample. However, additional study regarding the adequency of tank heat balance will be required.

3.3.2 MATERIALS RECLAMATION

Given that a specific satellite has been earmarked for disposal, propellant must be transported to the satellite via an EOTV and installed by the maintenance crew. If no maintenance crew is in permanent residence, the crew must be transferred from the SCB maintenance base by POTV or IOTV. The basic satellite maintenance concept entails RCS propellant tank removal and replacement with full tanks on a yearly basis. Utilizing the same procedures, the RCS tanks would be removed, replaced by the larger tanks, and then loaded on the EOTV for return. Additionally, pressurized modules utilized for crew habitat, etc., which are compatible with HLLV payload volume constraints, as well as certain types of high cost maintenance equipment such as manned manipulator modules would similarly be returned.

3.3.3 ALTERNATE USES

The 50 or more years which will elapse before the end of life of the first few satellites will make it possible to project specific requirements for alternate satellite system use during that period. General requirements would include communications, staging platforms, space industralization and astronomy—either solely or in multiple applications. Space Industrialization Implementation Concepts, Final Report, SD 78-AP-0055, dated April 14, 1978 (Contract NAS8-32198 to NASA/MSFC) identified a variety of potential space applications. These included communications, navigation, tracking and control, land data, weather data, and global environment. Additionally, in the products areas, various organic and inorganic materials were listed as potential items for space production. Tables 3.3-1, 3.3-2, and 3.3-3 summarize the potential applications developed in the report. The extent to which any or all of these concepts will be implemented by 2030-60 is unknown, but one or more SPS satellites could be used in furtherance of these proposed activities.

The scenário for alternate use would entail specific modifications and additions to the satellite in terms of equipment and crew habitat (if manned). The equipment to be installed would be transported to the satellite by EOTV, timed to coincide with arrival of POTV's carrying installation crews who would install, check out and activate the equipment. If the satellite is to be permanently manned, personnel would have to be rotated at 90 day cycles (unless experience dictates a different rotation cycle). Additionally, EOTV's would provide spares and propellants on a scheduled basis. If unmanned, periodic visits of maintenance personnel via POTV's would be required concurrently with EOTV arrivals.

Prior to a definite commitment to alternate use, specific requirements must be identified, the extent and cost of satellite modification determined, and operating costs, including transportation, defined. However, the concept is considered to be a viable option at this time.

Table 3.3-1. Attractive Opportunities in the Services Area*

Communications

Information Relay
- Direct TV broadcast
- Electronic mail
- Education broadcast
- Rural TV
- Meteorological information dissemination
- Interagency data exchange
- Electronic cottage industries
- World medical advice center
- Centralized "distributed" printing systems
- Environmental information distribution
- Time and frequency distribution

Personal Communications
- National information services
- Personal communications wrist radio
- Voting/polling wrist set
- Diplomatic U.N. hot lines
- 3-D holographic teleconferencing
- Mobile communications relay
- Amateur radio relay
- "Telegraphing" personal communications systems
- Worldwide electronic ping pong tournaments
- Central computer service (for transmitting hand-held calculators)
- Urban/police wrist radio

Disaster Warning
- Disaster warning relay
- Pre-disaster data base (earthquake)
- Earthquake fault measurements
- Disaster communication set

Navigation, Tracking, and Control

Navigation
- Public navigation system
- Global position determination
- Coastal navigation control
- Global search and rescue locator

Tracking and Location
- Implanted sensor data collection
- Wild animal/waterfowl surveillance
- Marine animal migrations
- Vehicular speed limit control
- Rail anti-collision system
- Nuclear fuel locator
- Vehicle/package locator

Traffic Control
- Multinational air traffic control radar
- Surface ship tracking

Border Surveillance
- U.N. truce observation satellite
- Border surveillance
- Coastal anti-collision passive radar

**Could use SPS to perform a number of functions.*

Table 3.3-1. Attractive Opportunities
in the Services Area (Cont.)

Land Data

Agricultural Measurements
- Soil type classification
- Crop measurement
- Crop damage assessment
- Global wheat survey
- Crop identification/survey
- Agricultural land use patterns
- Crop harvest monitor
- Range land evaluation
- Crop stress detection
- Soil erosion measurement
- Agricultural acreage survey
- Soil moisture measurement
- Soil temperature monitor

Forest Management
- Timber site monitoring
- Logging residue inventory
- Forest stress detection
- Forest fire detection
- Rural/forest environment hazards
- Lightning contact prediction/detection

Hydrological Information System
- Snow moisture data collector
- Wet lands monitor
- Tidal patterns/flushing
- Water management surveillance
- Irrigation flow return
- Run-off forecasting
- Inland water/ice cover
- Subsurface water monitor
- Water resource mapping
- Soil moisture data collector
- Irrigation acreage measurement
- Aquatic vegetation monitoring
- Underwater vegetation survey
- Lake/river suspended solids
- Sediment measurements (rivers)
- Flooded area monitoring

Land Management
- Land capability inventory
- Land use mapping
- Wild land classification
- Range vegetation mapping
- Rangeland utilization/population
- Flood damage assessment
- Beach erosion

Pollution Data
- Advanced resources/pollution observatory
- Salt accumulations (irrigation)
- Agricultural pollutant monitoring
- Lake eutrophication monitor
- Great Lakes thermal mapping
- Effluent discharge patterns
- Toxic spill detector
- Air quality profilometer
- Air pollutant chemistry (Freon)
- Pollution detection and distribution
- Mosquito control (wetlands flooding)

Resource Measurements
- Oil/mineral location
- Drilling/mining operations monitor

Geographic Mapping
- Urban/suburban density
- Recreation site planning
- High-resolution earth mapping radar
- Wildland vegetation mapping
- Offshore structure mapping

Weather Data
- Atmospheric temperature profile sounder
- Rain monitor

Ocean Data
- Ocean resources and dynamics system
- Marine environment monitor
- Oil spill
- Shoreline ocean current monitor
- Algae bloom measurement
- Saline intrusion

Global Environment
- Glacier movement
- Ozone layer replenishment/protection
- Highway/roadway environment impact
- Radiation budget observations
- Atmospheric composition
- Energy monitor, solar terrestrial observatory
- Tectonic plate observation

Table 3.3-2. Attractive Opportunities in the Products Area

Organic
- Isozymes
- Genetic engineering of hybrid plants
- Urokinase
- Insulin
- New antibiotics via rapid mutation

Inorganic
- Large crystals
- Super-large-scale integrated circuits
- Transparent oxide materials
- Surface acoustic wave devices
- New glasses (including fiber optics)
- Tungsten X-ray target material
- Hollow ball bearings
- High-temperature turbine blades
- Separation of radioisotopes
- High strength permanent magnets
- Magnetic bubble memory crystal film
- Thin film electronic devices
- Filaments for high-intensity lamps
- Aluminum-lead lubricated alloys
- Continuous ribbon crystal growth
- Cutting tools
- Fusion targets
- Microspheres

Table 3.3-3. Attractive Opportunities in the Energy Area

Lunetta
- Night illumination for urban areas
- Night illumination for argiculture and industrial operations
- Night illumination for disaster relief operations

Soletta
- Night frost damage protection
- Local climate manipulation
- Reflected light for ground electricity conversion
- Ocean cell warning for climate control
- Controlled snow-pack melting
- Stimulation of photosynthesis process

Other
- Satellite power system (solar)
- Fusion in space
- Nuclear waste disposal

4.0 SUMMARY AND CONCLUSIONS

- The solid state sandwich concept satellite configuration described herein has a greater mass per kilowatt than the Rockwell coplanar concept and will require more material and transportation to achieve the same overall output.

- The mechanics of satellite construction appear feasible, subject to results of the GBED and subsequent space experiments, including docking of large facilities.

- Additional study is required for further evaluation of the implications of rotating large sections of the SCB and of SCB rotation relative to the partially completed satellite.

- The several approaches to reflector deployment and installation (individual reflector roll dispensers versus cable-riding installation facilities) require more detailed trades to select a preferred concept. The cost of large, complex facilities as compared to the cost of a larger number of relatively simple spindle dispensers and automatic welding equipment must be considered.

- The dynamics, time, and propellants relative to (1) transfer of the SCB to the next construction site, and (2) visitation of operational satellites by the SCB-based maintenance crews requires additional study.

- If desired, the satellites may be disposed of in solar orbit at very low cost.

- Many alternative uses of the SPS have been hypothesized.

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Marshall Technical Monitor: Charles H. Guttman
Volume IV of the Final Report on Exhibit D

16. Abstract

The current study entailed, in part, a more detailed definition of solid-state devices for conversion from dc to RF on the satellite, primarily to improve reliability and reduce or eliminate maintenance requirements. Using the coplanar, end-mounted antenna defined in Exhibit C as a baseline, various configuration trades were performed to select a preferred solid-state concept. The increase in efficiency that could be realized by use of multi-bandgap solar cells, either with klystron or solid-state antenna, also was evaluated. Additionally, new satellite configurations were developed to exploit the sandwich antenna concept wherein solar cells are located on one side of the antenna panel and solid-state dc/RF converters on the other side. These concepts entailed various primary and secondary reflector arrangements for directing solar energy to the solar cell side of the antenna with higher concentration ratios than used on the coplanar configurations. The concepts developed bore little resemblance to previous configurations and generated a requirement for a specialized satellite construction base (SCB) specifically tailored to the selected concept.

The operations analysis effort during the current study was concentrated on the solid-state satellite. The scope of the analysis included development of a satellite construction scenario, a concept for the SCB, a top-level satellite construction operation, construction timelines and crew sizes, mass flows to orbit, and a satellite maintenance scenario. Additionally, the list of materials required for satellite construction identified in Exhibit C was updated to identify significant differences relevant to the solid-state satellite concept.

A special study involving feasible means of decommissioning satellites at the end of their design life was conducted. The implications of orbital change were defined and alternative uses of the satellite in lieu of disposal by orbital change identified.

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