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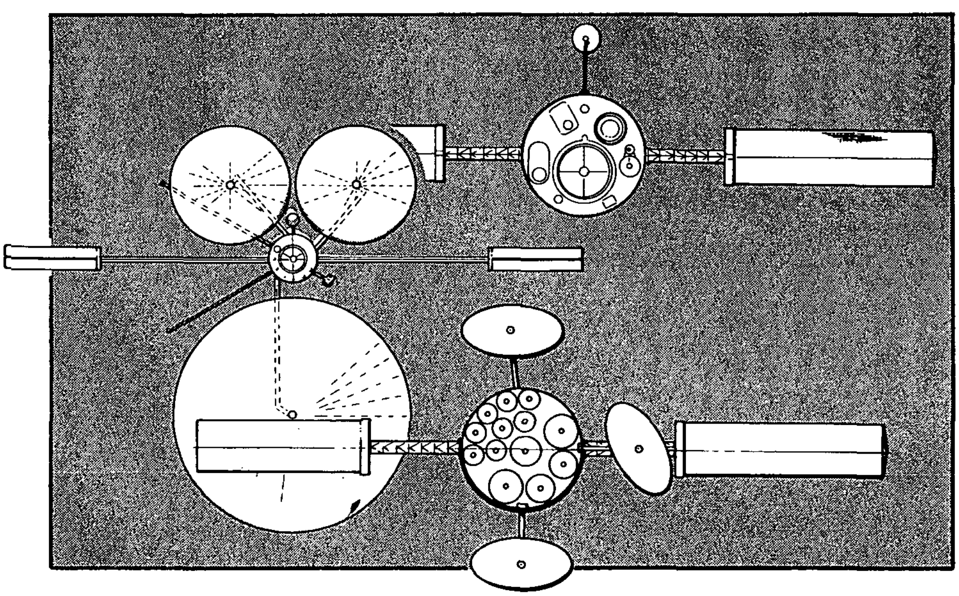
GEOSYNCHRONOUS PLATFORM DEFINITION STUDY

Volume IV - Part 1

TRAFFIC ANALYSIS AND SYSTEM REQUIREMENTS FOR THE BASELINE TRAFFIC MODEL



JUNE 1973

Space Division
Rockwell International

12214 Lakewood Boulevard
Downey, California 90241

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H L Myers

H. L. Myers
GPDS STUDY MANAGER

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FOREWORD

The Geosynchronous Platform Definition Study was a pre-Phase A analysis conducted by the Space Division of Rockwell International Corporation (Rockwell) under Contract NAS9-12909 for the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration. The study explores the scope of geosynchronous traffic, the needs and benefits of multifunction space platforms, transportation system interfaces, and the definition of representative platform conceptual designs. The work was administered under the technical direction of Mr. David Brown (Telephone 713-483-6321) of the Program Planning Office/Future Programs Division of the Lyndon B. Johnson Space Center.

This report consists of the following seven volumes:

Volume I - Executive Summary	SD 73-SA-0036-1
Volume II - Overall Study Summary	SD 73-SA-0036-2
Volume III - Geosynchronous Mission Characteristics	SD 73-SA-0036-3
Volume IV, Part 1 - Traffic Analysis and System Requirements for the Baseline Traffic Model	SD 73-SA-0036-4 Part 1
Volume IV, Part 2 - Traffic Analysis and System Requirements for the New Traffic Model	SD 73-SA-0036-4 Part 2
Volume V - Geosynchronous Platform Synthesis	SD 73-SA-0036-5
Volume VI - Geosynchronous Program Evaluation and Recommendations	SD 73-SA-0036-6
Volume VII - Geosynchronous Transportation Requirements	SD 73-SA-0036-7

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R. D. Meston	Mission and Program Analysis
L. R. Hogan	Systems Engineering and Spacecraft Design
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Dr. K. A. Ehricke	Advanced Mission Analysis
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E. L. Triman	Communications
E. G. Clegg	Spacecraft Design
K. B. Roberts	Operations Analysis
A. Gianformaggio	Cost Analysis
D. W. Earle	System Integration
R. E. Ogelvie	Guidance and Control
R. P. Arras	Thermal Control
W. C. Schmill	Electrical Power
J. B. Weddell	Astro-physics Programs
E. F. Kraly	Sensor Systems Analysis

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ILLUSTRATIONS

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ABBREVIATIONS

ASCS	Attitude stabilization and control system
ATS	Applications Technology Satellite
CCD	Charge coupled device
CCIR	Consultative Committee for International Radio
CM	Crew module
C/N	Carrier-to-noise ratio
COMM	Communications
Comsat	Communications Satellite
CSM	Common support module
DMS	Data management subsystem
Domsat	Domestic Communications Satellite
ECS	Environmental control subsystem
EIRP	Effective isotropic radiated power
EPS	Electrical power subsystem
FDMA	Frequency division multiplexing
FM	Frequency modulation
GEOPAUSE	Geodetic satellite in polar geosynchronous orbit
Geoseps	Geosynchronous solar electric propulsion stage
Intelsat	International Communication Satellite
IPACS	Integrated power and attitude control system
Mersat	Metrology and Earth Observations Satellite
Navsat	Navigation and Traffic Control Satellite

OTS	Orbital transportation system
PCM	Pulse code modulation
PSK	Phase shift keying
RCS	Reaction control subsystem
RSU	Remote service unit
SATA	Small Application Technology Satellite
SEP	Solar electric propulsion
SGLS	Space-ground link subsystem (part of U.S. Air Force Satellite Control Facility)
SNR	Signal-to-noise ratio
SSM	Spares storage module
STDN	Spaceflight tracking and data network
STS	Space transportation system
TDMA	Time division multiple access
TDRS	Tracking and Data Relay Satellite
TPS	Thermal protection subsystem
TT&C	Tracking, telemetry and command
UHF	Ultra high frequency
VHF	Very high frequency
WARC	World Administrative Radio Conference
XMTR	Transmitter

1.0 INTRODUCTION

This volume presents the traffic analyses and system requirements data generated during the Geosynchronous Platform Definition Study. It is divided into two parts: the baseline traffic model and the new traffic model.

The baseline traffic model discussed in this part was derived from current NASA mission planning data. It provides traceability between the numbers and types of geosynchronous missions discussed in the study and the entire spectrum of missions considered in the total National Space Program. Study results presented in this part include:

1. Definition of the baseline traffic model, including identification of specific geosynchronous missions and their payload delivery schedules through 1990.

2. Satellite location criteria, including the resulting distribution of the satellite population.

3. Geosynchronous orbit saturation analyses, including the effects of satellite physical proximity and potential electromagnetic interference.

4. Platform system requirements analyses, including satellite and mission equipment descriptions, the options and limitations in grouping satellites, and on-orbit servicing criteria (both remotely controlled and man-attended).

The origin of the baseline traffic model is described and its missions analyzed to develop potential groups for geosynchronous platforms. The basic need for multi-function space platforms also was investigated in terms of satellite crowding. These efforts, together with similar ones performed for the new traffic model, provided the system-level requirements and guidelines for development of the candidate platform designs presented in Volume V, and also were the source of key mission and schedule data used in the program evaluation presented in Volume VI.

2.0 SUMMARY

This section provides a condensed summary of the traffic analyses and systems requirements for the baseline traffic model. The results of each study activity are presented, key analyses are described, and important results are highlighted.

BASELINE TRAFFIC MODEL

The baseline traffic model was constructed from mission planning and source material familiar to the NASA and the total aerospace community and thus provides convenient comparison and traceability of study results to other similar activities, past and present. This traffic model is derived principally from historical trends. The new traffic model described in Part 2 was based on forecasts of user demands. Together, these models form the basis for defining the nature, number, and schedules of geosynchronous mission activities which are utilized as key input data to many important tasks.

The baseline traffic model was structured around the compilation of related mission planning and systems definition data. Descriptive mission material from many sources was reviewed and pertinent data were grouped into specific mission/functional categories. Missions requiring the unique features of geosynchronous orbit were identified and matched to the delivery schedules contained in the planning information. The resulting geosynchronous traffic model contains 180 satellites distributed among five categories (Table 2.0-1).

Since no single source of planning data treated the complete spectrum of mission categories or the total period of interest, three basic sources were used in constructing the model:

1. The Updated NASA Mission Model, dated June 1972, which provided data for the first four categories.

2. The "Fleming" Mission Model, dated October 1971, which provided data on the fifth category for the period 1979 through 1990.

3. Open literature, from which information of the fifth category covering the period through 1978 was assembled.

Satellite location criteria were established for each category and mission type contained in the model. These criteria, based chiefly on geometry considerations for earth viewing and communications access in conjunction with the parametric earth coverage data from Volume III, were applied to the elements in the traffic model to determine the distribution of the satellite population. Six longitudinal zones were defined, ranging in size from 25 to 120 degrees. The active satellite population contained in each of the zones is summarized in Figure 2.0-1.

Table 2.0-1. Baseline Traffic Model

PART "A" (NASA MISSION MODEL, JUNE 1972)

CATEGORY	TITLE	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL	SUB-TOTAL	CUM TOTAL
		SCHEDULE (CALENDAR YEAR)																				
ASTRONOMY	EXPLORERS						1			1			1			1			1	5	5	5
EARTH OBSERVATIONS	SYNCHRONOUS EARTH OBSERV. SAT								1		1			1		1			1	5		
	SYNCHRONOUS METEOROLOGICAL SAT	1				1				1	1									4		
	SYNC. EARTH OBSERV. SAT./PROTO																		1	1	10	15
EARTH AND OCEAN PHYSICS	GEOPAUSE							1	1											2	2	17
COMMUNICATIONS & NAVIGATION	APPLICATIONS TECHNOLOGY SATELLITE	1		1			1	1			1	1		1		1		1		9		
	COOPERATIVE APPLICATIONS SATELLITE			1			1													2		
	SMALL APPL. TECHNOLOGY SATELLITE				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15		
	TRACKING & DATA RELAY SATELLITE					1	2					3						3		9		
	DISASTER WARNING SATELLITE						1	1												2		
	SYSTEM TEST SATELLITE								1	1	1	1	1	1		1	1			8	45	62
NON-NASA OPERATIONAL SPACECRAFT	COMMUNICATION SATELLITE	1		2	3		2	2	1	1		2	1	1			2	1		19		
	U.S. DOMESTIC COMMUNICATION		2	2		2	2	1	2	1	1	2	2	2	2	2	2	2	2	29		
	FOREIGN DOMESTIC COMMUNICATION	4	1		1	2	3		2	6	2	2			4	5	2	1	2	37		
	NAVIGATION AND TRAFFIC CONTROL	1				1	2		1	1		1		1		1		1		10		
	SYNCHRONOUS METEOROLOGICAL			2		1		1	1	1	1	1	1	1	1	1	1	1	1	15		
	SYNCHRONOUS EARTH RESOURCES													4			4			8	118	180

PART "C" (OPEN LITERATURE)

PART "B" (FLEMING MODEL, OCTOBER 1971)

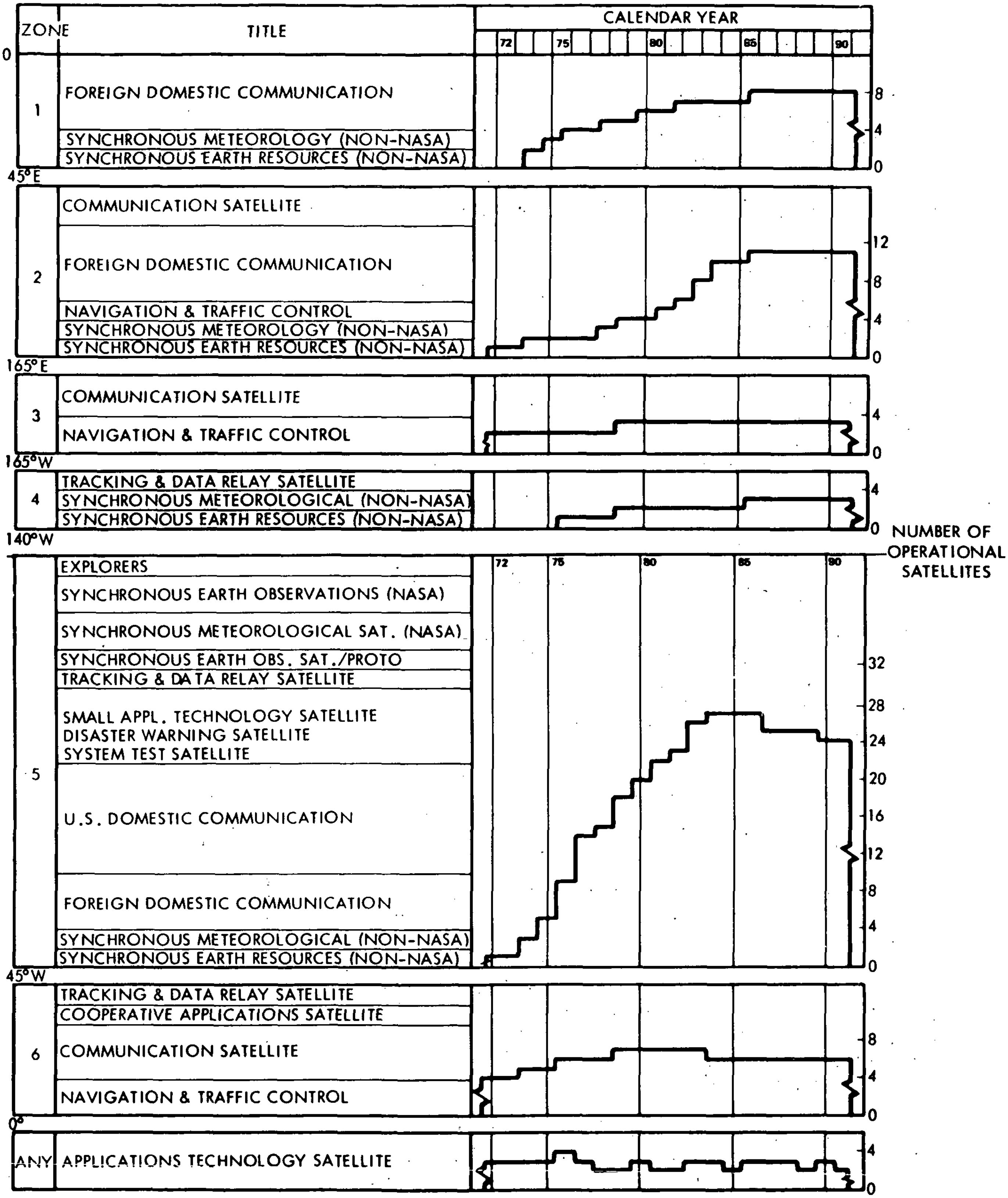


Figure 2.0-1. Active Satellite Population for the Baseline Traffic Model

GEOSYNCHRONOUS ORBIT SATURATION

The purpose of the orbit saturation analysis was to determine the nature and degree of satellite congestion in geosynchronous orbit if the current approach of launching individual satellites is continued through 1990. Its intent was to determine if satellite interference would reach acute levels, thereby forcing a change in program approach from individual satellites to multi-function platforms with grouped payloads.

To meet these objectives, physical proximity and potential electromagnetic interference (EMI) were analyzed for the active satellite population. The physical proximity analysis was also extended to the total satellite population, both active and inactive.

The active satellite distributions in the baseline traffic model were compared to a simplified, one-dimensional satellite spacing model which allowed for normal stationkeeping operations and perturbing influences. Although this model is highly conservative (1.15 degrees minimum spacing), no physical interference was predicted because the actual satellite spacing ranged from 3.1 to 11.0 degrees in the different zones.

To extend the physical proximity problem to the inactive satellites, the combined effects of all sources of orbital perturbations were analyzed. At the end of its mission life when stationkeeping ability is lost, the motion of a geosynchronous satellite is totally dictated by the influences of luni-solar perturbations, tesseral harmonics in the earth's gravity potential, solar pressure, and the residual deviations present when stationkeeping ceased. These perturbations introduce cyclic variations in longitude, altitude, and orbit inclination which produce a total "swept" volume occupied by all satellites of 3×10^{10} n mi^3 (Figure 2.0-2). Adding existing and projected foreign and DoD satellite traffic to the 180 satellites defined in the baseline traffic model produces a total world population of 295 geosynchronous satellites. The average occupied volume of space becomes approximately 100 million n mi^3 per satellite. (It is assumed that "dead" satellites are not retrieved through 1990.) This enormous volume means there is little likelihood of collision.

While the EMI is potentially more serious and must be considered in mission planning and control, no critical congestion problem was identified for the baseline traffic model. To analyze EMI, the active satellite distribution data derived in the baseline traffic model was expanded to define the locations and RF characteristics of the individual satellites. The most densely populated zone is shown in Figure 2.0-3. Different symbols are used to depict each type of satellite; all satellites operating in the same frequency band are placed in the same row. Only satellites operating on common frequencies pose a potential EMI problem.

As shown, the most populous satellite type is the C-band Domsat/Telesat. Careful placement and distribution of these C-band satellites results in greater than 6-degree spacing between adjacent satellites. To determine a "safe" spacing criterion, an interference noise model was constructed. This was based on the international limit of 1000 picowatts of noise power (psophometrically weighted) and reflected conservative assumptions regarding ground station separation

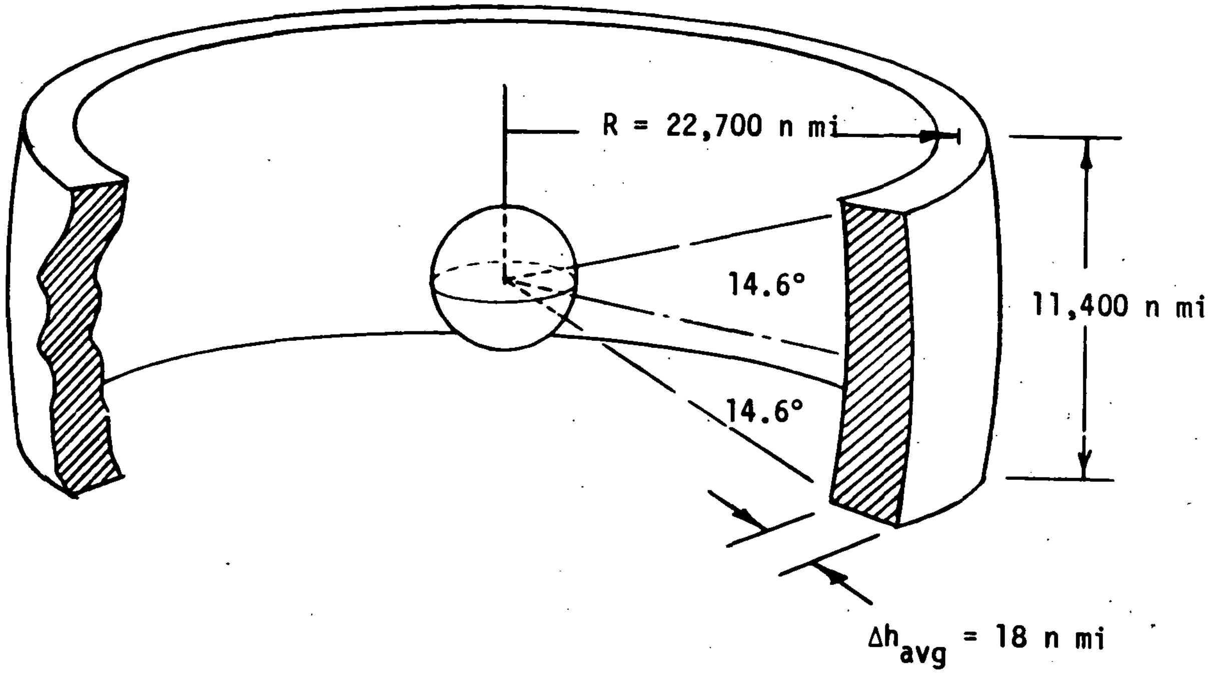


Figure 2.0-2. Total "Swept" Volume of Space Occupied by Free Drifting Geosynchronous Satellites

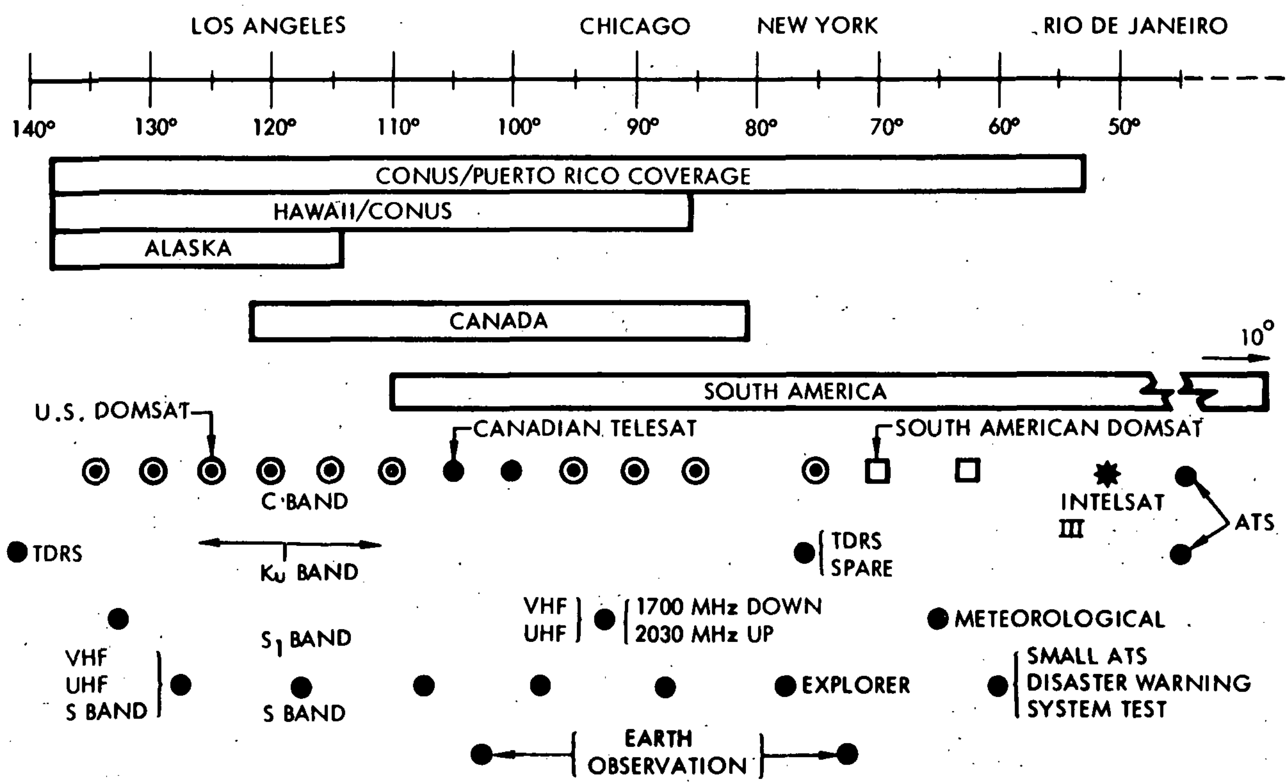


Figure 2.0-3. Representative Satellite Distribution - Maximum Density Zone

distance. With 60-foot diameter ground antennas the Domsat-type satellites could safely operate with 4.6-degree spacing. This reduces to about 3-degree spacing with 97-foot antennas. Thus EMI was not deemed to pose a critical problem for the baseline traffic model.

GEOSYNCHRONOUS REQUIREMENTS ASSESSMENT

In this activity the traffic analysis, satellite/payload definitions, and mission characteristics data developed previously were translated into system-level requirements for geosynchronous platforms. It includes the "groupability" of payloads through physical and functional considerations and the influences of various modes of on-orbit servicing and their related criteria. These requirements form the basis for the subsystem sizing, mission and subsystem equipment packaging, configurational arrangement, and other design analyses presented in Volume V.

To determine the general features and size of geosynchronous platforms, the important satellite characteristics and related mission requirements from the basic traffic and mission analyses were determined, then assessed for compatibility and commonality. It was determined that mission functions requiring global surveillance capability must be separated into four major regions (Figure 2.0-4). These regions are the result of competing earth coverage requirements for land mass viewing, monitoring major weather cells, and communications bridges between countries and across oceans. Four regions are the minimum number which provides high latitude coverage of the populated regions and which affords the multipath capability necessary to preclude political blockades of international communications.

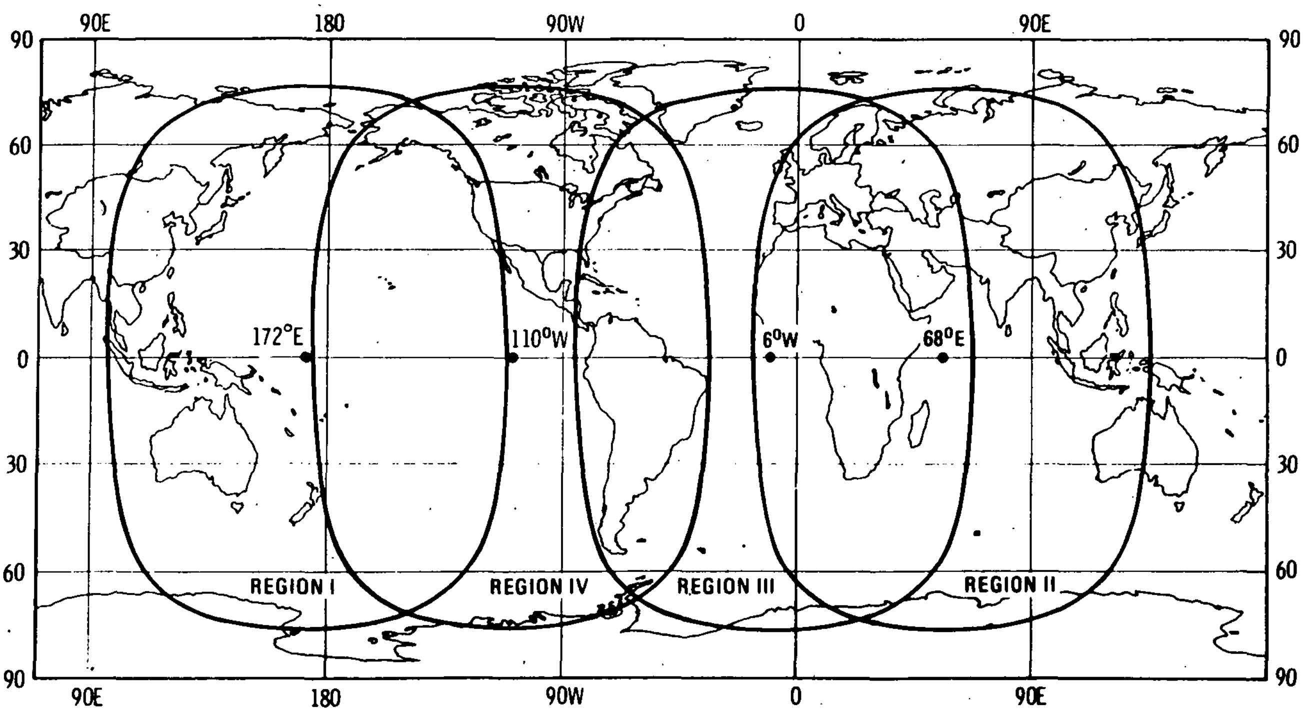


Figure 2.0-4. Global Coverage Regions

In addition to total world coverage, a number of other compatibility factors were considered in grouping payloads within each region. Among these is the solar noise outage which periodically interrupts communications between a given satellite and ground station, requiring separation of communications payloads within a region to maintain continuity of service. Data relay from low-orbit satellites to a central earth facility (TDRS function) requires unique positioning with respect to the ground facility. Also, with only one unit needed in each of three regions, their integration with other appropriate regional payloads would require two platform sizes, one standard size for terrestrial communications relay and one oversized with combined terrestrial communications and TDRS functions.

It was also determined that inertially pointed astronomy sensors and earth-looking communications equipment could not be combined because of pointing envelope constraints. Also, earth resource sensors require large and varied antennas which represent major design complexities, rendering their combination with other payloads difficult. Configuration complexities for non-interfering equipment installations and the very demanding requirement for sensor scanning operations involving the articulation of massive sensor elements indicated the impracticality of combining these payloads with others.

Certain other payloads were identified in the baseline traffic model as developmental. Their characteristics were undefined and thus they could not be combined with other payloads. Even if their characteristics were known, it is unlikely that the risk factors associated with relatively frequent servicing operations for R&D and experimental equipment would permit their incorporation on platforms carrying commercial-type payloads. However, it is likely that many of these developmental payloads could be supported by space platforms designed for the other payload groups. This would offer the added advantages of isolating the servicing risk factors from commercial payloads and locating developmental equipment together for improved servicing. The lack of equipment definition and support requirements data, however, precluded any firm identification of developmental payloads for platform requirements analyses.

The platform inventory resulting from the grouping analyses is summarized in Table 2.0-2. There are four types of payload groups but all are serviceable by a common set of utility support capabilities (electrical power, guidance and control, RCS, etc.). Important differences exist in the integration of mission equipment but all platform types fall into the same general size range of support requirements.

In addition to payload grouping and subsystem support requirements for platforms, the effects of on-orbit servicing were determined. On-orbit servicing includes maintenance and updating operations which may include replacing equipment, changing functions being performed on platforms, increasing functional capacity, or applying newer technology. Three basic servicing approaches were treated: (1) mechanical auto-remote, (2) EVA/IVA man-attended, and (3) shirtsleeve man-attended. The requirements imposed on platforms for all three modes fall into two fundamental categories: general configurational requirements and subsystem-related requirements.

Table 2.0-2. Platform Inventory for Baseline Traffic Model (Through 1990)

Platform Type	REGION			
	I	II	III	IV
Communications relay	2	2	2	2
TDRS*	-	-	1	2
Astro-physics	-	-	-	4
Earth observations	1	1	1	1

* Regional assignments are approximate because of unique placement requirements

The overall size, shape, and arrangement of the platform must provide for access by the selected servicing system. In the auto-remote case, the platform must allow a manipulative device to grasp, unlatch, and withdraw any replaceable unit and insert and install its replacement. For the manned approaches, clearance requirements must consider the man in a suited envelope.

The requirements imposed on the subsystems differ based on the servicing approach. Shirtsleeve servicing requires the greatest number of provisions, including a pressurized enclosure, atmospheric control, lighting, voice communications, crew aids, and special protection. EVA/IVA requires similar but fewer provisions since some life support and environmental protection is furnished by suits and backpacks. All concepts require a form of docking for rigid attachment, interface connections to the service unit, data links for trouble analysis and checkout, and the ability to deadface or shut down systems or equipment undergoing servicing.

The platforms must meet shuttle or tug safety criteria during all operations. No unique requirements can be seen to be imposed on the tug for unmanned operations; however, there are special requirements for the tug, the platforms, and for the man module in cases involving man-attended servicing. These include redundancy in critical areas and possible alternative methods for assuring safe return of the crew.

Unique factors associated with geosynchronous servicing are summarized in Table 2.0-3; they involve key differences between servicing in geosynchronous orbits and corresponding operations in low earth orbits. These factors, combined with the configurational and subsystem requirements attributable to servicing operations and the mission grouping and subsystem support functions, form the system-level requirements for candidate platform designs presented in Volume V.

Table 2.0-3. Unique Geosynchronous Servicing Factors (Compared to LEO)

Factor	Characteristics
Mission time	Less servicing time is available in geosynchronous orbit due to tug-shuttle separation and rendezvous operations, and increased phasing and orbit transfer times over low earth orbits.
Payload size/weight	Spares and servicing system length and weight are severely limited by shuttle-tug combined delivery capabilities; i.e., shuttle bay less tug length, shuttle weight to orbit less tug weight, and tug roundtrip delivery performance to geosynchronous orbit.
Remote (RF) checkout, trouble analysis, and command	Geosynchronous orbits provide an "optimal" ground link compared to low earth orbits considering the capability of using a single station and a minimal shuttle RF interface.

3.0 BASELINE TRAFFIC MODEL

A baseline traffic model of geosynchronous missions was developed for use as a basic study tool in several important task areas. It provides a compilation of organized data which defines the nature, numbers, and schedules of planned geosynchronous missions. It permits the evaluation of potential satellite physical contention conditions and geosynchronous orbit EMI saturation characteristics. It provides the framework and basis for the establishment of time-phased program objectives and mission requirements upon which alternate program approaches may be evaluated. It is derived from planning and source data widely familiar to NASA and the total aerospace community, thus providing convenient traceability of study results to other past and on-going industry and government activities.

3.1 TRAFFIC MODEL DEFINITION

DEVELOPMENT APPROACH

The objective of the baseline traffic model development activity was the definition of the time-phased geographic distribution of geosynchronous satellites contained in current NASA and industry planning literature (as opposed to information in the new traffic model). To achieve this objective the overall development approach depicted in Figure 3.1-1 was applied. Key input data were compiled and examined to identify specific geosynchronous missions from the entire spectrum of missions being considered within the total space program. These were grouped into generic categories and formatted to establish the basic delivery schedule by satellite type. The somewhat general mission characteristics data in the principal source material were supplemented by key data from various specific conceptual systems study results. These were further augmented by the orbit characteristics and parametric earth coverage features derived in Task 2.0 of this study and which are presented in Volume III. Generalized coverage requirements for each type of mission were formulated to establish preferred satellite locations. Based on these preferred locations and their basic delivery schedules, the satellite population histories were constructed. Both active and inactive satellite populations are included.

BASELINE TRAFFIC SCHEDULE

The principal source for the baseline traffic definition was the "Updated NASA Mission Model" dated June, 1972 in Reference 3-1. This model identifies the currently envisioned missions from 1973 through 1990 for seven basic categories as listed below:

- Astronomy
- Space physics
- Earth observations
- Earth and ocean physics
- Communication and navigation
- Life science
- Space technology and material science

However, the model did not explicitly identify those spacecraft which would be expected to operate in geosynchronous orbit. It was necessary, therefore, to review the model and develop a geosynchronous mission schedule. Additional data concerning non-NASA missions from the "Fleming" model dated October, 1971 in Reference 3-2 and other mission planning and definition material from References 3-3, 3-4, and 3-5 were analyzed to establish a final pattern of "baseline" geosynchronous missions.

The original seven categories of geosynchronous missions were reduced to five. Where other mission models (References 3-2 and 3-4) indicated no geosynchronous missions in a given category or where payload definition data from References 3-3, 3-4, and 3-6 indicated no basis for operating at geosynchronous altitudes the basic category was eliminated. Space physics, life science, and space technology and material science were deleted through this evaluation

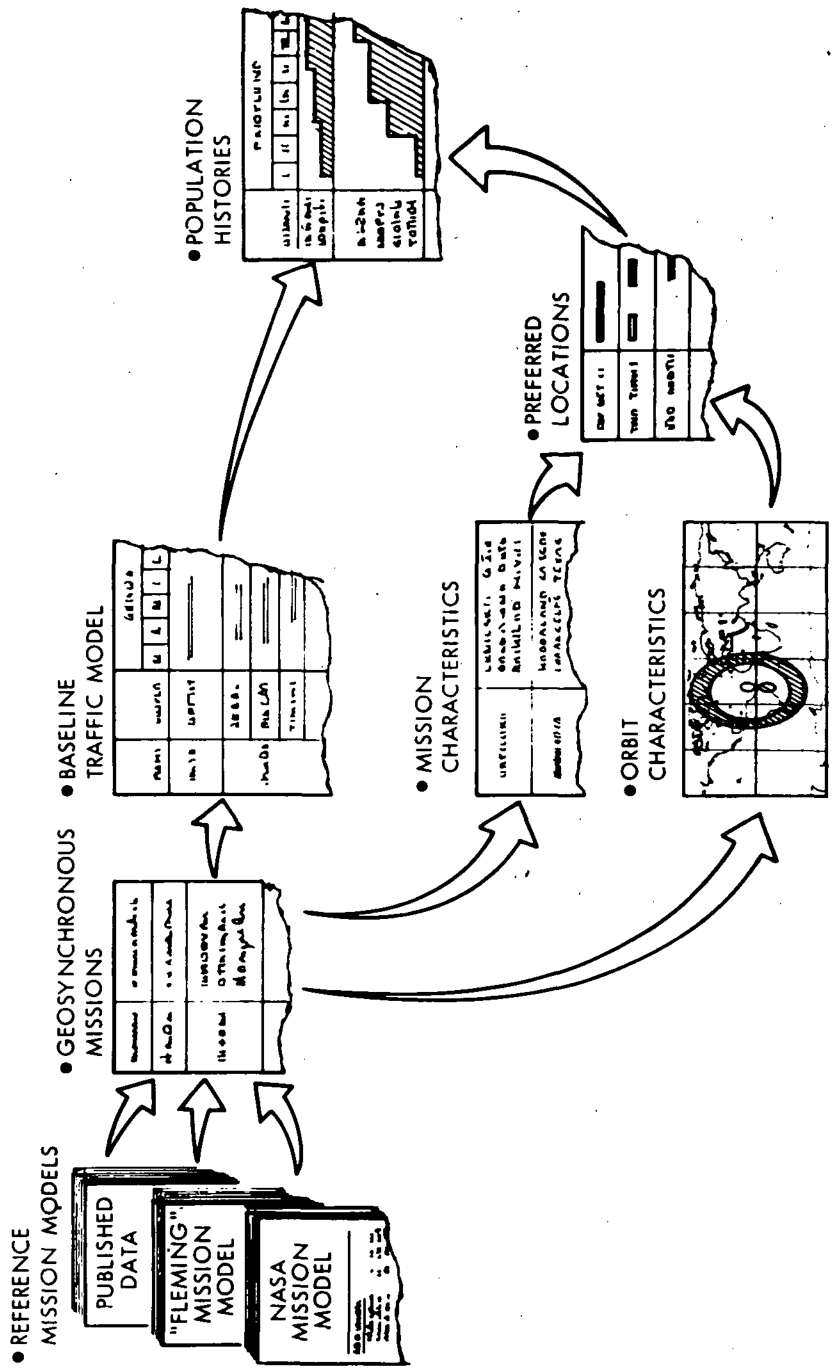


Figure 3.1-1. Baseline Traffic Model Development Approach

process. In addition to the remaining four categories, a "Non-NASA Operational Satellite" cateogry was introduced. This resulted in the above mentioned five categories of geosynchronous missions for which individual satellite schedules were derived. They are:

- Astronomy
- Earth observations
- Earth and ocean physics
- Communications and navigation
- Non-NASA operational spacecraft

The astronomy category reflects the operation of an on-going facility for supporting basic research. While it is operational rather than developmental, it was isolated from the other operational spacecraft (non-NASA operational spacecraft category) because it is research oriented and likely would be government funded. The next three categories, earth observations, earth and ocean physics, and communications and navigation are totally developmental in nature. They are government funded and are intended to provide the means for advancing space technology through hardware development and operational experience. The final category, non-NASA operational spacecraft, is essentially comprised of commercial spacecraft, funded by private capital, and for which there is a definable market potential for the services they provide. Having defined these basic categories of geosynchronous missions, specific delivery schedules were constructed for the individual satellite types in each category.

The fundamental schedule structure was derived from two principal sources (References 3-1 and 3-2) with additional information from other sources used as necessary to fill in important missing elements. The resulting delivery schedule for the baseline traffic model is summarized in Table 2.0-1. The delivery schedules for satellites in the first four mission categories were obtained directly from the NASA Mission Model (Reference 3-1) by matching satellite names and general descriptive material from all mission model sources to specific schedule dates in Reference 3-1. This covered all satellites in these categories from 1973 through 1990. However, the NASA Mission Model did not treat the expected non-NASA operational missions (fifth category) for which NASA would provide launch support. Therefore, to fill this void, the decision was made to use the non-NASA operational spacecraft defined in the "Fleming" Mission Model (Reference 3-2). The "Fleming" Mission Model identified all expected satellites in this category during the 1979 through 1990 time period, but it was again necessary to identify those which would be in geosynchronous orbit. The remaining delivery schedules in the 1973 through 1978 time period for the non-NASA operational spacecraft were obtained primarily from information available in the open literature. These are shown in Table 3.1-1. Although specific spacecraft titles were identifiable, they were grouped under the generic title used in the "Fleming" Mission Model," as shown in the table. For example, the Intelsats are grouped under "Communication Satellites".

As shown in Table 2.0-1, a total of 180 satellites was identified in the baseline traffic model with the majority (118) being non-NASA operational spacecraft. Peak traffic densities, in terms of the number of deliveries per year, range from 14 to 16 and occur in 1978, 1981, 1983, and 1987. The resultant average delivery rate for the 18-year period is 10 satellites per year.

Table 3.1-1. Non-NASA Operational Spacecraft (1973 through 1978)

Satellite Designation	Launch Date	References
COMMUNICATION SATELLITES		
Intelsat 4-F8	1973	Comsat Annual Report (1971)
Intelsat 4.5 (1)	1975	Hughes - BAC Study Plans - AW&ST, 9/11/72
Intelsat 4.5 (2)	1975	Hughes - BAC Study Plans - AW&ST, 9/11/72
Intelsat 4.5 (3)	1976	Hughes - BAC Study Plans - AW&ST, 9/11/72
Intelsat 4.5 (4)	1976	Hughes - BAC Study Plans - AW&ST, 9/11/72
Intelsat 4.5 (5)	1978	Hughes - BAC Study Plans - AW&ST, 9/11/72
Intelsat 4.5 (6)	1978	Hughes - BAC Study Plans - AW&ST, 9/11/72
DTS (Development test satellite)	1976	Lockheed Missiles and Space Company and 15-Member International Consortium Plan - AW&ST, 9/6/71
U.S. DOMESTIC COMMUNICATION		
These satellites may be built by Hughes, Western Union, WTCI, Comsat, Fairchild, or Lockheed MCI.	1974 1974 1975 1975 1977 1977 1978 1978	Rockwell estimate from Domsat studies and market analysis
FOREIGN DOMESTIC COMMUNICATION		
Anik - 1 (Canada)	1973	Telesat Canada Domestic Communications Satellite Plans - AW&ST, 9/6/71
Anik - 2	1973	Telesat Canada Domestic Communications Satellite Plans - AW&ST, 9/6/71
Sirio (Italy)	1973	Italian Agency for Space (SAS) Communications Satellite Plans - AW&ST, 6/5/72
Statsionar - 1 (USSR)	1973	European Space Program Status, AW&ST, 3/13/72
Symphonie (France-Germany)	1974	Leading U.S. & International Spacecraft Forecast and Inventory, AW&ST, 3/13/72
CEPT (ESRO)	1976	ESRO Regional Satcom Plans, AIAA 4th Communications Satellite Systems Conference, April 24-26, 1972
India India Japan Japan	1977 1977 1978 1978	Rockwell estimate from Domsat studies and market analysis
Germany	1978 or 1979	German Ministry of Education and Science (West Germany) Direct TV Broadcast Plans, AW&ST, 4/24/72
NAVIGATION AND TRAFFIC CONTROL		
Dioscures (France)	1973	Leading U.S. & International Spacecraft Forecast and Inventory, AW&ST, 3/8/71
Aerosat - 1	1977	IMCO Joint Aero-Maritime Communications Satellite Plans, Jan. 20-21, 1972, London, AW&ST, 2/28/72
Aerosat - 2	1978	ICAO Aerosat Plan, AW&ST, 5/15/72
Aerosat - 3	1978	ICAO Aerosat Plan, AW&ST, 5/15/72
SYNCHRONOUS METEOROLOGICAL		
Japan (GOES)	1975	Japan GOES Plan, AW&ST, 1/24/72
Metsat (GOES) (ESRO)	1975	European Space Program Status, AW&ST, 3/13/72
Meteosat (France)	1977	AIAA 4th Mtg. on Communication Satellite Systems, 4/24/72

3.2 SATELLITE POPULATION DISTRIBUTION

DEVELOPMENT APPROACH

The global distribution of geosynchronous satellite traffic is necessary to evaluate the degree of local clustering and consequent satellite congestion problems which might occur. It will also provide a necessary link to the establishment and grouping of geosynchronous mission requirements which can be used as the basis for the formulation of alternate program approaches. To meet these needs, the time-phased geographical distributions of the satellites in the baseline traffic model were derived.

It was first necessary to determine the preferred placement locations for each satellite type. Basic location criteria were developed from the payload and mission descriptive material contained in References 3-3, 3-4, and 3-5, and were based primarily on earth-viewing or line-of-sight access considerations. They are summarized in Table 3.2-1. In general, the astronomy, and NASA communications and navigation payloads are located such that direct communications and, in some cases, viewing of the contiguous United States, are possible. The non-NASA operational spacecraft have, in general, a world-wide distribution with specific locations dependent upon access to each of the continental regions. These location criteria were applied to each satellite type, along with quantitative earth coverage data from Volume III, to define bands of permissitle locations. The final step in constructing the time-phased geographical distributions of satellites was accomplished by applying the delivery schedule for each satellite type to its respective location band. The pattern of global buildups in local satellite populations is the desired result.

SATELLITE POPULATION SUMMARIES

As outlined above, the basic location criteria for each satellite type were quantitatively evaluated utilizing parametric earth coverage data from Volume III to determine permissible location bands. An example is illustrated in Figure 3.2-1 which shows the location band for all geosynchronous satellites which are constrained to have access to any location within the contiguous United States. All regions accessible within a 5-degree horizon mask angle are shown by the contours. At longitudes farther west than 135°W, access to the northeastern states begins to be lost. For locations east of 55°W, access to the northwestern U.S. is diminished. The functions requiring this general access pattern include many of the NASA programs; i.e., astronomy, earth observation, and some of the communications and navigation satellites.

The NASA earth observation and meteorological satellites were further constrained to 15-degree longitudinal bands specifically located to provide balanced coast-to-coast viewing of the continental U.S. (from the standpoint of line-of-sight incidence) and to cover the Aleutian and Carribean weather cells which influence U.S. weather patterns.

Table 3.2-1. Satellite Location Criteria

CATEGORY	TITLE	PRINCIPAL CRITERIA
ASTRONOMY	EXPLORERS	• DIRECT U.S. COMMUNICATIONS
EARTH OBSERVATIONS	SYNCHRONOUS EARTH OBSERVATION SATELLITE	• U.S. VIEWING • DIRECT U.S. COMMUNICATIONS
	SYNCHRONOUS METEOROLOGICAL SATELLITE	• OBSERVATION OF U.S. WEATHER SOURCES • DIRECT U.S. COMMUNICATIONS
	SYNCHRONOUS EARTH OBSERVATION SATELLITE/PROTOTYPE	• U.S. VIEWING • DIRECT U.S. COMMUNICATIONS
EARTH AND OCEAN PHYSICS	GEOPAUSE	• U.S. COMMUNICATIONS
COMMUNICATIONS & NAVIGATION	TRACKING AND DATA RELAY SATELLITE	• DIRECT COMMUNICATIONS WITH • SINGLE U.S. GROUND SITE
	APPLICATIONS TECHNOLOGY SATELLITE	• MISSION OBJECTIVE DEPENDENT
	COOPERATIVE APPLICATIONS SATELLITE	• U.S./EUROPEAN COMMUNICATIONS
	SMALL APPL TECHNOLOGY SATELLITE DISASTER WARNING SATELLITE SYSTEM TEST SATELLITE	• DIRECT U.S. COMMUNICATIONS
NON-NASA OPERATIONAL SPACECRAFT	COMMUNICATION SATELLITE	• WORLD-WIDE INTERCONTINENTAL COVERAGE
	U.S. DOMESTIC COMMUNICATION	• DIRECT INTRATIONAL (U.S.) COMMUNICATIONS
	FOREIGN DOMESTIC COMMUNICATION	• DIRECT INTRANATIONAL COMMUNICATIONS
	NAVIGATION AND TRAFFIC CONTROL	• WORLD-WIDE COVERAGE OF MAJOR AIR TRAFFIC CORRIDORS
	SYNCHRONOUS METEOROLOGICAL	• WORLD-WIDE COVERAGE OF MAJOR WEATHER SOURCES
	SYNCHRONOUS EARTH RESOURCES	• WORLD-WIDE COVERAGE

The Geopause mission was determined to require a polar orbit (at synchronous altitude) and thus cannot be shown as a simple longitudinal band. Orbit orientation constraints would likely place its nodal location somewhere within the longitudinal bounds of the U.S. This location assumption was applied later in the construction of detailed satellite distributions.

The tracking and data relay satellites (TDRS) were located as specified in a recent Rockwell TDRS study, Reference 3-7. Two active satellites are placed so that direct communication with a single ground station is possible and an on-orbit spare is located midway between the two active satellites.

The applications technology satellite (ATS) locations are dependent upon mission objectives yet to be defined and thus are shown in Figure 3.2-2 as a dashed line indicating potential placement anywhere.

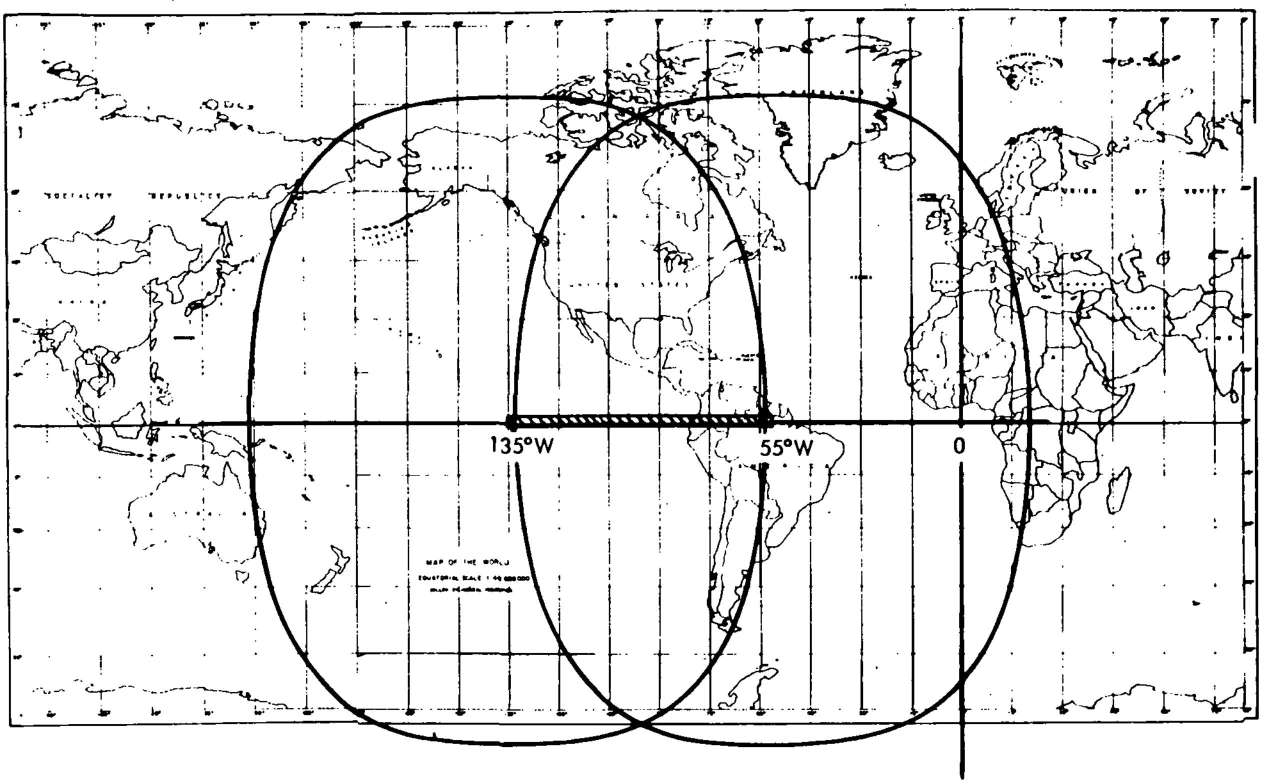
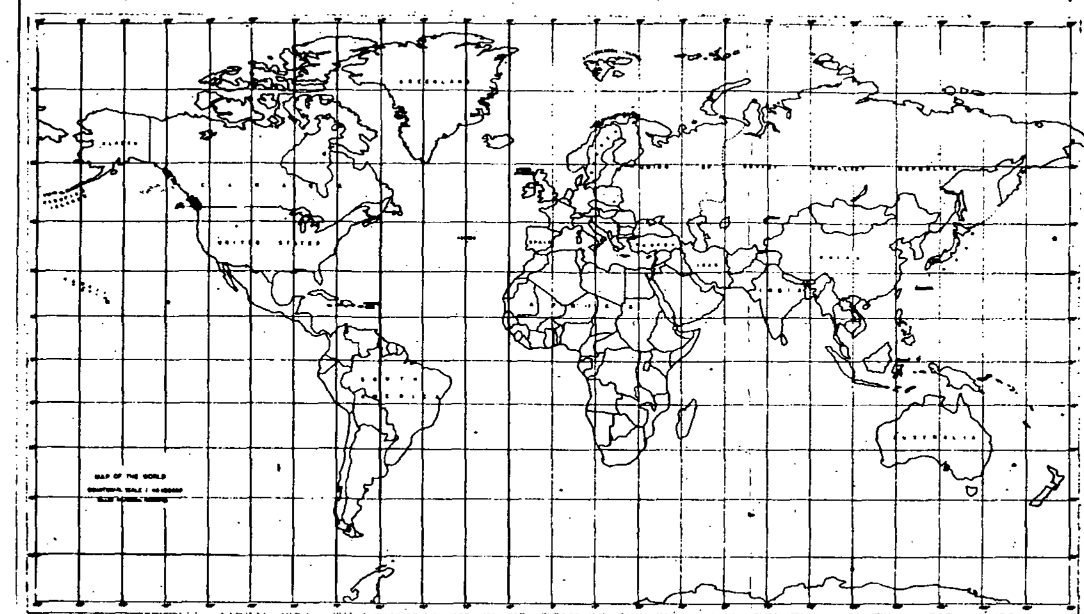


Figure 3.2-1. Example Earth Coverage Characteristics

The cooperative applications satellite was located to provide appropriate access for U.S./European communications. The remaining NASA developmental satellites were constrained only to provide direct access to the U.S. for convenient retrieval of data.

The non-NASA satellite location bands followed similar patterns. The communications satellites were placed in three location bands centered over the Atlantic, Pacific, and Indian Oceans. These permit world-wide international communications between the major land masses. U.S. domestic communication is limited by access to the continental U.S., Hawaii, and Alaska. Foreign Domsat communication satellites were located to provide coverage for Canada, Central and South America, Europe/Africa, and Asia. The non-NASA meteorological and earth resources satellites were configured to be sets of four equally spaced satellites which provide global surveillance capability. Their specific locations were the result of compromises between good viewing of weather patterns and low-incidence viewing of agricultural and other land mass regions.



ASTRONOMY	EXPLORERS	• DIRECT U.S. COMMUNICATIONS	
EARTH OBSERVATIONS	SYNCHRONOUS EARTH OBSERVATION SATELLITE	• U.S. VIEWING • DIRECT U.S. COMMUNICATIONS	
	SYNCHRONOUS METEOROLOGICAL SATELLITE	• OBSERVATION OF U.S. WEATHER SOURCES • DIRECT U.S. COMMUNICATIONS	
	SYNCHRONOUS EARTH OBSERVATION SATELLITE/PROTOTYPE	• U.S. VIEWING • DIRECT U.S. COMMUNICATIONS	
	GEOPAUSE		
COMMUNICATIONS & NAVIGATION	TRACKING AND DATA RELAY SATELLITE	• DIRECT COMMUNITIONS WITH SINGLE U.S. GROUND SITE	
	APPLICATIONS TECHNOLOGY SATELLITE	• MISSION OBJECTIVE DEPENDENT	
	COOPERATIVE APPLICATIONS SATELLITE	• U.S./EUROPEAN COMMUNICATIONS	
	SMALL APPL. TECHNOLOGY SATELLITE DISASTER WARNING SATELLITE SYSTEM TEST SATELLITE	• DIRECT U.S. COMMUNICATIONS	
NON-NASA OPERATIONAL SPACECRAFT	COMMUNICATION SATELLITE	• WORLD-WIDE INTERCONTINENTAL COVERAGE	
	U.S. DOMESTIC COMMUNICATION	• DIRECT INTRANATIONAL (U.S.) COMMUNICATIONS	
	FOREIGN DOMESTIC COMMUNICATION	• DIRECT INTRANATIONAL COMMUNICATIONS	
	NAVIGATION AND TRAFFIC CONTROL	• WORLD-WIDE COVERAGE OF MAJOR AIR TRAFFIC CORRIDORS	
	SYNCHRONOUS METEOROLOGICAL	• WORLD-WIDE COVERAGE OF MAJOR WEATHER SOURCES	
	SYNCHRONOUS EARTH RESOURCES	• WORLD WIDE COVERAGE	

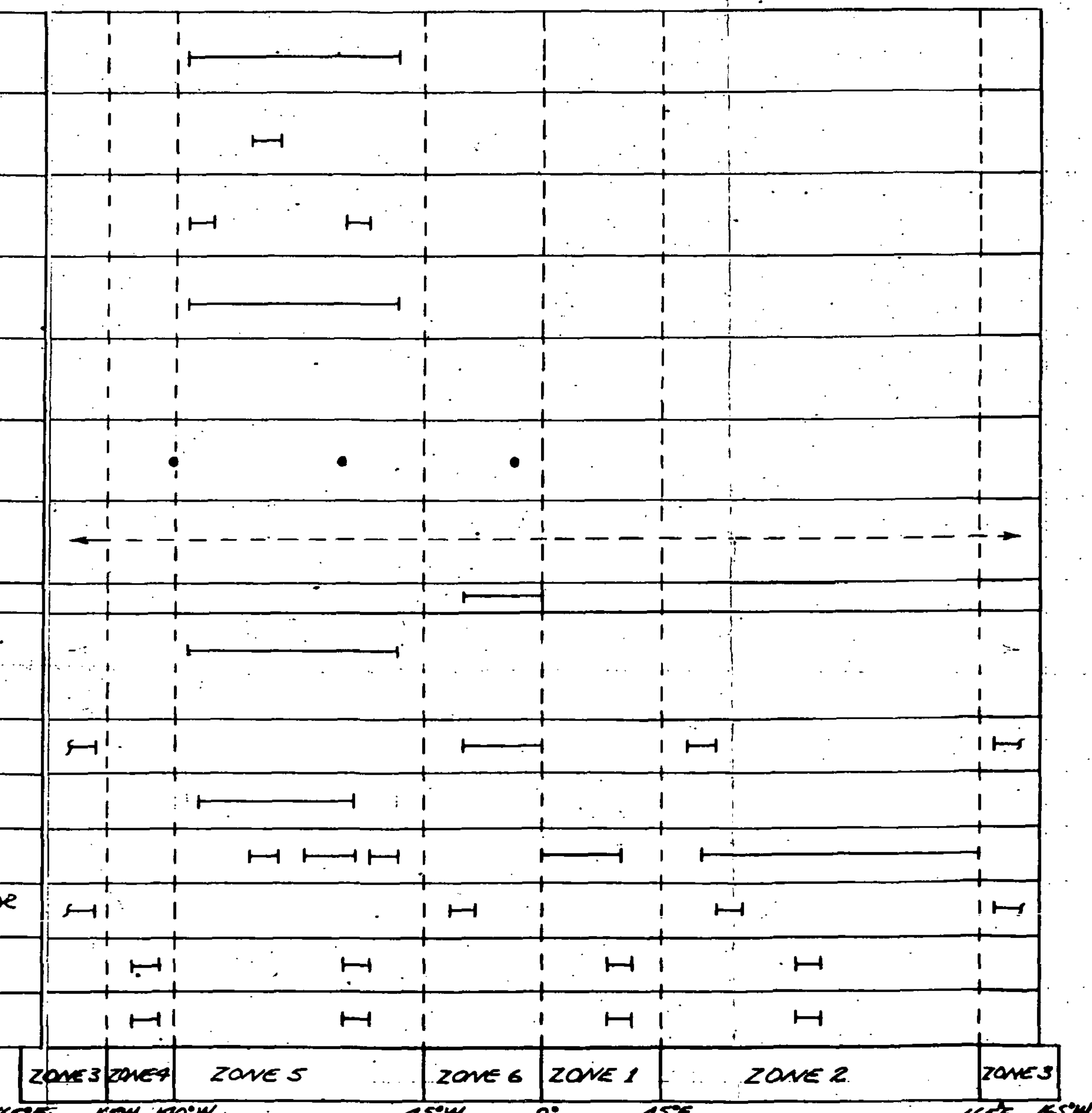


Figure 3.2-2. Preferred Geographic Locations

The resulting overall pattern of distributions is shown in Figure 3.2-2. Examination of this pattern revealed that the functional coverage bands could be separated into six separate zones for convenience in constructing individual satellite placements later in the study. These zones are identified by vertical dashed lines in the figure. Zone 1 covers Europe and Africa. Asia and Australia are covered by Zone 2. Zones 3, 4, and 6 cover the Pacific and Atlantic Oceans while Zone 5 covers North and South America. Although there is some potential overlap in coverage between adjacent zones, the identified zones were found to be useful in constructing the time-phased distributions of satellite population histories.

The satellite population histories were derived from the delivery schedule listed in Table 3.1-1 for the baseline traffic model and the preferred locations discussed above. However, to provide a basis for the determination of active and inactive satellite populations, and to aid in the development of a smooth buildup of functional capabilities, mission lifetimes were projected for each of the satellite types. Payload and mission descriptive material (References 3-3 through 3-7) were examined along with inputs from the open literature on commercial communication satellite plans. Consensus projections were established by correlating mission life data from all sources and selecting representative values. These are summarized in Table 3.2-2.

The resulting satellite population histories are presented in Figures 3.2-3 through 3.2-8. The left side of the figures shows the schedule and inventory buildup, with dashed lines indicating inactive satellites (assuming no retrieval) and solid lines indicating active satellites. The right side of the figures shows the location bands for each delivered satellite and for the active or operational satellite sets in the event that multiple satellites are required to achieve the desired coverage features.

During the development of these satellite population histories, it was determined that discontinuities in some functions would occur if the baseline traffic schedule and projected lifetimes were rigorously applied. The simplest example of this is the navigation and traffic control buildup profile. Direct use of the schedule shown in the baseline traffic model resulted in either nonuniform active lifetimes or the necessity to interrupt the "service" within a zone once it had been established. By modifying the delivery schedule, but not the total number of deliveries, a uniform buildup to a continuously active three-satellite traffic control system was possible. Similar problems were encountered with the communications satellite, U.S. domestic communication, and foreign domestic communication population histories. The population histories shown reflect buildup to, and maintenance of, an eight-satellite communication satellite population, a ten-satellite U.S. domestic communication population, and a 16-satellite foreign domestic communication population. The active satellite populations are summarized for each zone in Figure 3.2-9.

Table 3.2-2. Satellite Projected Mission Life

Satellite Type		Mission Life, years
Astronomy	Explorer	3
Earth observations	Synchronous earth observation sat.	5
	Synchronous meteorological satellite	4
	Synchronous earth observations satellite/prototype	5
	Geopause	5
Communications and navigation	Tracking and data relay satellite	6
	Applications technology satellite	5
	Cooperative applications satellite	2
	Small applications technology sat.	1
	Disaster warning satellite	5
	System test satellite	5
Non-NASA operational spacecraft	Communications satellite	7
	U.S. domestic communication	7
	Foreign domestic communication	7
	Navigation and traffic control	5
	Synchronous meteorological	4
	Synchronous earth resources	3

The data presented in the previously referenced figures are based on the payloads defined by the baseline traffic model. This model, as discussed previously, defines the currently envisioned NASA and NASA-supported missions for the 1973 through 1990 time period. Prior to examining the possibility of physical contention, it was necessary to project the total satellite population including foreign and DoD satellites. Generalized DoD geo-synchronous mission plans were obtained from SAMSO representatives. The resulting total geosynchronous satellite population is summarized in Figure 3.2-10. It was estimated that there are currently 59 satellites in geo-synchronous orbit. Adding the 180 satellites defined by the baseline traffic model and an estimated 47 additional DoD and nine foreign satellites, it is estimated that there will be 295 satellites in geosynchronous orbit by 1990 if no satellites are recovered. The 1990 population can be reduced to approximately 190 satellites by recovering all satellites which have an operational life ending in 1982 or subsequent years when the reusable tug becomes available.

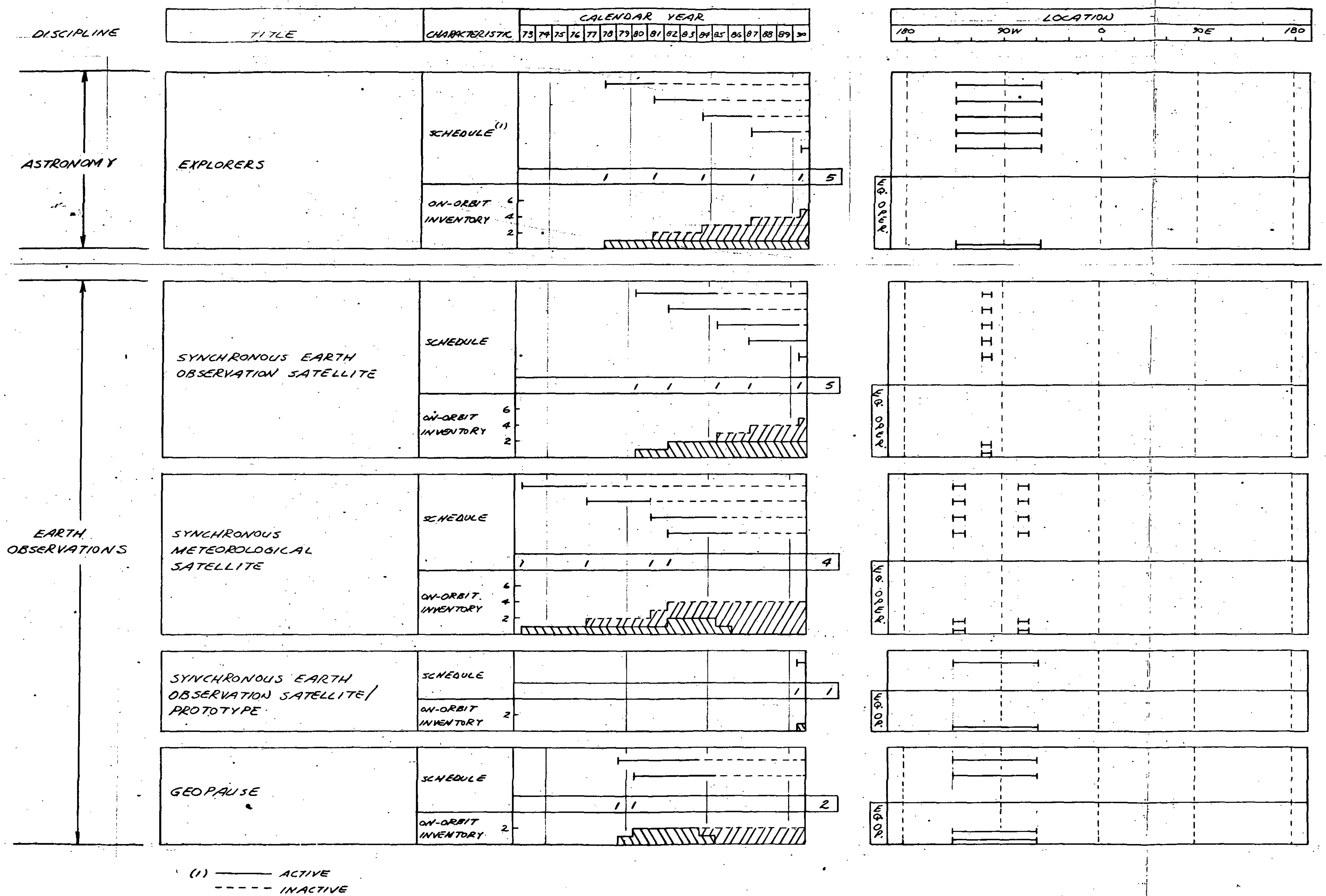


Figure 3.2-3. Satellite Population Histories - NASA Astronomy and Earth Observation Missions

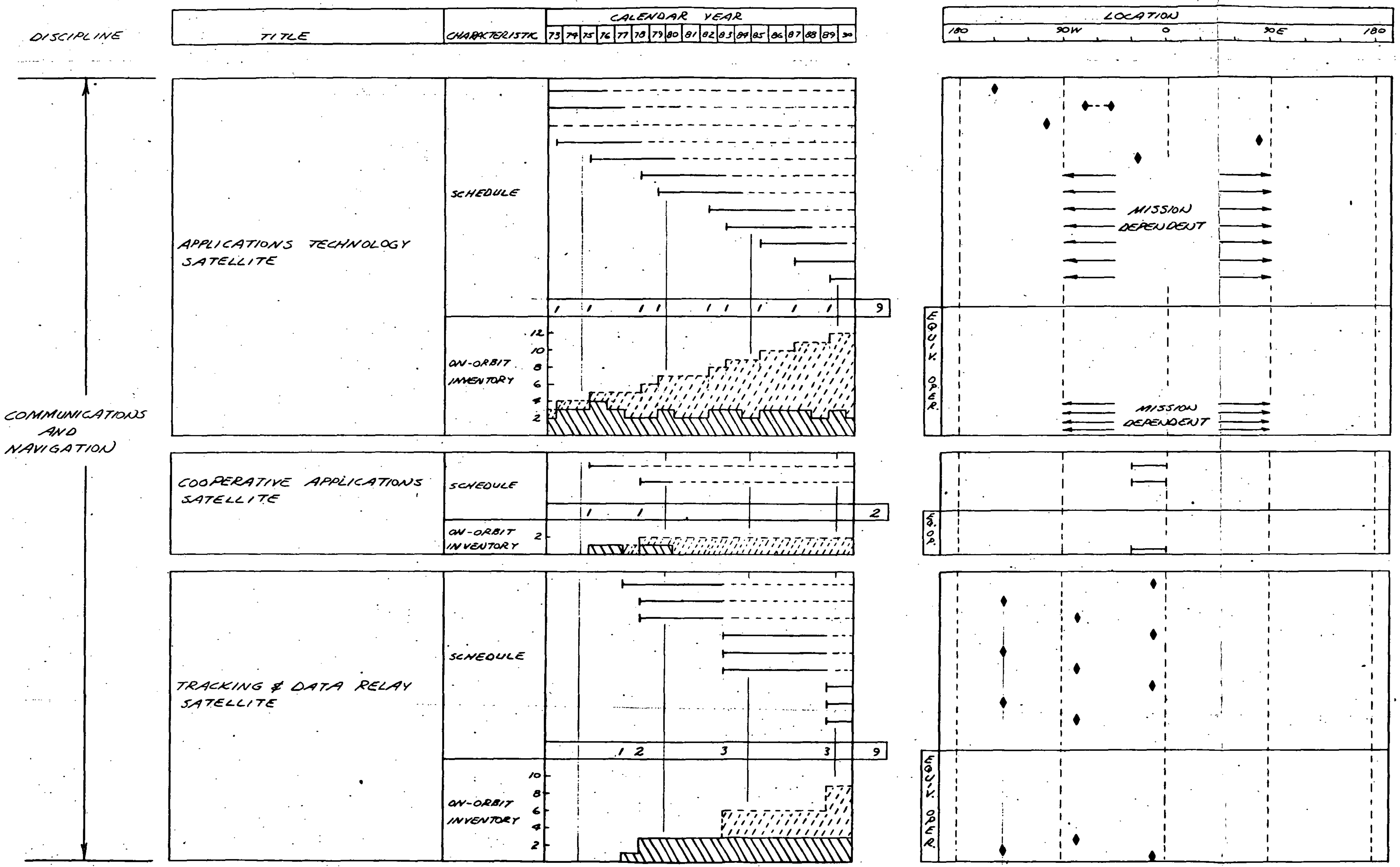


Figure 3.2-4. Satellite Population Histories - NASA Communications/Navigation Missions

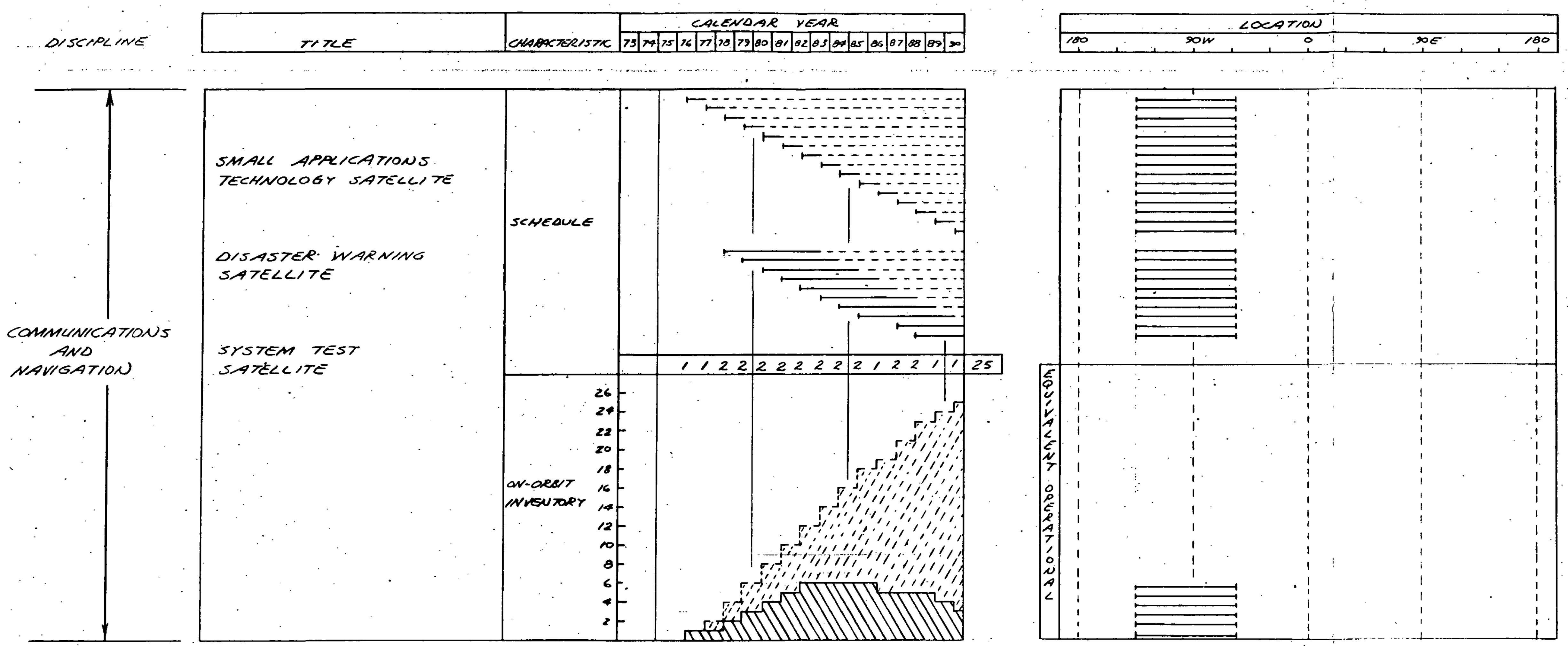


Figure 3.2-5. Satellite Population Histories - NASA Communications/Navigation Missions (continued)

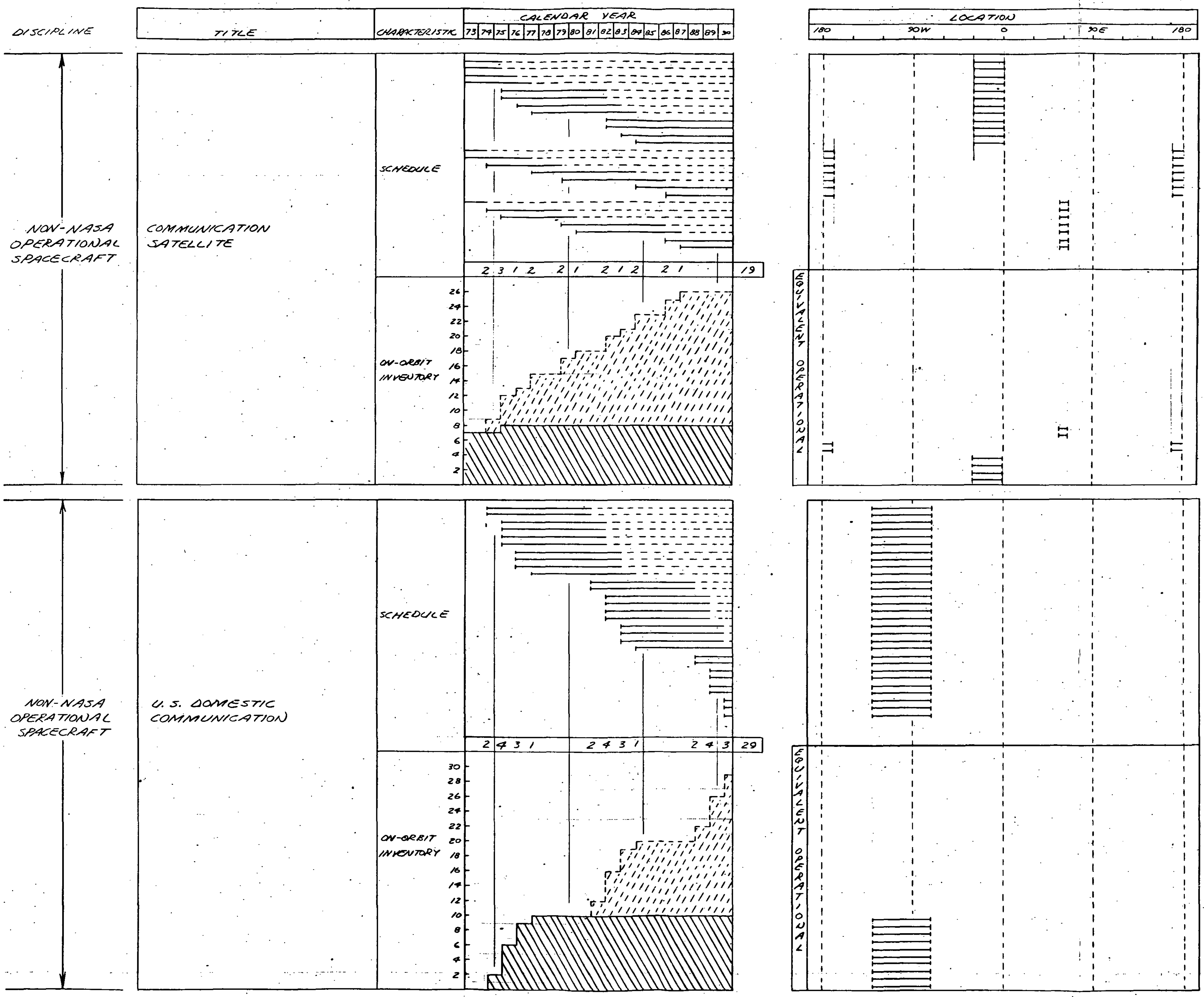


Figure 3.2-6. Satellite Population Histories - Non-NASA Missions

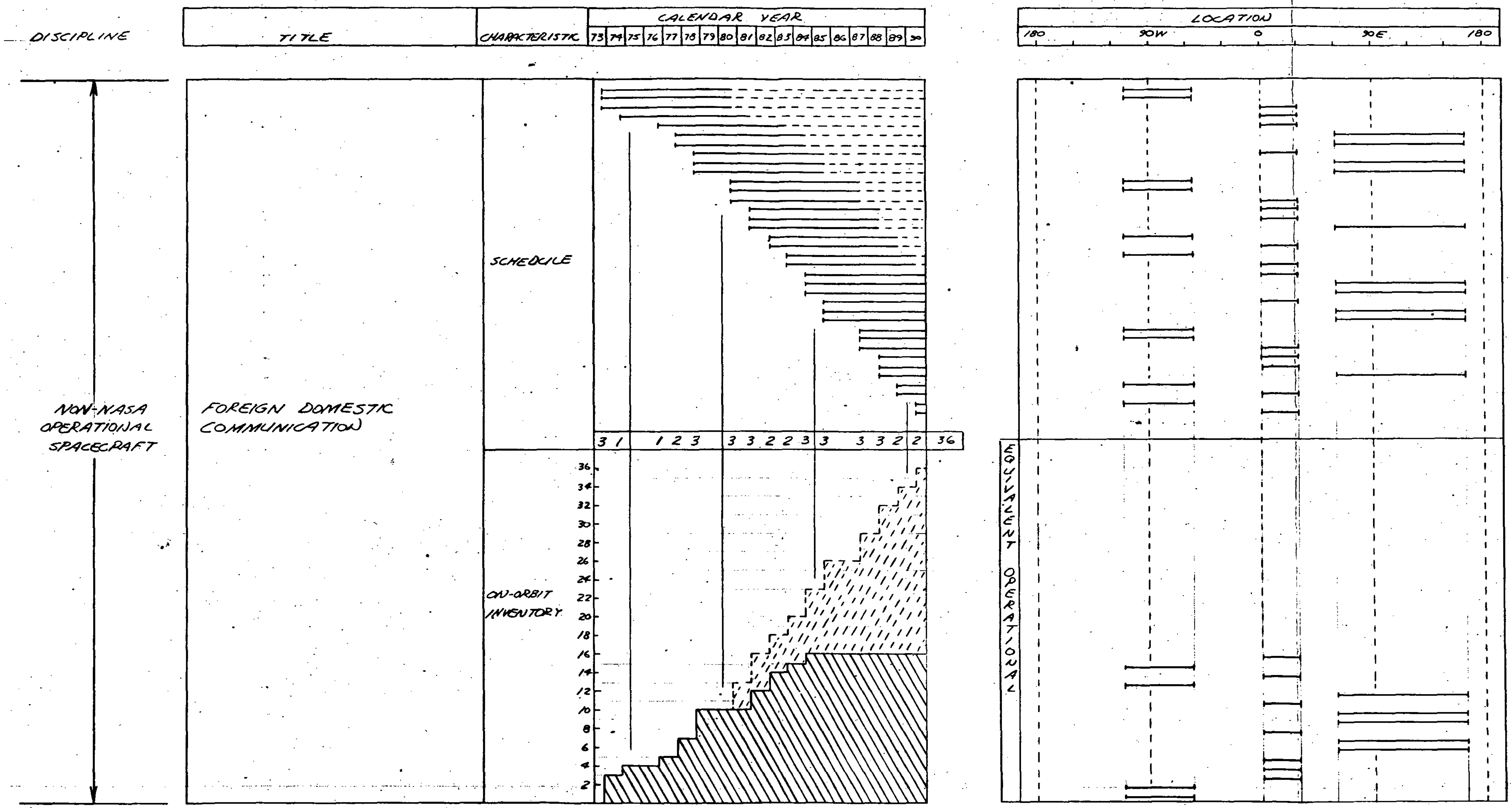


Figure 3.2-7. Satellite Population Histories - Non-NASA Missions (continued)

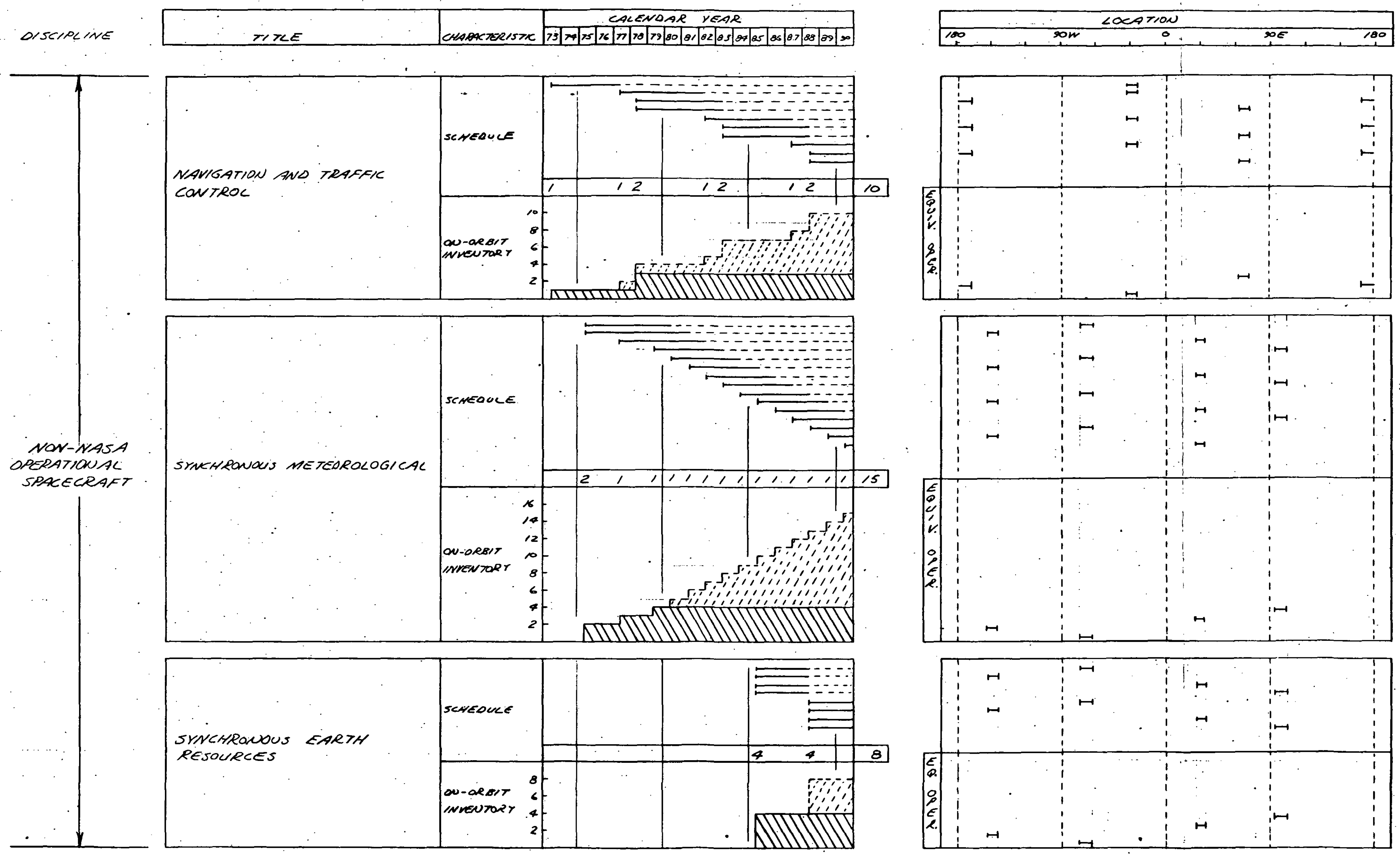


Figure 3.2-8. Satellite Population Histories - Non-NASA Missions (continued)

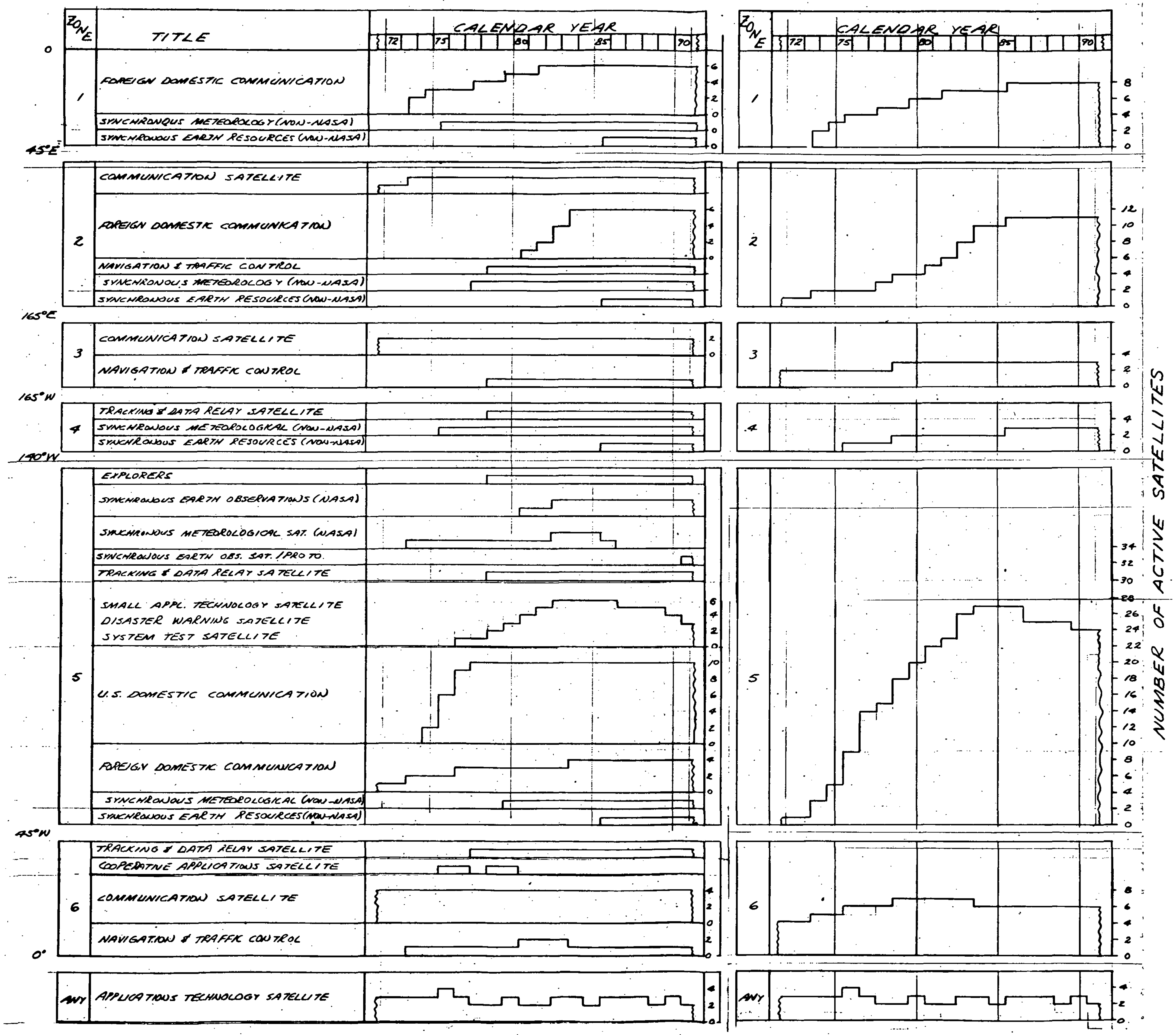
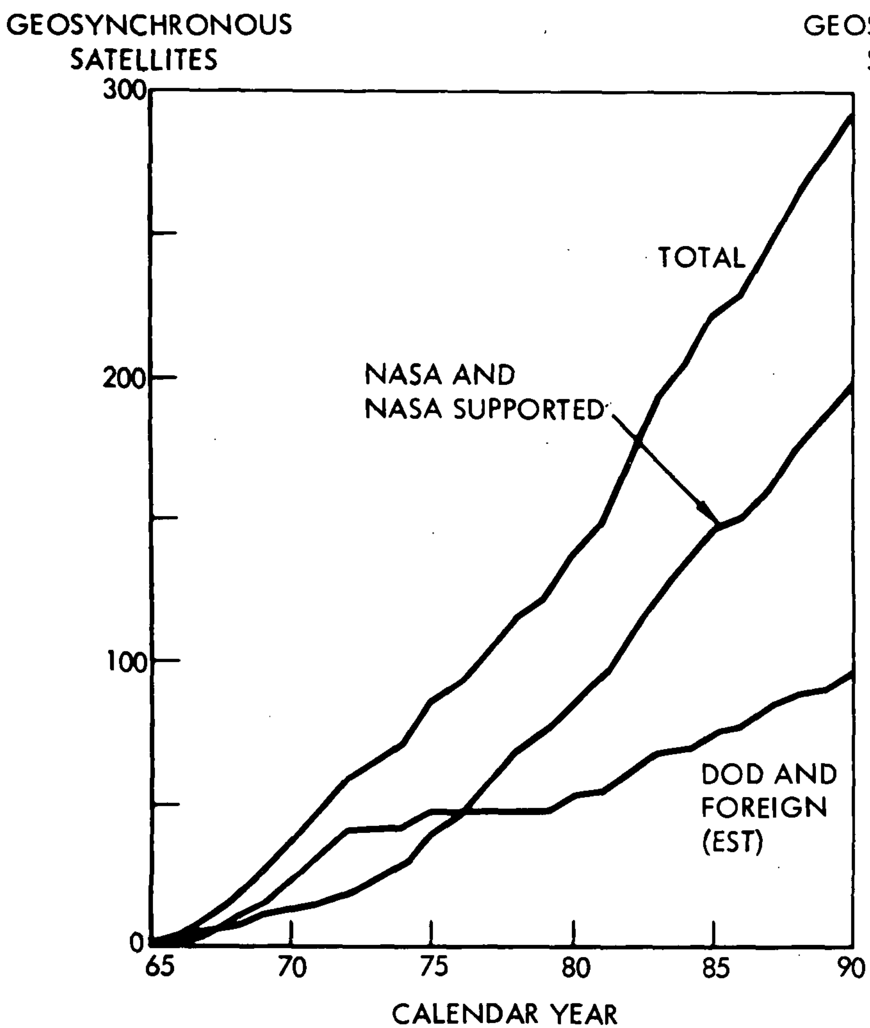


Figure 3.2-9. Active Satellite Population Distribution Summary



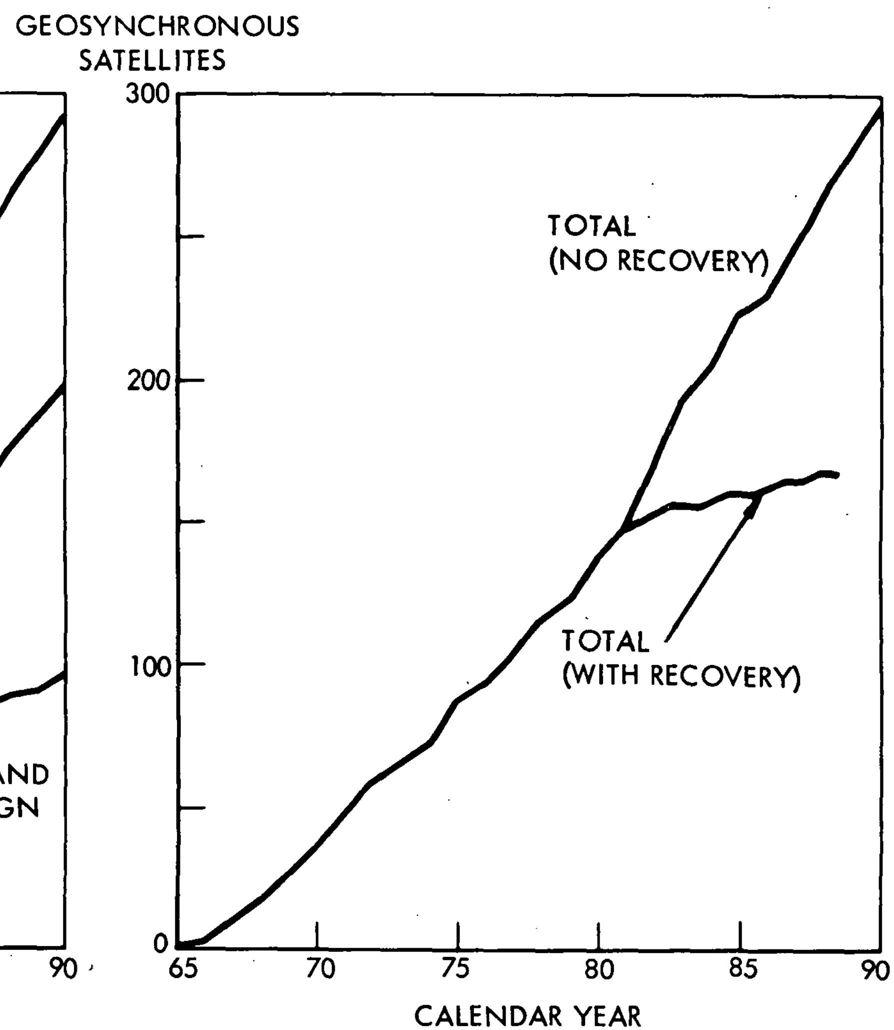


Figure 3.2-10. Total Population Summary

4.0 GEOSYNCHRONOUS ORBIT SATURATION

The objective of the orbit saturation analysis is to determine the nature and degree of satellite congestion likely to occur in geosynchronous orbits if the current approach of launching individual satellites/payloads without recovery or refurbishment is continued through the 1990 time period. At present, recognition of the value of geosynchronous space operations by organization and agencies other than the NASA has been greater than for any other class of missions. Of the 59 United States-launched satellites currently identified in geosynchronous orbit, 56 were developed by either commercial or military organizations acknowledging geosynchronous operations as the best means of providing needed capabilities and services. A major factor in these decisions was the relative efficiencies of satellites in these orbits in providing large bandwidth, long-distance communication links.

The continued demonstration of economic advantages of geosynchronous operations and the projected increases in demands for long-range communications are expected to produce a dramatic growth in both number and capabilities of geosynchronous systems. As an example, eight applications for licenses to operate domestic communications satellites have been filed with the Federal Communications Commission. These applications reflect the willingness of 11 private corporations to make an estimated $1.3 billion total investment to develop and build the equipment necessary to operate these systems.

The baseline traffic model presented in Section 3.0 acknowledges portions of this dynamic growth situation with substantial numbers of non-NASA operational spacecraft. The full traffic potential becomes further apparent with the new traffic model presented in Part 2 of this volume. Thus, the intent of the orbit saturation analysis is to determine if satellite interference reaches potential problem levels, thereby forcing a change in program approach from individual satellites to multifunction platforms with grouped payloads and/or functions. To meet this objective, both satellite physical proximity and electromagnetic interference (EMI) factors were considered.

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4.1 PHYSICAL CONTENTION ANALYSIS

GENERAL APPROACH

The physical contention analysis treated both active and inactive satellite populations. Active satellites are constrained principally by the precision of their stationkeeping capabilities and related operational margins. Once they become inactive, either through failure or depletion of mission consumables and are without stationkeeping capability, they drift freely and are subject to perturbing influences which totally dictate their orbital motion. Thus, orbit perturbation effects were analyzed to determine their contribution to satellite physical proximity and local congestion factors.

An understanding of these orbital motions was applied to develop a simplified model of satellite placement constraints. Using this model, conservative estimates of limiting satellite population densities were derived for comparison with the projected satellite distributions contained in the baseline traffic model. Emphasis was on the active satellite populations. Additionally, the long-term effects of orbit perturbations on the inactive satellite populations were analyzed to determine the total volume of "geosynchronous space" they occupy. The volume of space available per satellite provides an indication of the likelihood of physical interference or collisions between satellites.

ORBIT PERTURBATION SOURCES AND EFFECTS

The principal perturbations which must be considered for geosynchronous orbits are perturbations resulting from the tesseral harmonics in the gravitational potential function of the earth, luni-solar gravitational influences, and solar pressure.

Tesseral Harmonics Perturbations

A geosynchronous satellite will experience an effective geographic longitudinal oscillation about the major axis of the earth's equatorial ellipse and a radial oscillation about the mean synchronous altitude resulting from perturbations caused by the tesseral harmonics in the earth's gravitational potential. The resultant "banana-shaped" motion is pictured schematically in Figure 4.1-1. The longitudinal oscillation about the equatorial minor axis (stable axis) has an amplitude equal to the initial longitudinal displacement from the stable axis (located at 75°E or 105°W longitude). The initial displacement is established by the location of the satellite relative to the nearest stable point at the end of its active stationkeeping lifetime. The time required to complete one cycle of this "banana-shaped" motion is from two to eight years depending on the amplitude. This is shown in the graph at the lower right on the above figure.

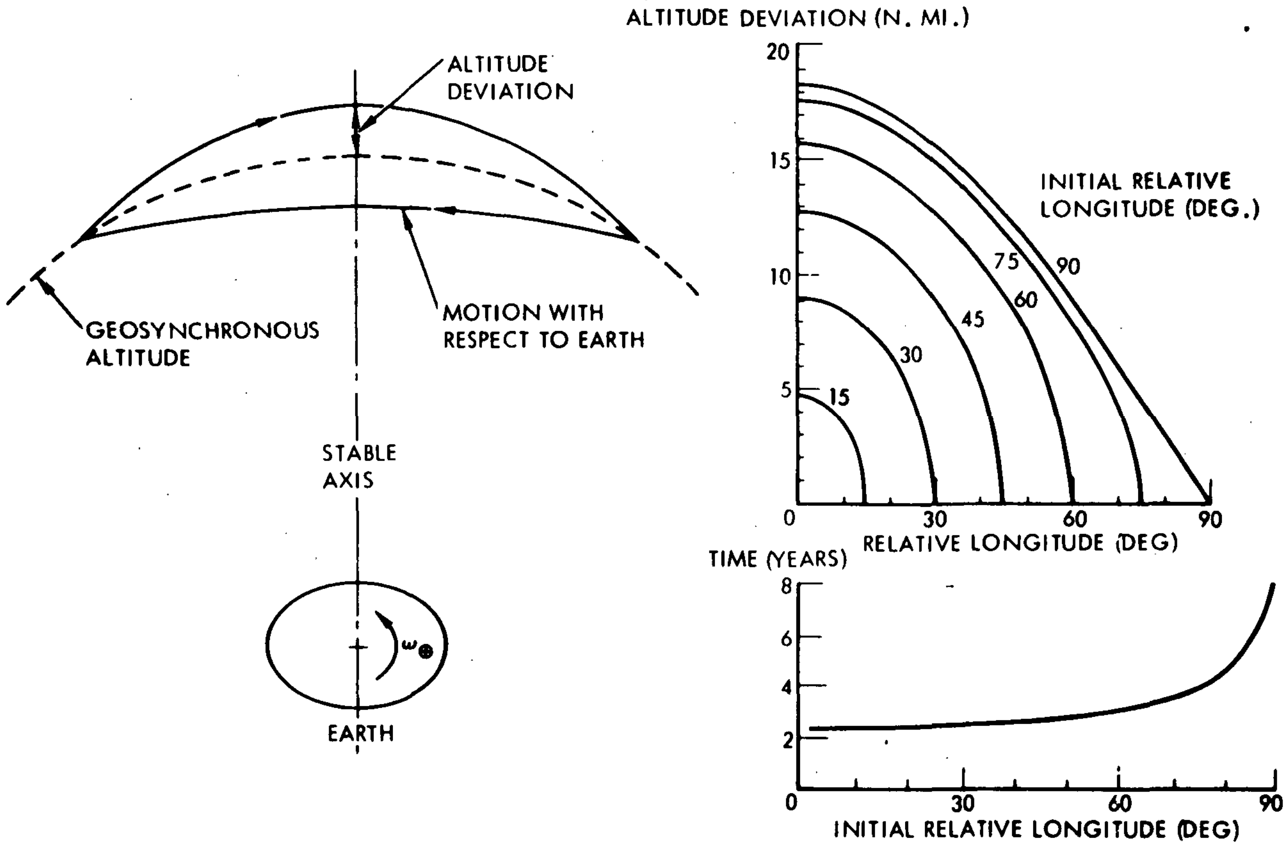


Figure 4.1-1. Tesseral Harmonics Perturbations
(Residual Velocity Error = 0)

The radial oscillation about the mean synchronous altitude has the same period as the longitudinal oscillation, with the radial amplitude a function of initial longitudinal displacement. The maximum altitude deviation is about ± 18 nautical miles with respect to the 24-hour synchronous orbit altitude and occurs for an initial displacement approaching 90 degrees longitude from the nearest stable point. Altitude deviation as a function of relative longitude is also shown in the figure for several initial conditions.

The perturbed longitudinal and radial motions described above are for a satellite which has no initial velocity or radial dispersions. In practice, a satellite will have velocity and position errors with respect to a nominal geosynchronous orbit at the end of active operations. These residuals will be produced by stationkeeping tolerances, orbit determination errors, and the satellite minimum impulse capability. Since the satellite oscillates radially and crosses the nominal orbit altitude of the points of maximum longitudinal motion, the dispersions in longitudinal amplitude are of major interest. These longitudinal dispersions are shown schematically in Figure 4.1-2.

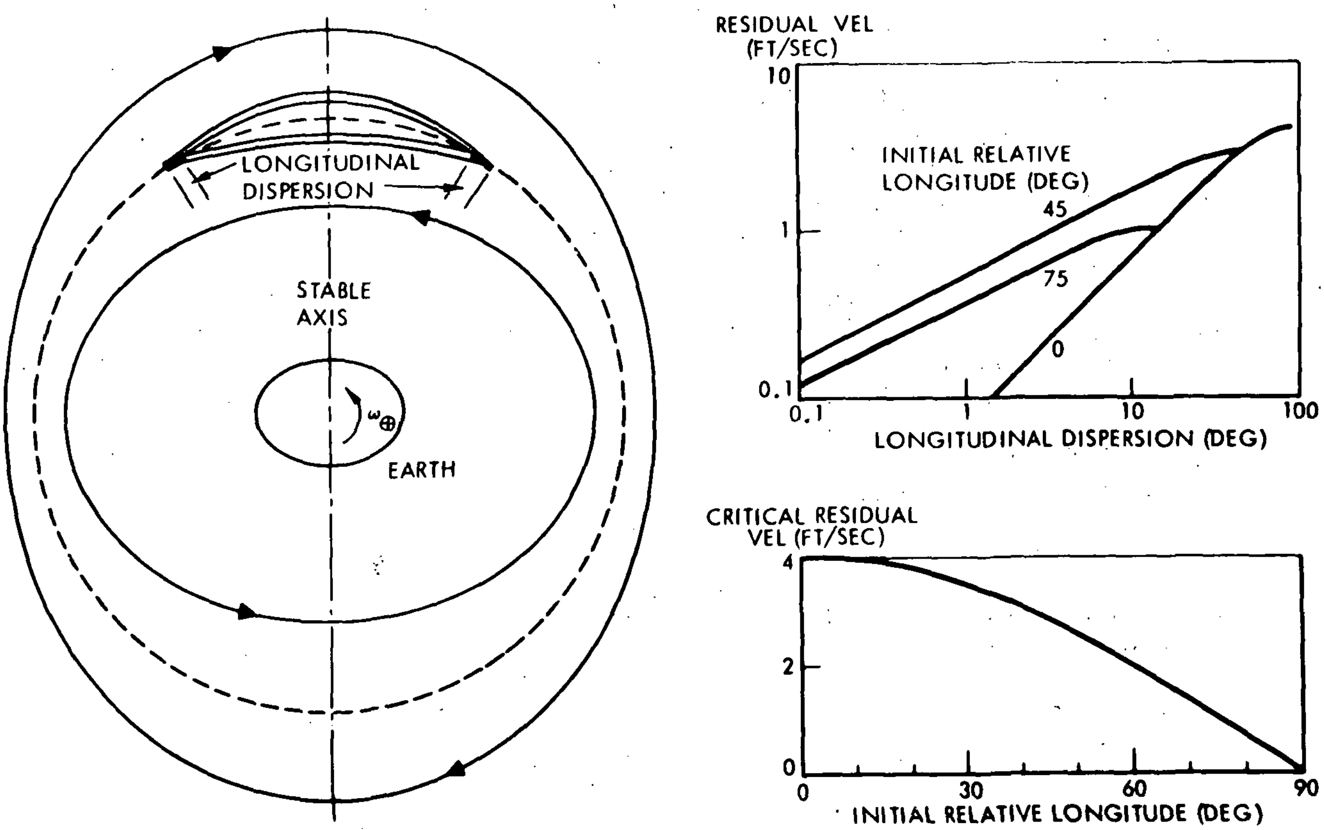


Figure 4.1-2. Tesseral Harmonics Perturbations
(Residual Velocity ≠ 0)

An important factor in determining dispersion amplitude is the tangential residual velocity component at the initial satellite position. The effect of this velocity component is an increase in the amplitude of the longitudinal excursion with the magnitude of the increase dependent upon the residual velocity magnitude and the satellite initial relative longitude. This relationship is shown in the graph at the upper right in Figure 4.1-2. If the residual velocity is sufficiently large, above some "critical" value, it will dominate the apparent motion and carry the satellite out of its synchronous orbit, either above or below depending upon its direction. The resultant satellite orbit will produce an apparent posigrade or retrograde motion with respect to the earth. Although the relative motion rate will vary, its direction will not. The apparent cyclic longitudinal drift will not occur and the satellite will follow a continuous pattern of posigrade or retrograde motion. These are illustrated by the solid orbital path lines in Figure 4.1-2. The magnitude of the "critical" residual velocity where continuous posigrade or retrograde motion occurs is shown as a function of initial relative longitude at the lower right of the figure.

Luni-Solar Perturbations

Lunar and solar gravitational perturbations result in a long-period (over 50 years) oscillation of the geosynchronous orbit inclination. Because of the long period of the cycle, luni-solar perturbations of the geosynchronous orbit inclination are usually approximated as a simplified secular motion. However, the actual effect is somewhat similar to the sun's gravitational perturbation of the moon's orbit about the earth. The lunar orbit plane maintains a fixed inclination with respect to the ecliptic plane while its node regresses along the ecliptic under the influence of solar gravitation. The mean 24-hour synchronous orbit motion under luni-solar gravitational perturbation is quite similar except that it can be shown that instead of the ecliptic, the orbit plane regresses about a reference plane inclined approximately 7.3 degrees to the equatorial plane. The node of the reference plane approximately coincides with the vernal equinox. The geometric relationships of these factors are pictured in Figure 4.1-3. The inclination of an equatorial geosynchronous orbit would be 7.3 degrees with respect to the reference plane. The satellite orbit maintains the 7.3-degree inclination with respect to the reference plane, and regresses completely around the reference plane in about 53 years. Therefore, the inclination of an initially equatorial orbit varies from zero degrees to a maximum of about 14.6 degrees and back to zero degrees in about 53 years. This is shown by the dashed line on the graph at the right of the figure.

Synchronous orbits which are initially inclined to the equator will have an inclination with respect to the reference plane which is a function of the right ascension of the synchronous orbit ascending node. The inclination of the orbit with respect to the reference plane remains constant as its node regresses along the reference plane. The inclination with respect to the equator then varies between 14.6 degrees plus or minus the initial inclination value over the 53-year period. Typical inclination histories are shown for various ascending node locations in Figure 4.1-3.

Solar Pressure Perturbations

Solar pressure produces a cyclic perturbation in the orbit eccentricity with the magnitude of the perturbation dependent upon the satellite area-to-weight ratio. Since the direction of the perturbing force is along the earth-sun line, it sweeps through 360 degrees as the earth orbits the sun each year. The maximum eccentricity deviation occurs six months after the end of active (stationkeeping) operations. The perturbing force sweeps through the opposite hemisphere and nulls its effects during the last half of the year and the orbit is again circular after one year. The disturbed and nominal orbits are pictured in Figure 4.1-4 with dashed and solid lines, respectively.

The eccentric orbits produce an apparent longitudinal libration with respect to the earth since the angular motion of an eccentric orbit is not constant. The libration magnitude is a maximum when the eccentricity is greatest and is also dependent upon satellite area-to-weight ratio. Area-to-weight ratio effects on orbit eccentricity and longitudinal libration magnitude are shown in the graphs at the right in Figure 4.1-4. For an Intelsat IV satellite, the area-to-weight ratio is approximately 0.06 ft^2/lb resulting in a maximum longitudinal libration of less than 0.1 degree.

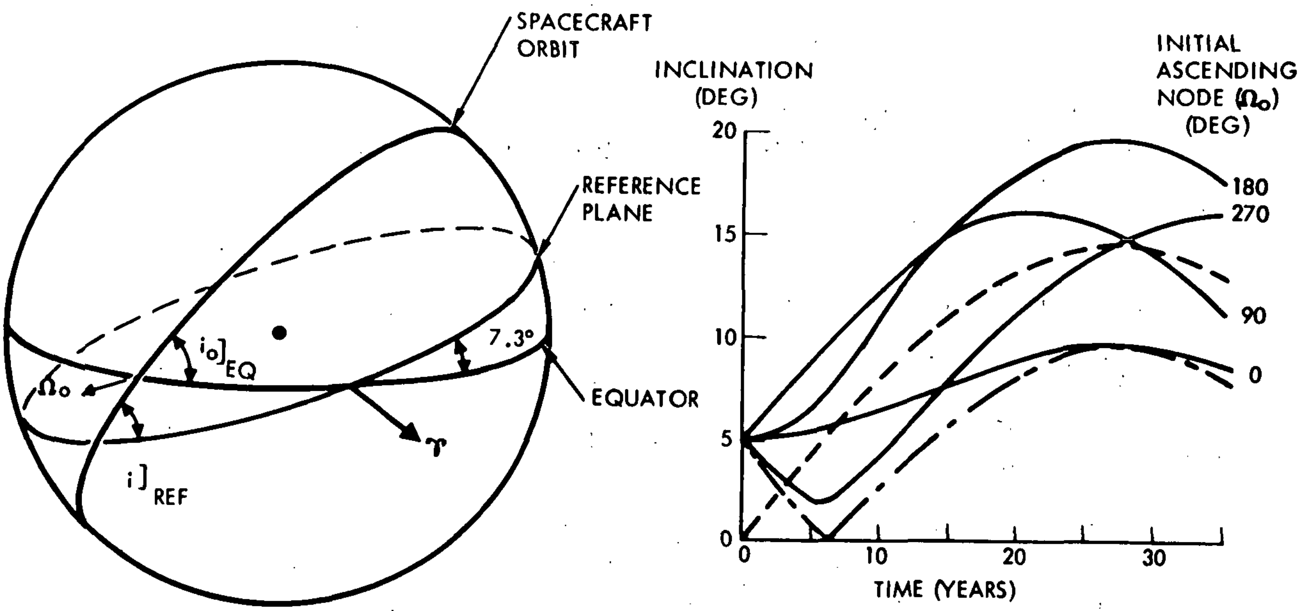


Figure 4.1-3. Luni-Solar Perturbations

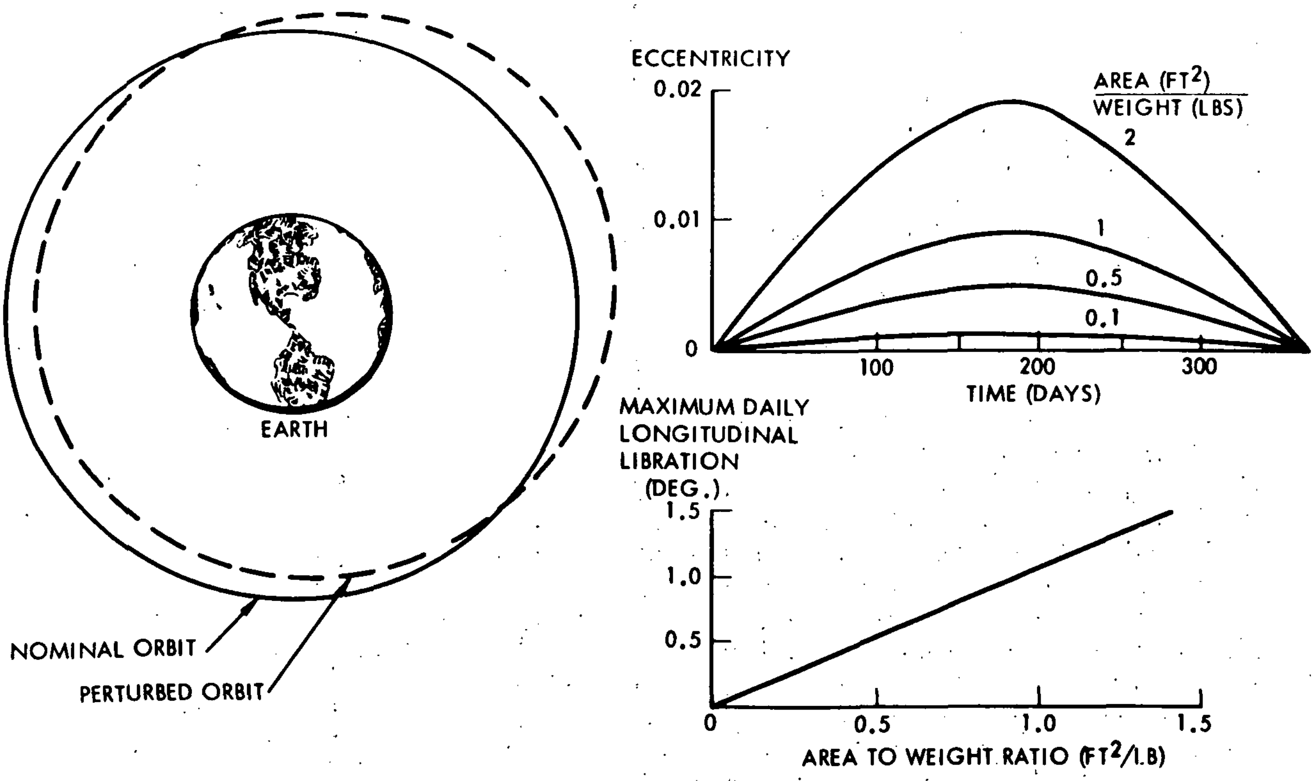


Figure 4.1-4. Solar Pressure Perturbations

SATELLITE CONGESTION

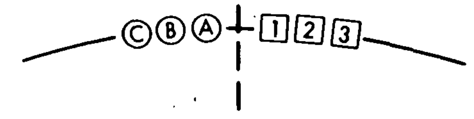
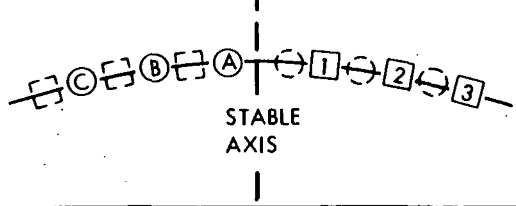
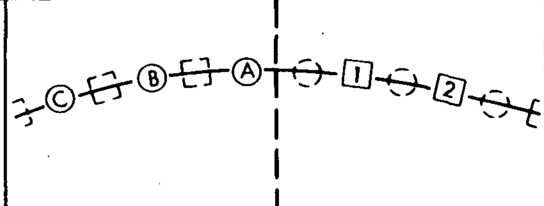
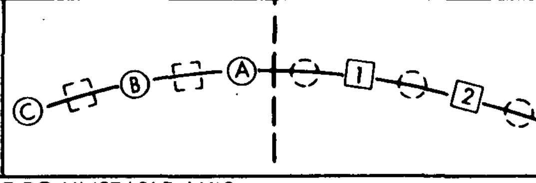
To aid in understanding the physical contention problem, a simplified one-dimensional model for limiting satellite populations was constructed. This permitted a gross but conservative evaluation of satellite congestion associated with the active satellites in the baseline traffic model. Further analyses were conducted to determine the three-dimensional effects introduced by the long-period orbit perturbations. These primarily affect the congestion potential of the inactive satellite populations.

Simplified Congestion Model

A simplified model for establishing population limits for active satellites was constructed by assuming all satellites are initially in a geosynchronous equatorial orbit (geostationary) and considering in-plane perturbations only. The "limiting population" of such a model is a function of the stationkeeping capability of the active satellites, the perturbations resulting from tesseral harmonics, and the solar pressure perturbations. Considering stationkeeping only, satellites could be positioned such that a collision would not occur between two adjacent satellites operating within their respective position deadbands. This is depicted by the schematic in the top row of Figure 4.1-5. The square and circular symbols reflect satellite locations on either side of the stable axis associated with the tasseral harmonic perturbations. Ignoring three-dimensional effects, the tesseral harmonics would cause the "square" and "circular" satellites to drift across the stable axis and pass through the nominal synchronous orbit altitude at their respective mirror image position. In this simplified model, a "slot" must be reserved on the opposite side of the stable axis. Thus, the "limiting population" is one-half the allowable population when only stationkeeping effects are considered. This is shown by the dashed symbols in row two of the above figure. The effects of residual velocity errors and solar pressure perturbations further decrease the allowable population through the amount of space consumed by their longitudinal dispersions, $\Delta\lambda_v$ and $\Delta\lambda_e$. These are depicted in the bottom two rows of the figure.

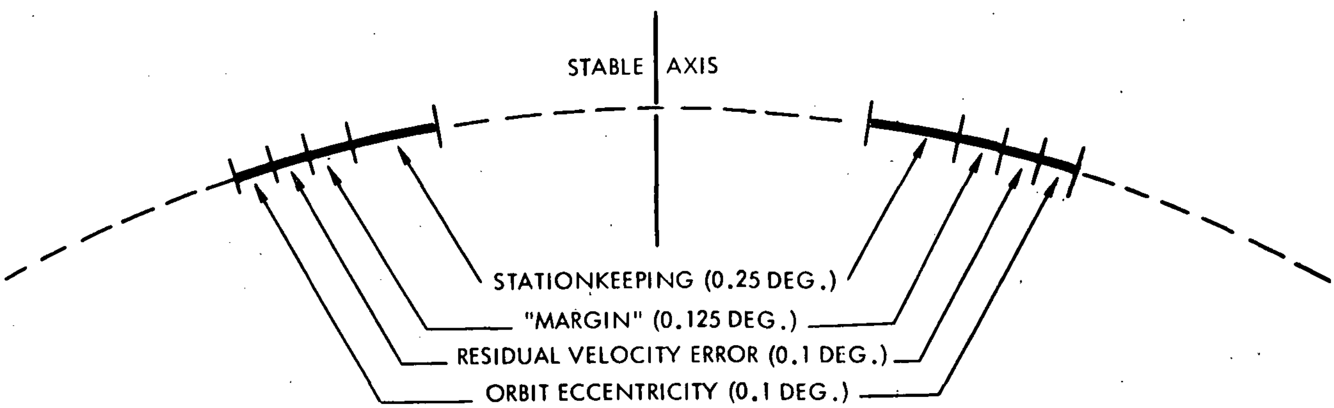
Allowable Satellite Population

The "allowable" satellite population was estimated using the simplified model presented in the preceding pragraphs and worst-case values for the terms affecting the spacing. This is summarized in Figure 4.1-6. The stationkeeping deadband of ± 0.125 degree is the value defined during the Rockwell International TDRS study (Reference 3-7), although lower values are feasible by increasing the stationkeeping maneuver frequency. A 50-percent stationkeeping margin was coupled with maximum values for residual velocity errors and solar pressure effects. As shown previously, the magnitude of the longitudinal dispersion because of a given residual velocity error is a function of the initial placement of the satellite relative to the stable axis. Also, the effect of solar pressure is periodic, reaching a maximum every six months. Not all satellites could be expected to reach their maximum excursions at the same time. However, based on the worst-case values shown, the required "space allocation" per satellite is a conservative 1.15 degrees, permitting a total theoretical population of 312 satellites, if all were evenly spaced.

CONSIDERATION	CONFIGURATION	NUMBER PER "HEMISPHERE"(1)
STATIONKEEPING PLUS "MARGIN"		$\frac{180}{(1.5)(\Delta\lambda_S)}$
TESSERAL HARMONICS (ZERO RESIDUAL VELOCITY ERROR)		$\frac{180}{(2)\left[(1.5)(\Delta\lambda_S)\right]}$
TESSERAL HARMONICS (NONZERO RESIDUAL VELOCITY ERROR)		$\frac{180}{(2)\left[(1.5)(\Delta\lambda_S)+\Delta\lambda_V\right]}$
SOLAR PRESSURE		$\frac{180}{(2)\left[(1.5)(\Delta\lambda_S)+\Delta\lambda_V+\Delta\lambda_e\right]}$

(1) MEASURED WITH RESPECT TO UNSTABLE AXIS

Figure 4.1-5. Satellite Population "Limit" (Simplified Model)



- "ALLOCATION" = (2)(0.25 + 0.125 + 0.1 + 0.1) = 1.15 $\frac{\text{DEGREES}}{\text{SATELLITE}}$

Figure 4.1-6. "Allowable" Satellite Population Density

These values compare very favorably with the projected satellite populations in the baseline traffic model. Satellite population buildup profiles for each of the six zones were constructed in Figure 3.2-9 of Section 3.0. The maximum active satellite populations from these data are summarized in Table 4.1-1, along with their resultant spacing characteristics. The satellite spacing was calculated on the basis of actual satellite placement bands which in many cases did not extend through the entire zone. Thus, the spacing values are slightly tighter than would be obtained by simply dividing the zonal bounds by the number of satellites it contains. It is readily apparent that actual satellite spacing in the baseline traffic model is well within the limits defined above. The space available in the simplified model exceeds the space required by factors ranging from 3 to 10. Even loading those satellites with undefined placement into various potentially appropriate zones would not create a hazardous situation. Thus, it was concluded that physical contention will not be a problem with the satellite populations projected for the baseline traffic model.

Table 4.1-1. Active Satellite Distribution and Spacing for Baseline Traffic Model

Zone	Maximum Number of Active Satellites	Actual Satellite Spacing
1 - Europe/Africa (0°-45°E)	9	3.9 deg/satellite
2 - Asia/Australia (45°E-165°E)	10	11.0 deg/satellite
3 - West Pacific (165°E-165°W)	3	8.3 deg/satellite
4 - East Pacific (140°W-165°W)	3	3.3 deg/satellite
5 - North/South America (45°W-140°W)	27	3.1 deg/satellite
6 - Atlantic	7	5.0 deg/satellite
Undefined placement	3	Not applicable

Three-Dimensional Effects

The preceding analysis was based on the simplified model which assumed all satellites remained in equatorial orbits. Further confidence in the above conclusion was developed through a brief consideration of three-dimensional effects. The luni-solar perturbations shown previously produce an orbital regression with respect to the luni-solar reference plane resulting in a long-term variation in the orbital inclination with respect to the equatorial plane. Assuming each satellite is initially placed in an equatorial orbit, after 26.5 years its orbit will have an inclination of 14.6 degrees. This, coupled with the nodal regression and the altitude deviations caused by the tesseral harmonics and solar pressure, results in a total "swept volume" of space approaching 3 x 10^{10} n mi^3. This is illustrated by the shaded region in Figure 4.1-7. (Figure 4.1-7 is a repeat of Figure 2.0-3.) Applying the entire population of 295 geosynchronous satellites projected to exist through the 1990 time period (Figure 3.2-10) to this volume results in an average occupied space for each satellite of approximately 100-million cubic nautical miles. This enormous volume for freely drifting satellites virtually eliminates any concern over the possibility of collision hazards within the satellite populations in the baseline traffic model.

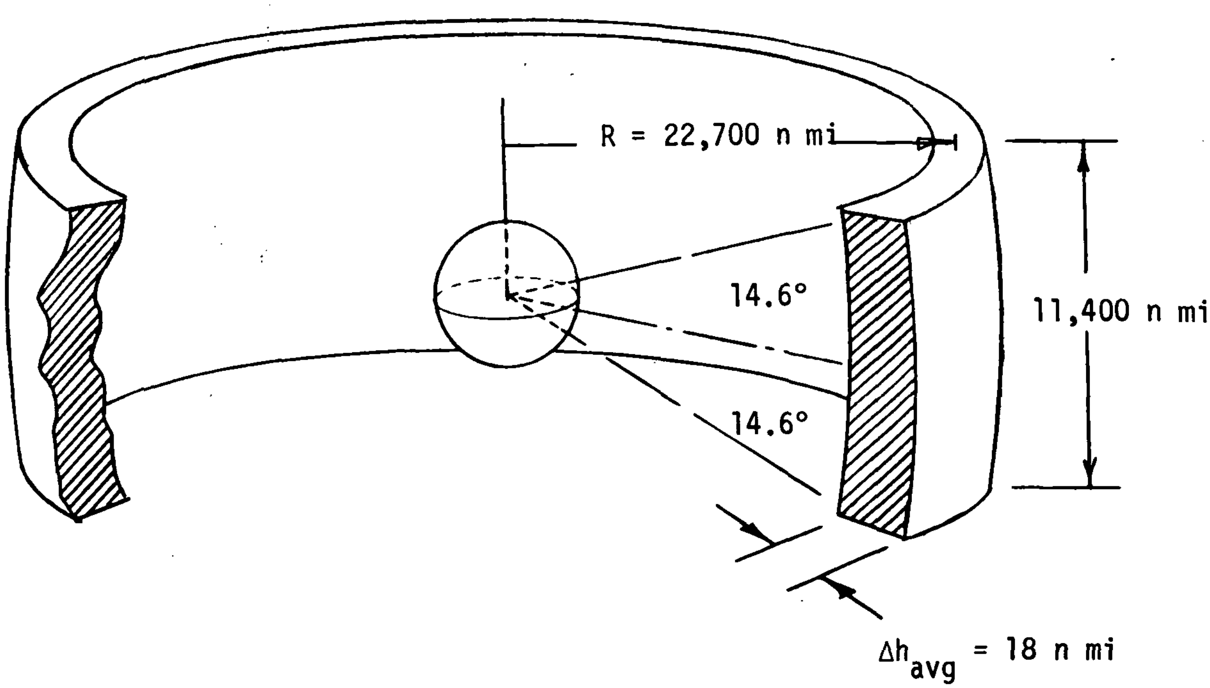


Figure 4.1-7. Total "Swept" Volume of Space Occupied by Free-Drifting Satellites

While average volume would be a true indication of collision probability only for purely random conditions, it is felt to provide a strong indicator in this case, particularly in light of the magnitude involved. The year of initial satellite placement, the placement location, and the residual conditions at the end of life all interact with the perturbing forces to influence the exact time histories of satellite motion during free drift. They all introduce spreading effects on the individual satellites. While these factors do not produce equal spacing effects, their overall influences are dispersive in nature. Thus, the average volume per satellite is felt to be an adequate measure of the collision hazard.

4.2 EMI CONTENTION ANALYSIS

Electromagnetic interference (EMI) between satellites is the result of unwanted radiation from adjacent satellites impinging into the desired communication link at the same operating frequency. Its level is dependent on the shape of both the desired and undesired link ground antenna pattern and the satellite spacing. Section 5.5 of Volume III details the method for calculating the interference level. The limit of this level is recommended by an international group called the Consultative Committee of International Radio (CCIR). As expressed in Section 5.5, a level of 1000 pW0p (picowatts of power psophometrically weighted) is used for the telephony case for the interference noise in the top telephone baseband channel.

A series of analytical steps is necessary to perform this contention analysis and determine the interference level of the satellite systems associated with the baseline traffic model. The steps are outlined in the flow diagram of Figure 4.2-1 and are discussed below.

The first step examines the baseline traffic model to define the various types of satellites by their communication or electromagnetic radiation and mission characteristics. A set of tables was constructed defining each type of satellite in terms of frequency, bandwidth, radiated power, data rate, and type of service including ground system details. This is accomplished in sufficient detail to provide the necessary data for determination of orbital location and ultimately the EMI characteristics of the total system.

The next step involves a review of the baseline traffic model and the satellite characteristics to define the orbital positions of all model satellites by zone, by frequency, and by mission. Zonal maps ensuring maximum spacing of like frequency satellites consistent with their missions and service were then generated.

The third step reviews the defined satellite distribution and identifies the "worst-case" situations to be examined for EMI contention. In the baseline traffic model this turns out to be a data relay group of satellites in Zone 5, the North and South America service area.

CCIR standards are used to determine the limits of interference level. An analysis based on these standards is made of the baseline system defined in the third step. This analysis is performed in accordance with the calculations outlined in Volume III, Section 5.0.

In the case of the baseline traffic model, no area was found that provided interference levels greater than CCIR standards. Zone 5 data relay satellites were the most closely spaced at 6 degrees. Calculations showed that for this model they could conservatively be spaced as close as 4.6 degrees without harmful interference.

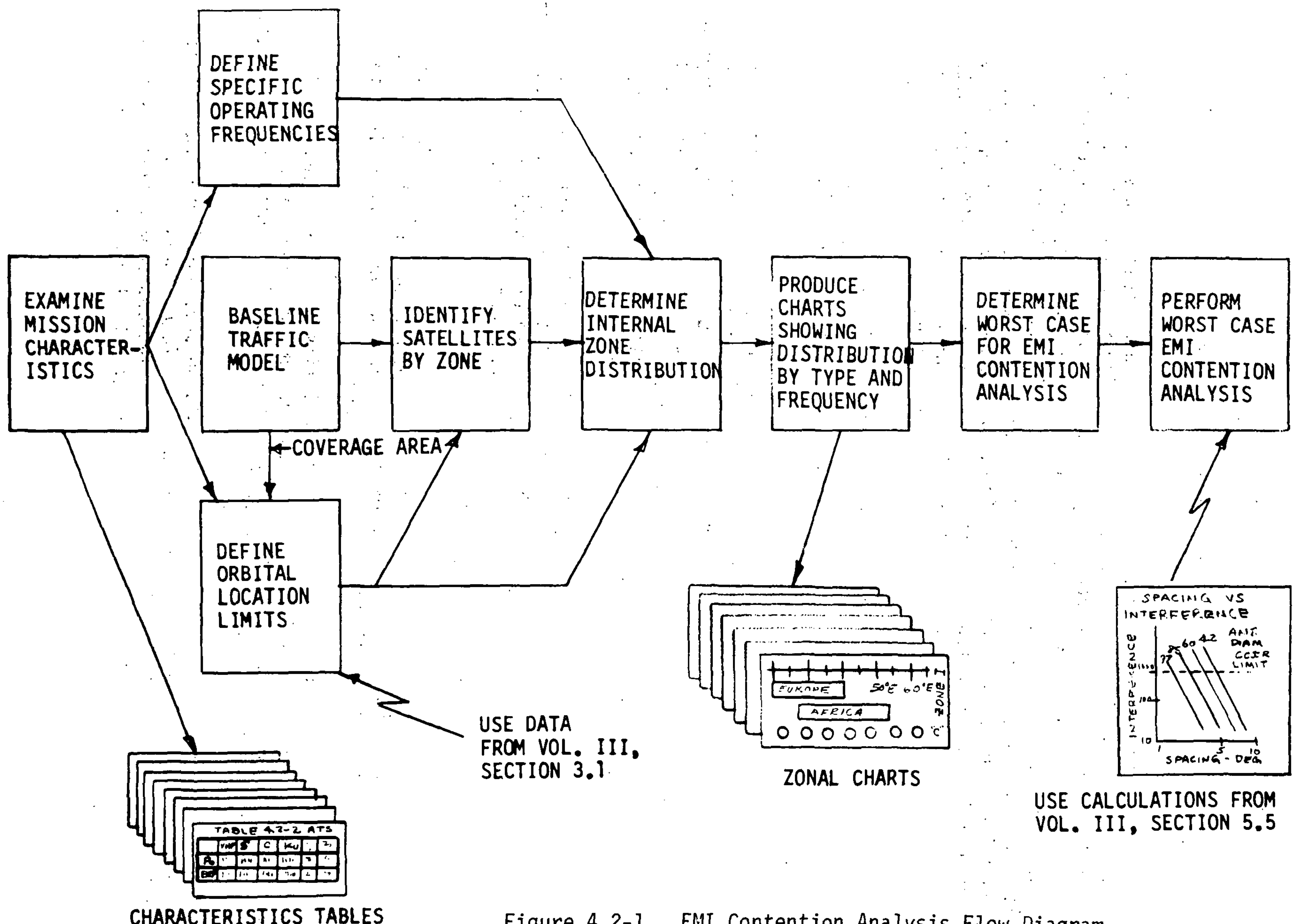


Figure 4.2-1. EMI Contention Analysis Flow Diagram

A secondary review was made of the baseline traffic model after DoD spacecraft were added. This review was supported by several coordination meetings with SAMSO personnel. Projections of DoD plans for geosynchronous missions, including general spacecraft locations and RF frequency usages, were disclosed within security constraints. A total of 47 satellites was identified in geosynchronous orbits. Although exact locations were not specified, sufficient location information was available to allow their insertion in the Zonal Charts for analysis of EMI impact.

This addition of 47 satellites provided no impact on the geosynchronous orbit EMI levels. Most of the DoD operations are in S-band; none are on the same frequency--C-band--where the data relay satellites are the major contributors to interference problems. Operation in S-band does, however, create an overall orbital operations problem outside the scope of this study. S-band is used by both NASA and DoD in their STDN and SGLS networks for operation of geosynchronous, low-earth orbit, and deep-space missions. Because of this widespread use, an EMI problem currently exists at S-band and will become more severe with increased traffic. Careful planning and cooperation between NASA and DoD will be required for S-band frequencies and scheduling mission operations.

SATELLITE RF CHARACTERISTICS

Data from several sources was used to project satellite characteristics according to the types identified in the baseline traffic model. FCC, industry, and Space Division reports were useful in providing data on the data relay-type satellites. Domsat (Domestic Communication Satellite), Intelsat (International Telecommunications Satellite), and TDRSS (Tracking and Data Relay Satellite System) are in this category.

Domsats are presently in the early stages of development. Projections indicate that the first-generation Domsats will be 24-channel (transponder) systems operating in C-band. The space-to-earth link (downlink) is in a 500 MHz band from 3.7 to 4.2 GHz and the earth-to-sapce link (uplink) is in the band from 5.925 to 6.425 GHz. All Domsat characteristics pertinent to the data baseline for EMI analysis are contained in Table 4.2-4.

Intelsats are presently operational in these same frequency bands. The characteristics projected are similar to those of Domsat. There is particular emphasis on communications or data relay-type systems. Data relay satellites are the most numerous type in the traffic model and potentially are the most likely candidates for an EMI problem.

The TDRS is still in a state of development. Operational frequency bands and general characteristics have been identified. The system utilizes Ku-band, S-band, VHF, and UHF for its various links. Table 4.2-1 identifies the frequencies and the associated links. TDRS relays data both ways between earth and low earth orbital satellites.

Most other satellites operate in S-band with a few in L-, VHF-, and UHF-bands.

Table 4.2-1. TDRS Frequency Plan

	Frequency	
	User to TDRS	TDRS to User
Low data rate	136 to 138 MHz	401 MHz
Medium data rate	2.20 to 2.30 GHz	2.025 to 2.120 GHz
High data rate	13.6 to 14.0 GHz	14.6 to 15.2 GHz
	TDRS to Ground	Ground to TDRS
Ground/TDRS Data Ku	14.6 to 15.2 GHz	13.4 to 13.6 GHz
VHF	136.11 MHz	148.26 MHz
S-band	2.025 to 2.110 GHz	2.20 to 2.30 GHz

All frequencies to illustrate the spread and density of use are compiled in Table 4.2-2. This chart will be helpful in identifying potential problem areas when correlated with zonal distribution charts. Data were gathered from the individual satellite characteristics charts (Table 4.2-3 through 4.2-10).

Data for preparing the characteristic tables (Tables 4.2-3 through 4.2-10) were obtained from the previously mentioned reports and from Aerospace Fleet Analysis and numerous NASA reports and data. In many cases, projections of data were made based on judgment. Placement and proximity of satellites in orbit determined the important characteristics necessary for EMI analysis. EMI is basically affected by the satellite spacing. The following major parameters were included in the tables:

1. Operating frequency
2. Antenna characteristics
3. Receiver characteristics — Satellite and Ground
4. Radiated power (EIRP)
5. Bandwidth
6. Modulation techniques
7. Earth coverage area — Satellite
8. Ground station location

Tables 4.2-3 through 4.2-10 are the data for each of the types of satellite systems.

SATELLITE DISTRIBUTION

An in-depth analysis of the traffic model and the satellite characteristics provided the background to construct zonal distribution charts. Zonal charts are used to identify location and spacing of the various types of satellites. Several factors are used to determine placement and spacing. In each zone, the various types and their number and characteristics are identified. Coverage area is identified from the traffic model. Limits of the satellite orbital positions are then determined using the tools and data generated in Section 3.1 of Volume III that define mask angle coverage constraints. This allows placement of satellites in the proper zones and then their distribution or spacing

Table 4.2-2. Geosynchronous Baseline Traffic Model Frequency Band Utilization

SATELLITE TYPE	LINK	FREQUENCY BANDS						
		VHF (MHz)	UHF (MHz)	L (MHz)	S (GHz)	C (GHz)	X (GHz)	K_u (GHz)
DOMSAT	DOWN UP	X X	X X	X X	X X	3.7 to 4.2 5.9 to 6.4	X X	X X
INTELSAT	DOWN UP	X X	X X	X X	X X	3.7 to 4.2 5.9 to 6.4	X X	X X
TDRS	DOWN UP	136.11 136 to 138 148	401	X X	2.02 to 2.12 2.20 to 2.30	X X	X X	14.6 to 15.2 13.4 to 14.0
ATS	DOWN UP	136 to 137 148 to 154	850 BC TV	1550 1650	1.800 2.25	3.75 to 4.15 5.95 to 6.35	X X	11.7 to 12.2 14.0 to 14.5
EARTH RESOURCES OBSERVATION	DOWN UP	X X	X X	X X	2.2 to 2.3 2.09 to 2.12	X X	X X	X X
NAVIGATION AND TRAFFIC CONTROL	DOWN UP	X X	X X	1542 to 1559 1636 to 1645	X X	5.0 to 5.25	X X	X X
METEOROLOGICAL	DOWN UP	136 148	468 401.85	1670 to 1695	2.025-2.035	X X	X X	X X
DOD SATELLITES								
COMMUNICATION		X	FLEET SATCOM	X	FLEET SATCOM DSCS-Ø2	X	FLEET SATCOM	X
OTHER		X	X	DNSS	DSP EXPERIMENTAL	DNSS	X	X

X INDICATES NO ACTIVITY IN THIS FREQUENCY BAND

Table 4.2-3. TDRS Characteristics

MISSION/FUNCTIONAL GROUPING: TDRS

	Operating Frequency							
	13.4 to 14.0 GHz	14.6 to 15.2 GHz	136.0 to 138.0 MHz	401.0 MHz	2.025 to 2.110 GHz	2.2 to 2.29 GHz	13.25 to 14.2 GHz	14.4 to 15.35 GHz
SATELLITE	UPLINK	DOWNLINK	LDR RET.	LDR FWD	MDR FWD	MDR RET.	MDR RET.	MDR FWD
Antenna gain (dB)	39.3	40.0	9.0	15.0	29.5	29.5	47.0	48.0
Antenna field of view (deg)	1.75	1.6	45.0	31.0	7.5	7.5	0.8	0.75
Antenna polarization	Circular	Circular	Orth. linear	Circular	Circular	Circular	Circular	Circular
System noise temp. (deg K)	3335	-	-	-	-	-	-	-
Rec. G/T (dB/deg K)	4.1	-	TBD	-	-	-	-	-
Trans. output power (dBw)	-	3.9	-	15.0	11.5	-	-	-2.5
EIRP (dBw)	-	43.9	-	30.0	41.0	-	-	43.5
GROUND STATION								
Antenna gain (dB)	65.5	66.4	LOW ORBIT USERS	LOW ORBIT USERS	LOW ORBIT USERS	LOW ORBIT USERS	LOW ORBIT USERS	LOW ORBIT USERS
Antenna field of view (deg)	.08	.075						
System noise temp. (deg K)	-	754.0						
Rec. G/T (dB/deg K)	-	37.6						
Trans. output power (dBw)	28.5	-						
EIRP (dBw)	94.0	-						
SYSTEM								
Bandwidth	240 MHz	600 MHz	2 MHz	1 MHz	85 MHz	-	-	85 MHz
Modulation	ΔPSK	FM	ΔPSK	PSK				
Geography	Rosman	Rosman	LOW ORBIT USERS					

Table 4.2-4. Domsat Characteristics

MISSION/FUNCTIONAL GROUPING: Domsat - 1975		
	Operating Frequency	
	3.7 to 4.2 GHz	5.9 to 6.4 GHz
SATELLITE	DOWNLINK	UPLINK
Antenna gain (dB)	30.0	33.5
Antenna field of view (degrees)	2.5 x 6.0	2.5 x 6.0
Antenna polarization	Alternate orthogonal	Alternate orthogonal
System noise temp. (deg K)	--	1480
Rec. G/T (dB/degrees K)	--	1.9
Trans. output power (dBw)	6.0	--
EIRP (dBw)	36.0	--
GROUND STATION		
Antenna gain (dB)	54.0	58.7
Antenna field of view (degrees)	.34	.19
System noise temp. (deg K)	123.0	--
Rec. G/T (dB/degrees K)	33.0	--
Trans. output power (dBw)	--	28.0
EIRP (dBw)	--	84.0
SYSTEM		
Bandwidth	500	500
Modulation	FM	FM
Geography	CONUS	

Table 4.2-5. ATS F&G Characteristics

MISSION/FUNCTIONAL GROUPING: ATS F&G	Operating Frequency								
	136 to 137 MHz	148 to 154 MHz	850 MHz	1550 MHz		1650 MHz		1800 MHz
SATELLITE	DOWNLINK	UPLINK	BC TV	FAN	PENCIL	FAN	PENCIL	To S/C
Antenna gain (dB)	19.5	17.0	33.0	31.5	38.5	31.5	38.5	39.0
Antenna field of view (deg)	17.0	16.0	3.0	1 x 7.5	1.5	1 x 7.5	1.5	1.3/13.0 scan
Antenna polarization	Linear	Linear	RC	RC		RC		RC
System noise temp. (deg K)	--	5000	--	--		2240	2000	--
Rec. G/T (dB/deg K)	--	-20	--	--		-2	5.5	--
Trans. output power (dBw)	3.0	--	19.0	16.0		--		13.0
EIRP (dBw)	22.5	--	52.0	48.5	54.5	--		52.0
				TO AC		FROM AC		
GROUND STATION	SATAN		COMMUNITY RECEIVERS	INTERNATIONAL AIRCRAFT		INTERNATIONAL AIRCRAFT		LOW-ORBIT SPACECRAFT (NIMBUS)
Antenna gain (dB)	31.0	13.0						
Antenna field of view (deg)	13.0	23.0						
System noise temp. (deg K)	1150	--						
Trans. output power (dBw)	--	34.0						
EIRP (dBw)	--	47.0						
SYSTEM								
Bandwidth	2 MHz	6 MHz	40 MHz	12 MHz		12 MHz		12 MHz
Modulation	PM	AM						
Geography	Rosman - from 94°W	Rosman - from 94°W	India - from 35°E					

Table 4.2-5. ATS F&G Characteristics (Cont)

MISSION/FUNCTIONAL GROUPING: ATS F&G	Operating Frequency				
	2250 MHz	3.75 to 4.15 GHz	3.75 to 4.15 GHz	5.95 to 6.35 GHz	5.95 to 6.35 GHz
SATELLITE	FROM SC	HORN	30-FT ANTENNA	HORN	30-FT ANTENNA
Antenna gain (dB)	40.5	16.6	46.0	16.5	49.0
Antenna field of view (deg)	1.0/13.2 SCAN	20.0	0.6	20.0	0.4
Antenna polarization	RC	LINEAR	LINEAR	LINEAR	LINEAR
System noise temp. (deg K)	1260	--	--	2240	3550
Rec. G/T (dB/deg K)	9.5	--	--	-17.0	13.5
Trans. output power (dBw)	--	13.0	13.0	--	--
EIRP (dBw)	--	29.6	59.0	--	--
		DOWNLINK	DOWNLINK	UPLINK	UPLINK
GROUND STATION	LOW ORBIT SPACECRAFT (NIMBUS)				
Antenna gain (dB)		58.0	58.0	61.0	61.0
Antenna field of view (deg)		0.2	0.2	0.14	0.14
System noise temp. (deg K)		--	--	--	--
Rec. G/T (dB/deg K)		THRESHOLD -100 dBm	THRESHOLD -100 dBm	--	--
Trans. output power (dBw)		--	--	30.0	30.0
EIRP (dBw)		--	--	91.0	91.0
SYSTEM					
Bandwidth	40 MHz	40 MHz	40 MHz	40 MHz	40 MHz
Modulation		PM and FM	PM and FM	SSB and FM	SSB and FM
Geography		ROSMAN	ROSMAN	ROSMAN	ROSMAN

Table 4.2-6. ATS H&I Characteristics

MISSION/FUNCTIONAL GROUPING: ATS H&I	Operating Frequency			
	11.7 to 12.2 GHz	14.0 to 14.5 GHz	11.7 to 12.2 GHz	14.0 to 14.5 GHz
SATELLITE	DOWNLINK	UPLINK	DOWNLINK	UPLINK
Antenna gain (dB)	37.4	48.7	37.4	37.4
Antenna field of view (deg)	3.5 x 1.4	0.6	3.5 x 1.4	3.5 x 1.4
Antenna polarization	--	--	--	--
System noise temp. (deg K)	--	1200	--	1200
Rec. G/T (dB/deg K)	--	17.9	--	6.6
Trans. output power (dBw)	31.0	--	31.0	--
EIRP (dBw)	67.9	--	67.9	--
GROUND STATION	LOW COST EXPERIMENTER'S STATION		CONTROL STATION	
Antenna gain (dB)	44.6	45.9	58.5	59.8
Antenna field of view (deg)	1.0	0.8	0.2	0.17
System noise temp. (deg K)	3890	--	1200	--
Rec. G/T (dB/deg K)	8.7	--	27.7	--
Trans. output power (dBw)	--	20.0	--	23.0
EIRP (dBw)	--	64.9	--	81.8
SYSTEM				
Bandwidth	40 MHz	40 MHz	40 MHz	40 MHz
Modulation	FM	--	FM	--
Geography	ETZ, MTZ, ALASKA, HAWAII	SAME	SAME	SAME

Table 4.2-7. Intelsat Characteristics

MISSION/FUNCTIONAL GROUPING: Intelsat IV		
	Operating Frequency	
	3.7 to 4.2 GHz	5.925 to 6.425 GHz
SATELLITE	DOWNLINK	UPLINK
Antenna gain (dB)	19.5	19.5
Antenna field of view (deg)	17.0	17.0
Antenna polarization	LHC	RHC
System noise temp. (deg K)	--	2290
Rec. G/T (dB/deg K)	--	-14.1
Trans. output power (dBw)	6.0	--
EIRP (dBw)	25.5	--
GROUND STATION	85 FEET	
Antenna gain (dB)	58.0	61.0
Antenna field of view (deg)	0.21	0.14
System noise temp. (deg K)	55.0	--
Rec. G/T (dB/deg K)	40.7	--
Trans. output power (dBw)	--	31.0
EIRP (dBw)	--	92.0
SYSTEM		
Bandwidth	36 MHz/CHANNEL	
Modulation		
Geography	GLOBAL COVERAGE--GAIN AND EIRP INCREASED BY 11.5 dB BY USE OF SPOT BEAM ANTENNAS (4.5 DEG BEAMWIDTH)	

Table 4.2-8. Synchronous Earth Observatory-Type Characteristics

MISSION/FUNCTIONAL GROUPING: SYNCHRONOUS EARTH RESOURCES SURVEY SYNCHRONOUS EARTH OBSERVATORY		
	Operating Frequency	
	2.09 to 2.12 GHz	2.2 to 2.3 GHz
SATELLITE	UPLINK	DOWNLINK
Antenna gain (dB)	0.0	0.0
Antenna field of view (deg)	OMNI	OMNI
Antenna polarization	--	--
System noise temp. (deg K)	--	--
Rec. G/T (dB/deg K)	--	--
Trans. output power (dBw)	--	+7.0
EIRP (dBw)	--	+7.0
GROUND STATION	30 ft/85 ft	30 ft/85 ft
Antenna gain (dB)	43.0/51.0	44.0/53.5
Antenna field of view (deg)	1.0/0.3	1.0/0.3
System noise temp. (deg K)	--	125.0
Rec. G/T (dB/deg K)	--	23.0/32.5
Trans. output power (dBw)	43.0	--
EIRP (dBw)	86.0/94.0	--
SYSTEM		
Bandwidth	500 kHz	500 kHz
Modulation	--	--
Geography	EARTH COVERAGE	EARTH COVERAGE

Table 4.2-9. Navigation and Traffic Control Characteristics

MISSION/FUNCTIONAL GROUPING: NAVIGATION AND TRAFFIC CONTROL			
	Operating Frequency		
	1.5425 to 1.5585 GHz	1.6365 to 1.645 GHz	5.0 to 5.25 GHz
SATELLITE	DOWNLINK	UPLINK	GROUND LINK
Antenna gain (dB)			
Antenna field of view (deg)	OMNI	OMNI	
Antenna polarization	EARTH COVERAGE	EARTH COVERAGE	
System noise temp. (deg K)			
Rec. G/T (dB/deg K)			
Trans. output power (dBw)			
EIRP (dBw)	+3.0		27.0 to 30.0
GROUND STATION			
Antenna gain (dB)	SHIPS AND AIRCRAFT (4 dB REFERENCE AC ANTENNA GAIN)		
Antenna field of view (deg)			
System noise temp. (deg K)			
Rec. G/T (dB/deg K)			
Trans. output power (dBw)			
EIRP (dBw)			
SYSTEM			
Bandwidth			50 kHz
Modulation			
Geography	EARTH COVERAGE--GROUND STATIONS LOCATED ON VARIOUS COASTS OF PACIFIC AND ATLANTIC OCEANS		

Table 4.2-10. Meteorological Satellites and GOES Characteristics

MISSION/FUNCTIONAL GROUPING: SYNCHRONOUS METEOROLOGICAL SATELLITE & GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE

	Operating Frequency					
	136 MHz	148 MHz	1.67 to 1.695 GHz	2.025 to 2.035 GHz	468 MHz	401.85 MHz
SATELLITE	DOWNLINK	UPLINK	DOWNLINK	UPLINK	DOWNLINK	UPLINK
Antenna gain (dB)	-6.0	-6.0	20.0	18.0	8.0	8.0
Antenna FOV (deg)	OMNI	OMNI	10.0	ELECT. PHASED ARRAY	EARTH COVERAGE	
Antenna polarization	RHC	RHC	--			
System noise temp (deg K)	--	1200*	--	500*	--	1000*
Rec. G/T (dB/deg K)	--	-36.8*	--	9.0*	--	-22*
Trans. output pwr (dBw)	9.0	--	13.0	--	10 to 13	--
EIRP (dBw)	3.0	--	33.0	--	18 to 21	--
	VHF		IDENTIFIED AS S_1 BAND ON CHARTS		UHF	
GROUND STATION	40 FT	SATAN				
Antenna gain (dB)	16.0	13.0	45.0	45.0	13.0	13.0
Antenna FOV (deg)	13.0	23.0				
System noise temp (deg K)	1500	--		--		--
Rec. G/T (dB/deg K)	8.2	--	(22.0 dB C/N)	--		--
Trans. output pwr (dBw)	--	34.0	--	0.0	--	7.0
EIRP (dBw)	--	47.0	--	45.0	--	20.0
SYSTEM						
Bandwidth	70 kHz		9 MHz	9 MHz	280 kHz	280 kHz
Modulation	PM	FSK/AM/PM		PSK		PSK
Geography	WALLOPS ISLAND AND STDN		WALLOPS ISLAND AND DUS AT SAN FRANCISCO, KANSAS CITY, AND SUITLAND		DATA COLLECTION PLATFORMS	

*Estimates

within that zone. Maximum spacing of the same frequency band satellites was one of the criteria used. Different frequency satellites were interspersed while still maintaining maximum physical spacing.

The result was a set of charts for the six zones that illustrates the zonal population and orbital position bounds for the specific areas being serviced. Each satellite is described by function and operational frequencies.

Discussions with SAMSO resulted in general information concerning DoD geosynchronous satellites. Because of security, exact orbital positions and frequencies were not fully defined. Estimates of the catalog of 47 satellites defined were made for orbital placement and operating frequency bands. These were then included in the satellite distribution charts. Orbital position is Space Division's estimate, not DoD plans. It was felt that any conflicts that might occur would require direct DoD/NASA discussion.

Examination of the distributions constructed in the previous section shows showed significant population density. Data relay satellites (commercial) are by far the most numerous. Zone 5 was the most dense. The satellites showed the following minimum spacings:

C-band data relay = 6 degrees minimum spacing

S-band satellites = 6 degrees minimum spacing

Ku, VHF, UHF, and L-band systems were in such small numbers that they were not considered.

Figures 4.2-2 through 4.2-6 define the zonal satellite population distribution.

EMI MODEL CRITERIA AND WORST-CASE ANALYSIS

Examination of the distribution effected in the previous section shows that the major problem is in Zone 5 with data relay satellites operating in C-band. Other operational satellites at other frequencies do not exhibit spacings that indicate any problems at geosynchronous orbit.

The model used for analysis was, therefore, a C-band system. All C-band-type satellites were assumed to have identical characteristics. That is, each C-band satellite had characteristics as outlined in the section on satellite RF characteristics. A homogeneous system was used. Each satellite had the same (1) antenna characteristics (gain, beamwidth), (2) radiated power (EIRP), (3) frequency of transmission and reception, (4) receiver characteristics (noise temperature, gain, linearity), (5) number of circuits per channel, and (6) modulation technique. In a similar manner, the ground stations were assumed to have identical characteristics. Figure 4.2-7 illustrates these basic characteristics.

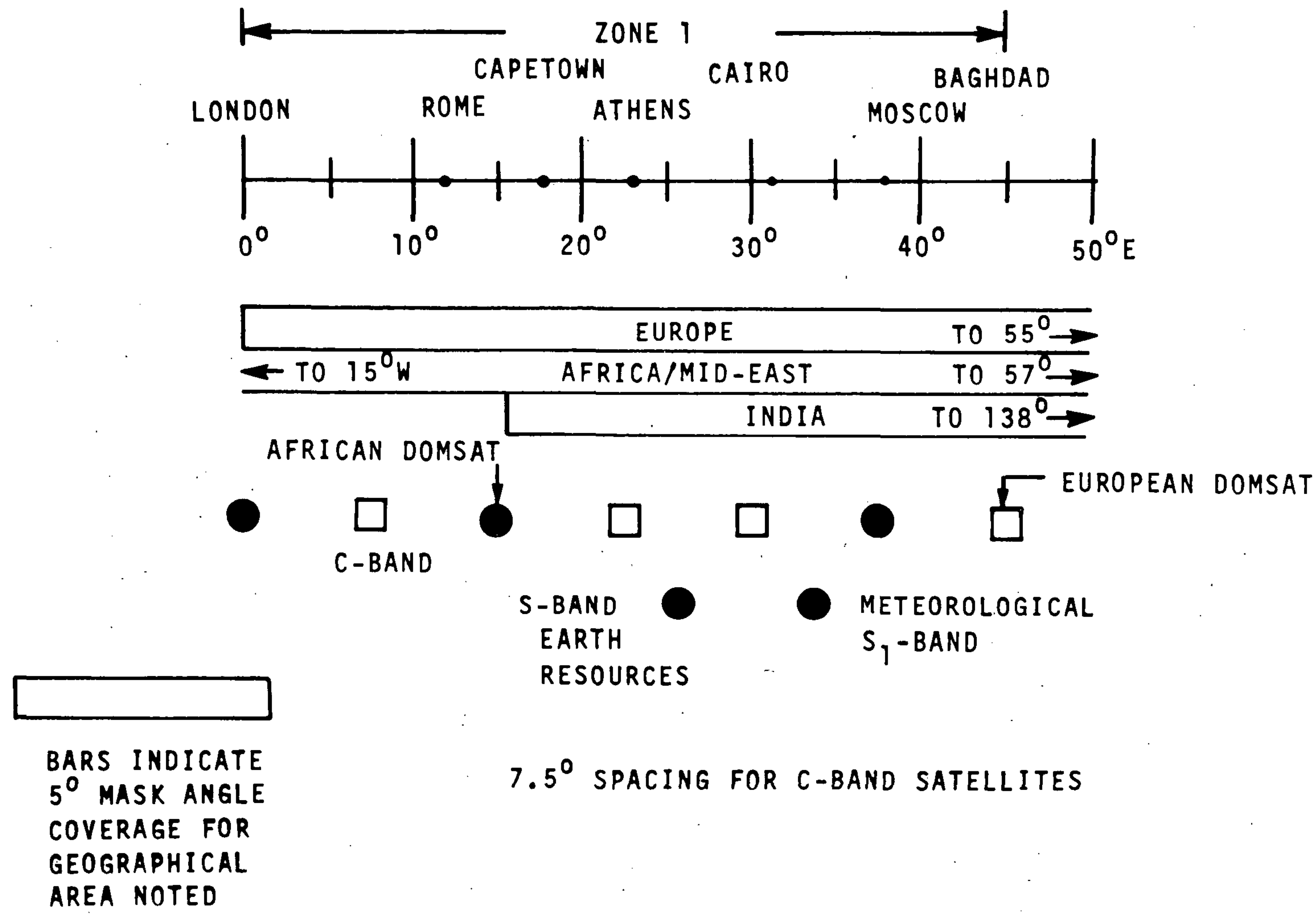


Figure 4.2-2. Zone 1 Satellite Distribution Chart

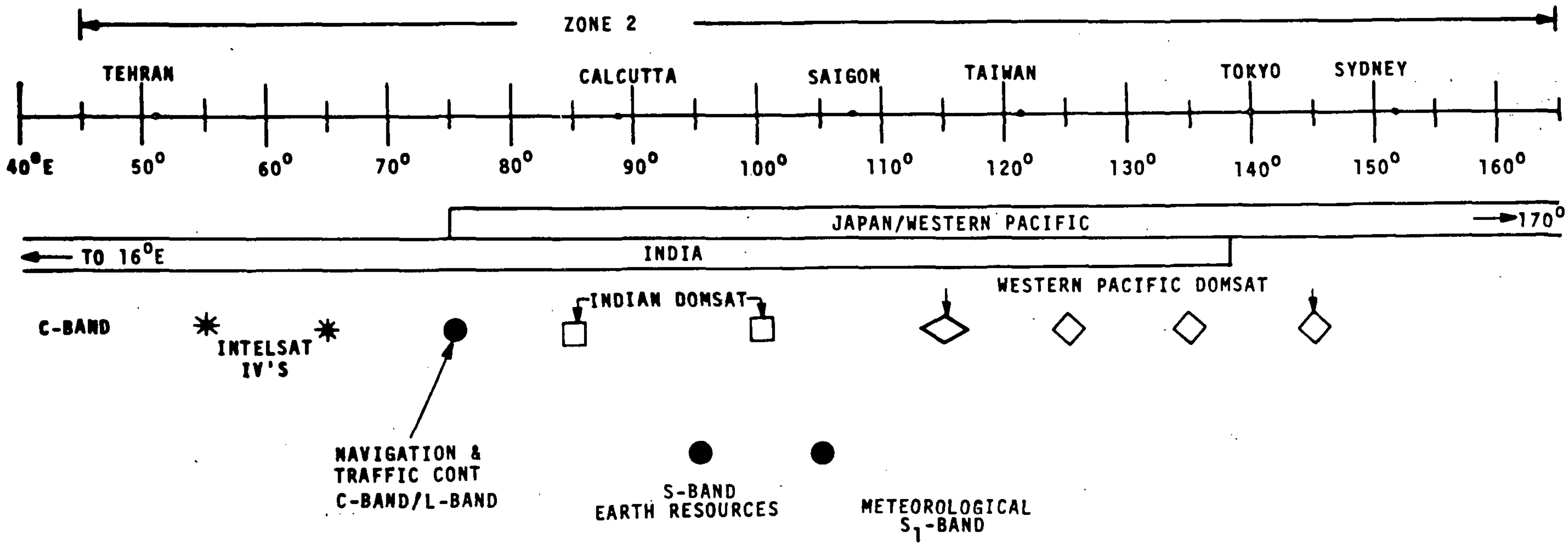


Figure 4.2-3 Zone 2 Satellite Distribution Chart

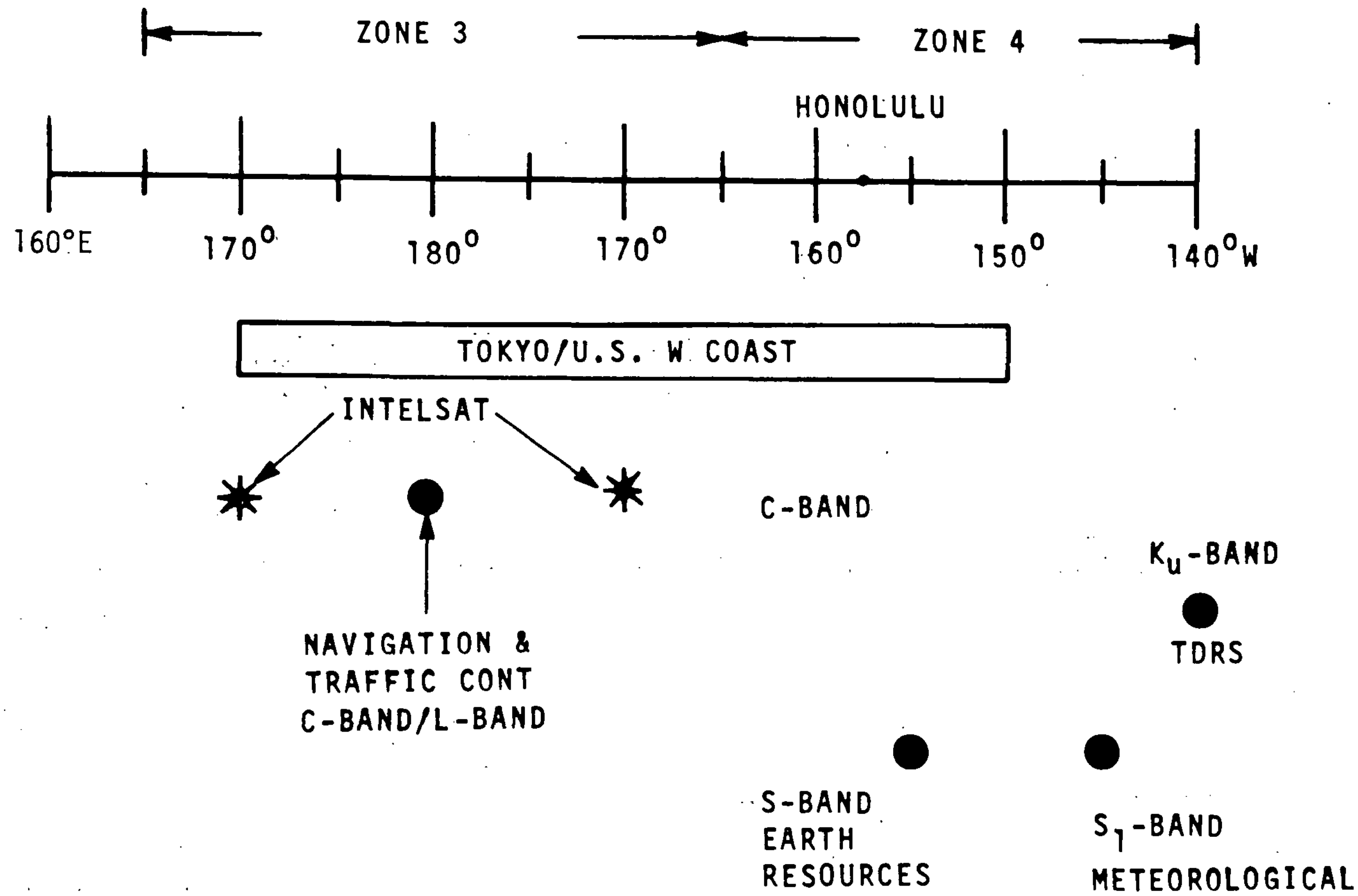


Figure 4.2-4 Zones 3 and 4 Satellite Distribution Chart

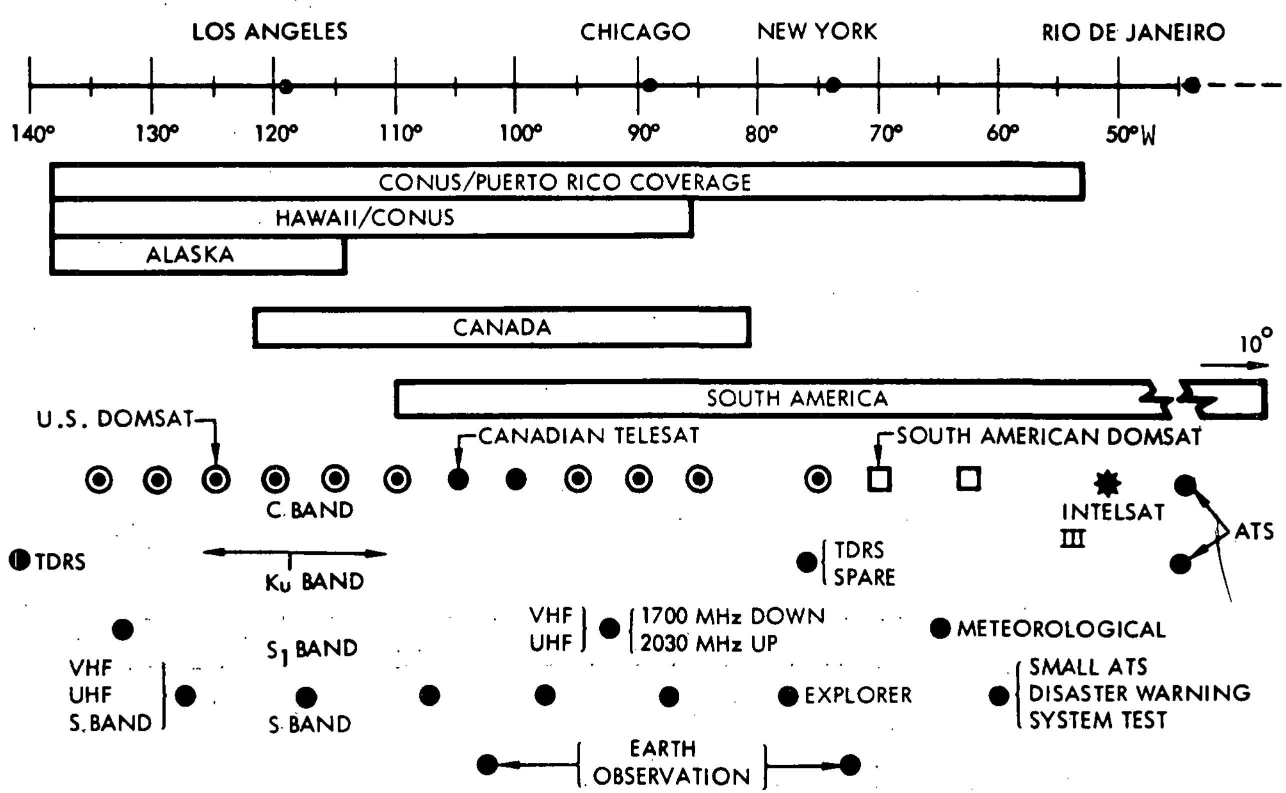


Figure 4.2-5. Zone 5 Satellite Distribution Chart

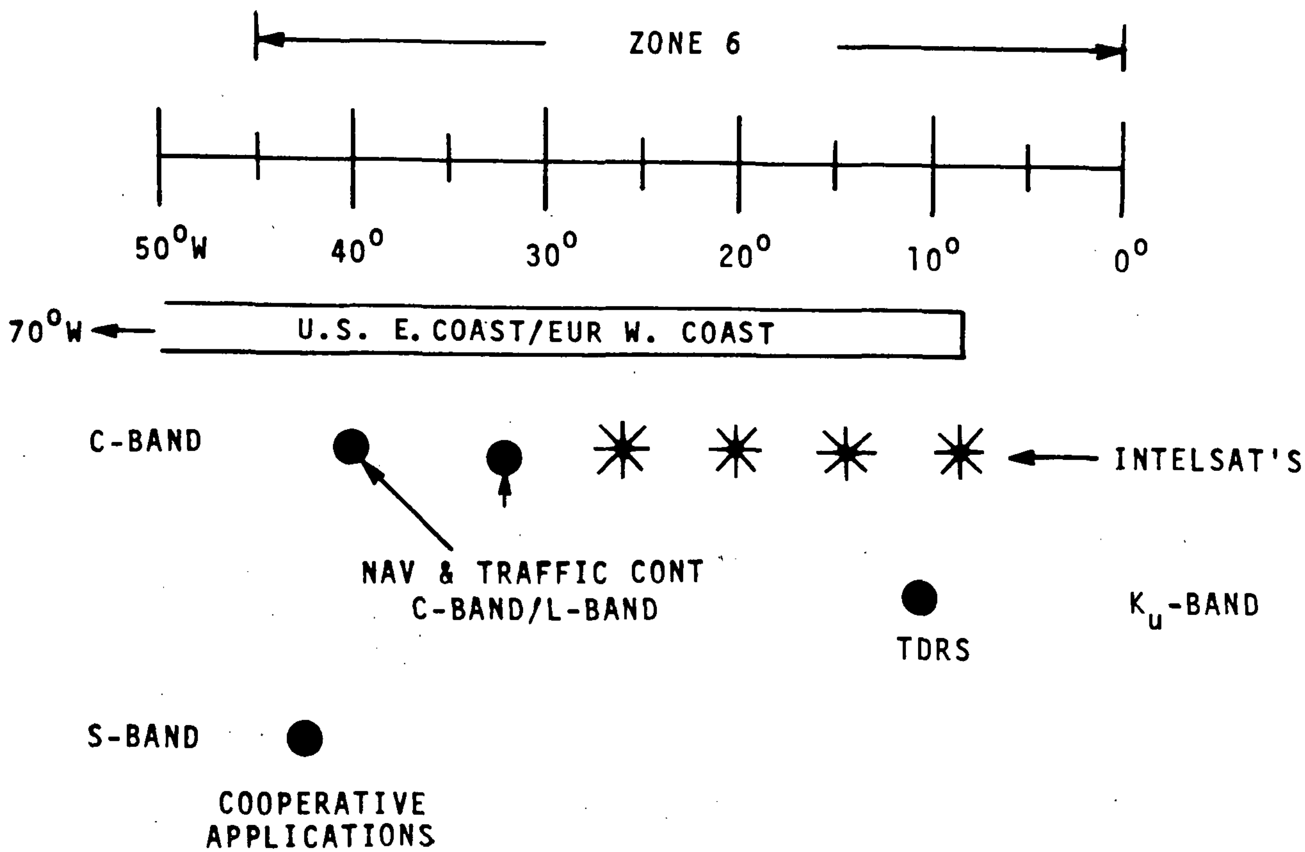


Figure 4.2-6 Zone 6 Satellite Distribution Chart

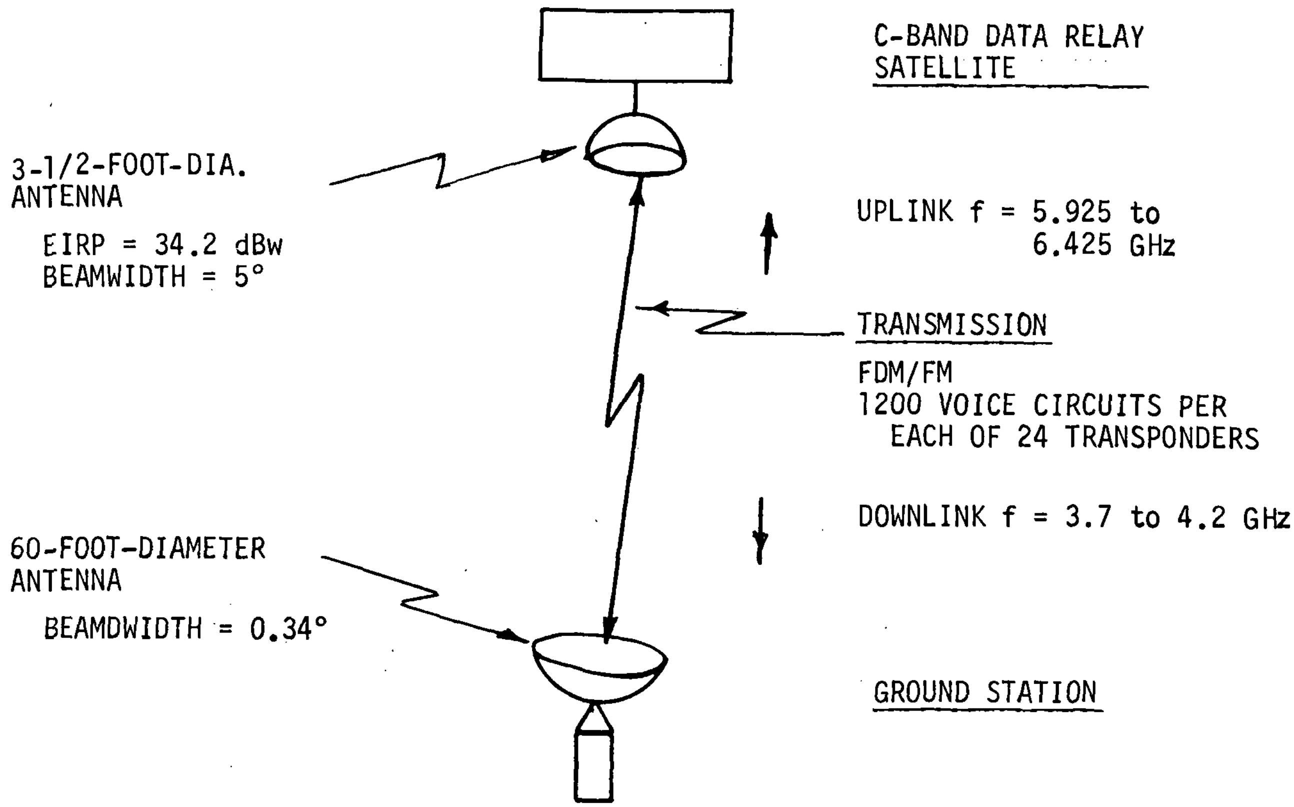


Figure 4.2-7. C-Band Data Relay System Basic Characteristics

A group of 11 satellite links was assumed for the EMI model. Section 5.5, Volume III calculations (Table 5.5-4) show that the noise contribution of the fourth (2.1 percent) and fifth (1.4 percent) satellites on either side of the interfered-with satellite affects the total noise by only 4 percent or less. This holds true for all cases that total within the 1000 pWOp established limits. A total of 11 equally spaced, homogeneous satellites would, therefore, provide answers within one percent of the actual interference level. This is the type model that is used for interference level estimation.

Figure 4.2-8 incorporates spacing associated with the worst case--most densly populated C-band satellites--to determine the interference level.

Zone 5, the North/South America zone, results in a 6-degree, C-band Domsat spacing. Reference to Figure 4.2-8 shows that the interference level is well within the CCIR limits of 1000 pWOp. At 6-degree spacing, the level is approximately 600 pWOp. As indicated by the chart, use of a 60-foot ground antenna will allow minimum satellite spacing of approximately 4.6 degrees. With 97-foot antennas, minimum spacing approaches 3 degrees. If polarization diversity were used with alternate satellites, this spacing could be decreased.

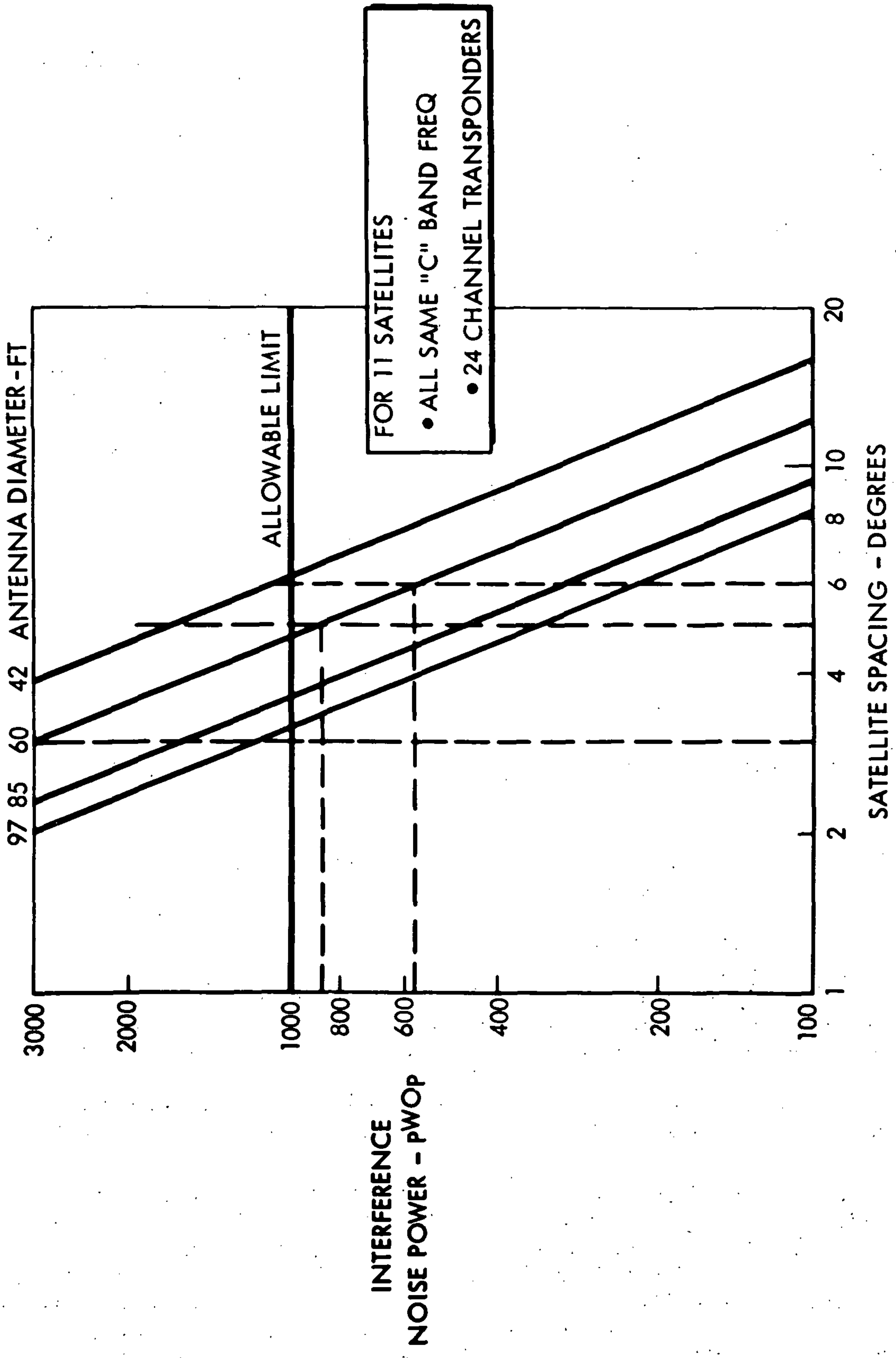


Figure 4.2-8. Interference Noise versus Satellite Spacing

The baseline traffic model world-wide spacings and interference levels are illustrated below. No EMI problem exists for this model.

	Zone I	II	III	IV	V	VI
No. of C-band satellites	7	9	3	0	15	6
C-band spacing (deg)	7.5	15	15	-	6	11
Interference level - pWOp	330	<100	<100	-	590	125

5.0 GEOSYNCHRONOUS REQUIREMENTS ASSESSMENT

One of the primary drivers in the definition of platform concepts is the potential economic savings of a geosynchronous platform program as compared to a customized expendable satellite program. It is anticipated that a significant reduction in the on-orbit inventory of space elements can be achieved with the platform approach. In this section, the system level requirements for platforms that will provide at least the same capability as the satellites of the baseline traffic model are derived.

Section 5.1 presents the characteristics of the satellite inventory of the baseline traffic model. The data primarily consists of extractions from open literature, NASA reports, and NASA contractor documents as well as Rockwell data. Gross performance requirements are also listed.

Two platform approaches are defined. One approach is to define a common support module that will provide the utilities to individual satellite payloads (single function platforms). The second approach is to group satellite payload functions and/or equipment on the minimum number of geosynchronous orbit space elements (multifunction platforms). Section 5.2 establishes the minimum number of geosynchronous platforms that will provide the same capability as the satellites in the baseline traffic model.

Four basic types of platforms are identified. Global coverage requirements dictate that at least four of the data relay type platforms are required. Sun outage problems, which would interrupt a platform-ground station communication link, result in the doubling of the number of required data relay platforms. Tracking and data relay platforms require unique placement and orbital spacing; thus, three of this type of platform are required. In order to provide world-wide coverage of weather sources plus observation and evaluation of earth resources, four earth observation platforms are required. This type of platform requires a continuously scanning local vertical maneuver. The design concept that would result if earth observation functions and data relay functions (which require fixed local level orientation) were grouped on a single platform, is considered to be too complex to be practical or economical. Four different astro-physics platforms are identified. Sensor, pointing, and EM incompatibilities preclude the grouping of these four platforms with other platform types.

The platform system level performance requirements are presented in Section 5.3. In the case of the common support module platform approach the requirements are specified at the subsystem function level of detail.

One of the primary characteristics of the platform concept is the inclusion of on-orbit servicing capability. Provisions must be included for auto-remote and manned attendance (both pressure suited and shirtsleeve). Section 5.4 presents platform design criteria for all three servicing modes.

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5.1 SATELLITE INVENTORY ANALYSIS

The baseline traffic model identified a population of 120 satellites in the first ten years of shuttle operations, which were used as the basis for the derivation of potential mission/payload groupings. The objective of the satellite inventory analysis was to define the key physical characteristics for each satellite such that subsystems and utilities support requirements could be determined for groups of payloads. While no specific baseline definition of these satellites was furnished, various literature sources were used to establish characteristics and performance requirements associated with each satellite payload. In some cases, however, it was only possible to identify typical characteristics by satellite type, either due to lack of information or because the satellites are, in effect, a "production run" of common configuration, either for buildup of on-orbit capability, or for orbital replacement of an expended satellite. An analysis of these synthesized characteristics was used to define platform requirements.

PROGRAMMATIC DESCRIPTIONS

The identified satellites were grouped into eleven programmatic areas, which included various quantities and types of spacecraft to accomplish a range of developmental, scientific, or operational objectives.

Astronomy

Four spacecraft were identified that support scientific objectives in astronomy for the continental United States zones. They consist of: optical interferometer, radio astronomy, solar orbit, and X-ray astronomy satellites.

Developmental Earth Observations

Eight spacecraft are operational during the 12-year program, reaching a level of four concurrently. From data in the baseline model, these were identified as a synchronous earth observations prototype, two synchronous meteorological and five synchronous earth observational satellites.

Advanced Technology

The five Advanced Technology Satellites (ATS) include the functions of cooperative applications satellites, medical network, education broadcast, and disaster warning. However, due to insufficient definition of different payloads, the satellites are not identified individually.

System Test Satellites

This group, consisting of eight spacecraft will support development testing of as yet undefined payloads.

Small ATS

Small ATS payloads would permit short-term application development of unique payloads. Eleven spacecraft launches are included in the program with no individual definition.

Tracking and Data Relay

Six operational NASA spacecraft are identified for the relay of communication, tracking, and real-time or recorded data between low earth orbiting spacecraft and a ground station. Two spacecraft are continuously operational with one available "on-orbit backup" unit.

Communications Satellite (Comsat)

Operational Comsats provide international commercial networks. Programmatically, the spacecraft are launched sequentially to achieve a full operational level of eight. Comsats are defined as consisting of 12-channel, C-band transponders, having a total relay rate of 432 mega-bits per second.

United States Domestic Satellites (Domsats)

Internal United States communications are accommodated by 19 production run satellites which are maintained at a constant level of ten. Private and commercial needs are accommodated on 24-channel C-band transponders with a relay capability of 864 megabits per second for each Domsat.

Foreign Domsat

A total of 26 spacecraft at a steady-state level of 16, provide for all intra-national communications outside the continental United States. Foreign Domsats, based on current design, are defined as having 12-channel C-band transponders, with a data rate capability of 432 megabits per satellite.

Navigation and Traffic Control

Six data relay-type satellites provide communication links for ships and aircraft for purposes of navigation and traffic control. A constant level of three satellites, each with a 250 kilo bits per second data rate meets the baseline traffic functional requirement.

Operational Earth Observations

The 19 earth observation satellites were functionally defined as including synchronous meteorological and earth resources observations satellites, reaching a steady-state level of eight. On the basis of analyses which indicated a reasonable global coverage by four satellites, the delivery of meteorology satellites were grouped into sets of 3, 4, 4, and 4 (per the traffic model) of increased sophistication, plus four earth resources deliveries, also per the traffic model.

SPACECRAFT CHARACTERISTICS

A variety of open literature sources was used to define the characteristics of these "custom designed", spacecraft. Primary sources were published reports (References 3-5 and 5-1), and currently reported procurements. Table 5.1-1 defines the basic characteristics of the satellite inventory in terms of equipment weights, satellite size, power, and data rate characteristics. Thirty percent of the satellites have a weight of 1000 pounds or less while 80 percent are 1900 pounds or less. Similarly, power requirements for 50 percent of the satellites are 500 watts or less; and in 95 percent of the satellites required 1000 watts or less. These and other characteristics are shown in cum percent in Figure 5.1-1 for the total satellite inventory. The sizing data show that many of the satellites are designed for compatibility with various launch vehicles or kick stages other than the tug, and may not be optimum for shuttle operations in terms of efficient use of shuttle capabilities. This conclusion is also borne out by the JSC side-by-side and end-to-end loading studies (Reference 3-5). Data rate requirements do not present a homogeneous grouping. The function of TDRS, Comsat, and Domsat groups is to provide for data relay with capability measured in number of channels for a given type of system, plus some minimal status data transmission. Other satellites generate various levels of data as a function of sensor requirements and sophistication. The maximum data rate that was identified was 50 Mbps. Table 5.1-2 summaries the performance characteristics of the satellites.

Table 5.1-1. Systems Characteristics

Name	No. S/C	Weight (lb) Mission Equip.	Subsyst.	Gross	Size (feet) Length	Diameter	Power (watts)	Data (bps)
rferometer	1	1280	600	2400	19	7	230	2×10^4
nomy	1	540	450	1250	8	4	530	2×10^4
er	1	580	500	1500	12	8	500	2×10^7
onomy	1	1200	600	2300	18	10	570	8×10^6
is Meteorology	1	307	400	1000	8	5	300	25×10^5
is Meteorology	1	553	500	1450	12	5	800	5×10^7
is Earth Observ. Proto.	1	350	420	1000	6	4	400	5×10^6
is Earth Observations	1	830	550	1900	12	6	600	5×10^6
is Earth Observations	3	1300	800	2600	18	6	800	5×10^7
is Earth Observations	1	2168	800	3500	22	10	1000	5×10^7
Technology	5	500	500	1700	6	10	2K→10K	2×10^4
est	8	350	450	1200	6	10	1000	2×10^4
;	10	150	300	750	10	7	500	5×10^7
;	1	300	450	1150	12	10	750	5×10^7
	6	200	300	900	12	8	275	12 CH
	8	200	400	1000	12	6	300	12 CH
isat	19	300	400	1100	10	10	500	24 CH
omsat	26	150	400	1000	12	4	230	12 CH
n and Traffic Control	6	100	300	700	8	5	200	25×10^4
eorology	4	250	300	1000	6	5	400	25×10^5
orology	3	350	400	1200	10	5	450	3×10^6
eorology	4	300	400	1100	10	5	800	5×10^7
gy and Earth Resources	4	800	500	1700	15	10	600	5×10^7
rth Observations	4	2000	800	3300	20	12	1000	5×10^7

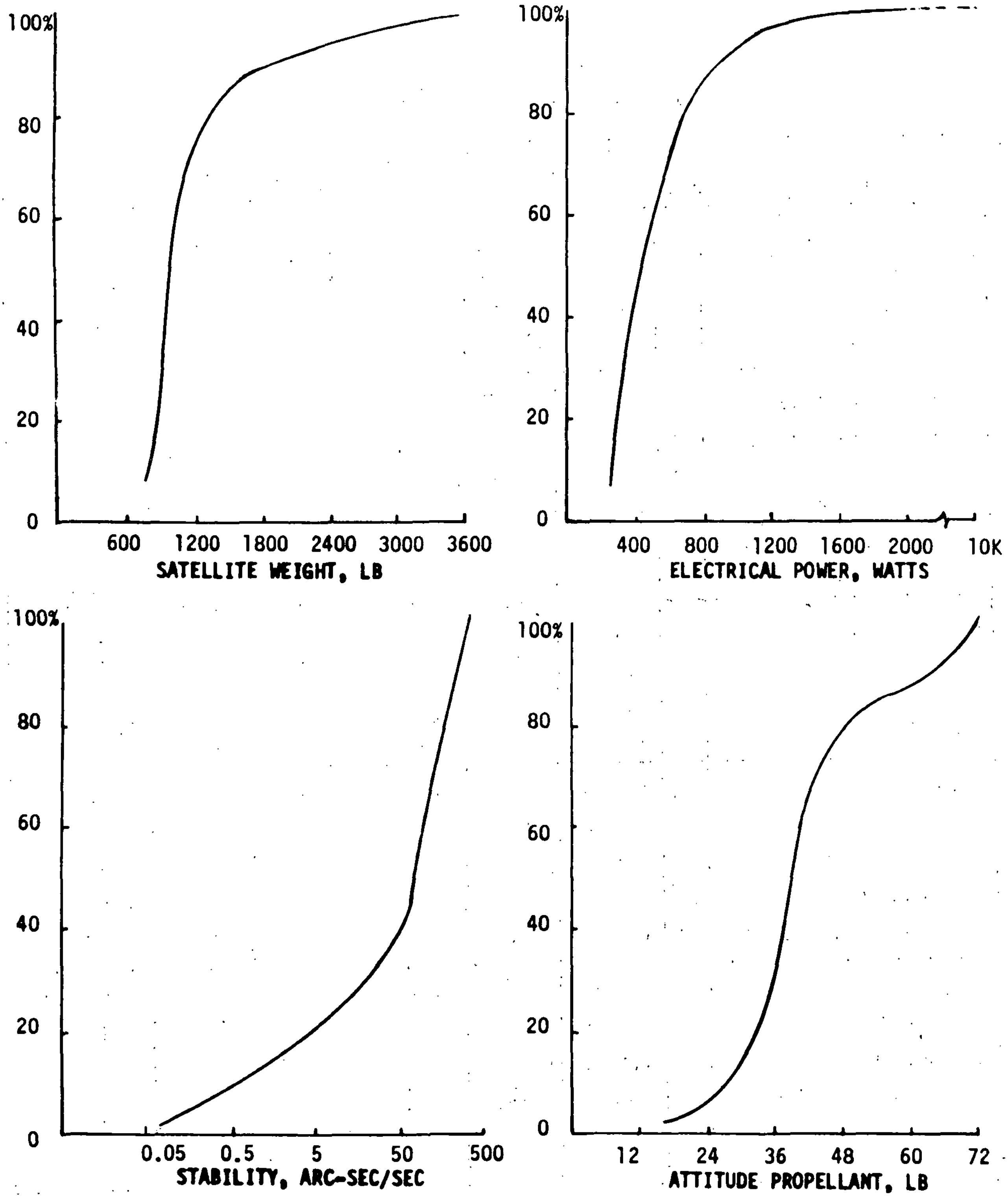

Figure 5.1-1. Summary of Selected Characteristics of the Satellites

Table 5.1-2. Performance Characteristics

Name	No. S/C	Pointing Accuracy (±)	Stability Per Second	Flight Mode	Planned Mission Life (yr)	Propellant (lb)	Attitude Control
Optical Interferometer	1	0.1 sec	0.05 sec	Inertial	3	65	N_2H_4, 3-axis
Radio Astronomy	1	10 sec	0.05 deg	Inertial	3	15	GN_2, 3-axis
Solar Orbiter	1	1 sec	1 sec	Inertial	3	60	N_2H_4, spin
X-Ray Astronomy	1	1 sec	1 sec	Inertial	3	65	N_2H_4, 3-axis
Synchronous Meteorology	1	0.1 deg	1 minute	Local vertical	4	50	N_2H_4, 3-axis
Synchronous Meteorology	1	0.1 deg	1 minute		4	55	
Synch Earth Observ. Proto.	1	0.1 deg	1 minute		5	40	
Synchronous Earth Observations	1	0.1 deg	1 minute		5	60	
Synchronous Earth Observations	3	10 sec	1 minute		5	65	
Synchronous Earth Observations	1	2 sec	2 sec	Local vertical	5	70	N_2H_4, 3-axis
Advanced Technology	5	0.05 deg	0.05 deg	Any	5	35	N_2H_4, 3-axis
Systems Test	8	0.2 deg	0.1 deg		5	65	
Small ATS	10	10 sec	1 sec		1	30	
Small ATS	1	10 sec	1 sec	Any	1	30	N_2H_4, 3-axis
TDRS	6	0.1 deg	0.05 deg	Local vertical	6	35	N_2H_4, spin
Comsat	8	0.2 deg	0.1 deg		7	50	
U.S. Domsat	19	0.2 deg	0.1 deg		7	35	
Foreign Domsat	26	0.2 deg	0.1 deg		7	40	N_2H_4, spin
Navigation and Traffic Control	6	0.5 deg	0.1 deg	Local vertical	5	35	GN_2, 3-axis
Early Meteorology	4	0.1 deg	1 minute	Local vertical	4	50	N_2H_4, 3-axis
Mid Meteorology	3	0.1 deg	1 minute		4	50	
Late Meteorology	4	0.1 deg	1 minute		4	50	
Meteorology and Earth Resources	4	10 sec	1 minute		4	50	
Integ. Earth Observations	4	2 sec	2 sec	Local vertical	3	60	N_2H_4, 3-axis

5.2 MISSION OBJECTIVES GROUPING

Analysis of the characteristics of the satellites of the baseline traffic model indicates that combining some sets of mission objectives and the associated equipment into geosynchronous platforms is feasible. This section develops the requirements and constraints of multifunctional geosynchronous platforms. The approach is to minimize the required number of platforms; and thus to minimize the total costs of the geosynchronous program.

GLOBAL COVERAGE

The baseline traffic model reflects communication and observation requirements on a world-wide basis. Thus, one platform that would combine all functions is impossible.

An evaluation was conducted to determine the minimum number of global regions that would meet the following operational requirements:

1. Observation of weather sources (e.g., Aleutian low, Icelandic high)
2. Communications to all population centers
3. Multi-path international data relay (Comsat)
4. Transoceanic data relay (Comsat)
5. Intranational data relay (Domsat) via a single platform

A three-platform or regional concept (spaced approximately 120 degrees apart) could not fulfill all requirements. For example, manipulation of platform locations to meet Item 5 resulted in not accomplishing Items 3 and/or 4. Global division into four regions does permit compliance with all five requirements. Figure 5.2-1 illustrates the selected global regions. The ground contours correspond to a 5-degree mask angle/elevation angle. A 5-degree mask angle is a reasonable limit for communications line of sight because of potential terrain interference and atmospheric attenuation of radio frequency signals.

The spacing of regions is intentionally non-uniform. The selection was made to maximize the capability of international communications via a single satellite and still meet the basic set of requirements. Examination of Figure 5.2-1 will show that with the exception of a direct South American-East Asian/Australian link, any country can communicate with any other country via a single satellite.

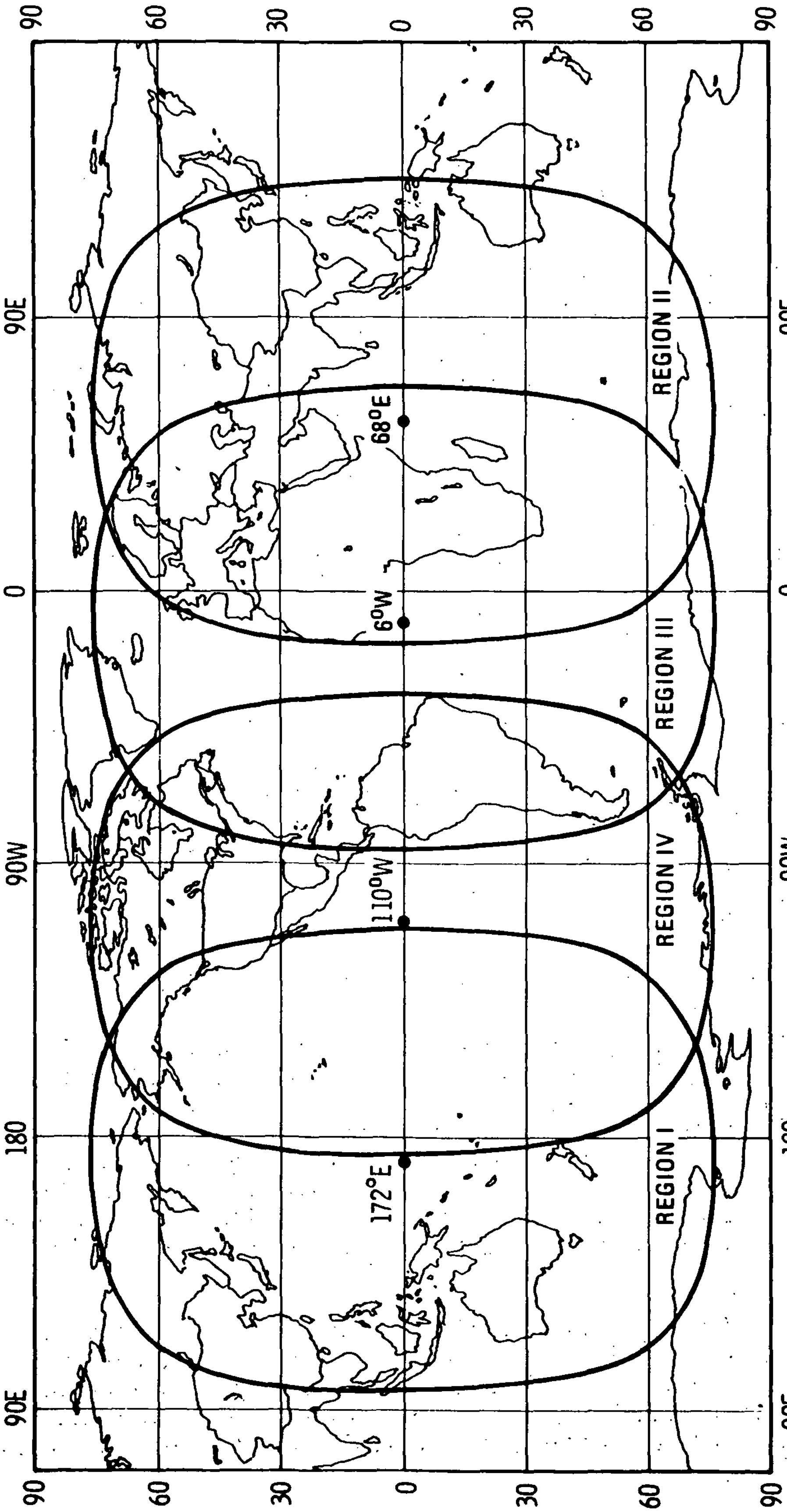

Figure 5.2-1. Selected Global Regions

Although five or more platforms would provide additional flexibility, the additional geosynchronous elements would not resolve the South American direct global link. Thus, from strictly a global coverage standpoint, at least four geosynchronous platforms are required. The geographical characteristics of each region will also dictate that the platforms in each region will be different at least for data relay purposes.

SOLAR NOISE OUTAGE

Twice a year during the vernal and autumnal equinox periods, a juxtaposition of the sun, platform, and the ground station will occur for several minutes a day over approximately a two-week interval. During the juxtaposition periods the sun increases the noise density at the ground antenna by approximately 85 dB. Utilizing current state-of-the-art communications equipment and considering only galactic noise at the frequencies of interest, communication link calculations indicate that signal-to-noise ratios of 19 dB are readily obtainable. However, devising communication systems that would increase signal power by 85 dB to compensate for the added noise power of the sun is totally impractical if not technologically impossible.

The precise duration of sun outage is dependent upon orbit inclination of the platform and the latitude of the ground station. The maximum period of solar noise outage for any location will be at least six minutes. Admittedly this is a short period of time, but all communications via the geosynchronous platform to the affected ground terminal would be suspended. This is considered to be an intolerable situation.

The solar disc subtends an angle of approximately 0.5 degree at the surface of the earth. With reasonable ground antenna design the solar noise outage problem can be circumvented by pointing a second ground terminal antenna at a second geosynchronous platform located 10 degrees in longitude from the platform with the interrupted service. The relative geometry of the sun, platforms, and ground terminal is illustrated in Figure 5.2-2.

Each of the platforms defined in the basic four global regions include data relay functions. In order to circumvent the sun outage problem, at least two platforms in each region are required. It is not suggested that each platform include the capability to meet the total data relay requirement of each global region. Rather, each platform should provide half the required capability. Thus, the worst case would be to reduce the data capability of a ground terminal by 50 percent during a sun outage period. A more practical method of implementation is feasible because only discrete ground stations included in the sun disc subtended angle are disabled. By judicious time sharing and real time allocations of channels nominally assigned to ground terminals in other time zones that are in non-peak traffic periods, a ground terminal that has access to only one of the two regional platforms because of sun outage could still operate at peak traffic loads. That is, for short time durations it would be practical for a ground terminal to fulfill all of the communication link channel requirements by means of only one of the regional platforms.

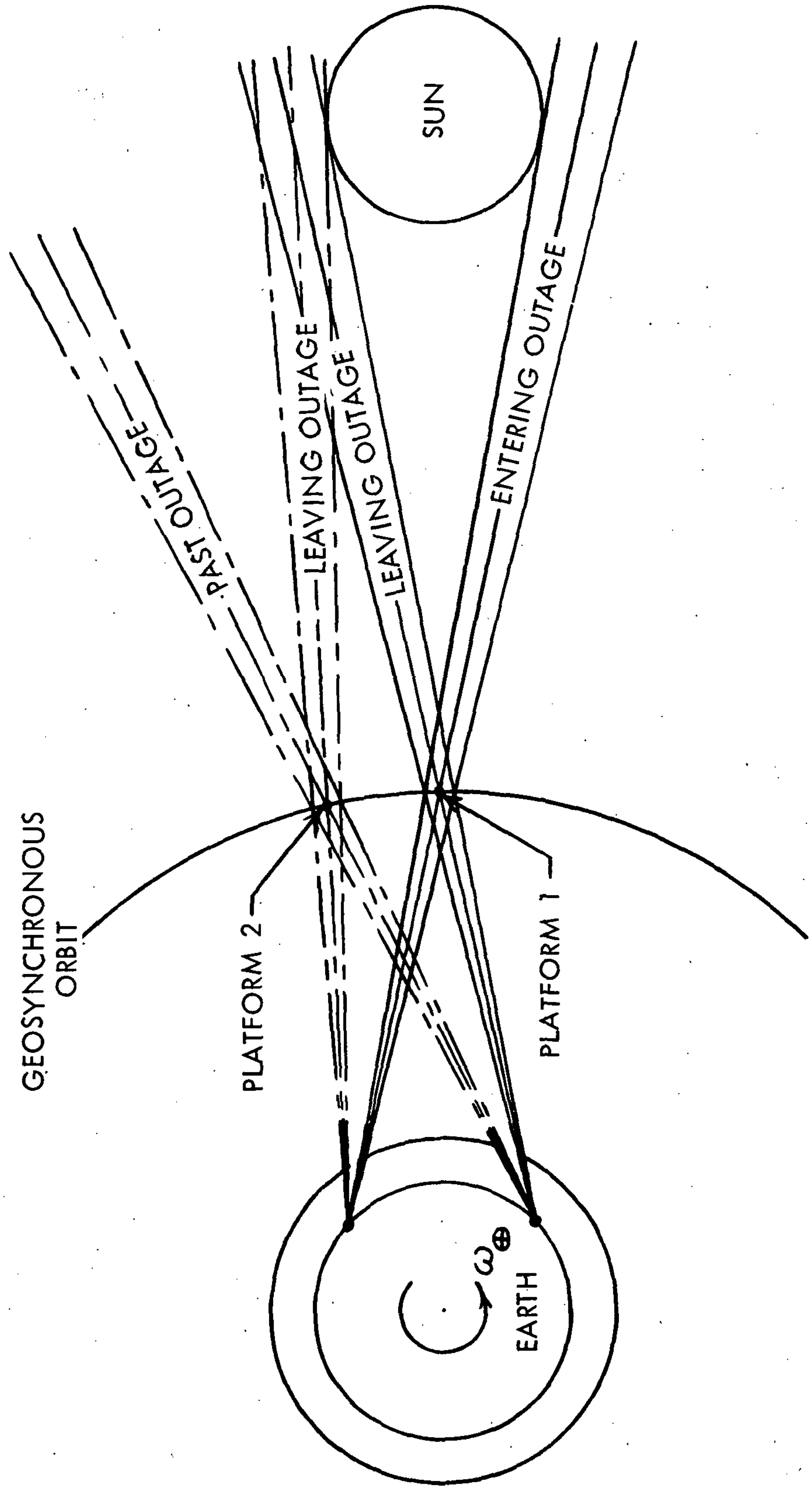

Figure 5.2-2. Solar Outage Geometry

RELAY OF LOW EARTH ORBIT SATELLITE DATA

A unique class of data relay requirements involves the transfer of data from low earth orbiting satellites via a geosynchronous orbit satellite to a ground terminal. The geosynchronous satellites are commonly known as the Tracking and Data Relay Satellite system (TDRS). One of the primary reasons for the TDRS concept is to facilitate satellite data relay to a single continental United States data processing ground terminal without a world-wide network of ground terminals.

On-going NASA studies are conducting trades to optimize the location of the satellites of the system. Satellite spacing and inclinations directly affect the feasibility of maintaining contact with a singular ground terminal and also maintaining line-of-sight contact capability with low orbit satellites. Figure 5.2-3 illustrates this interdependency. It can be seen that maximum allowable spacing of the satellites is about 132 degrees. This spacing would also maximize the coverage of low earth orbiting satellites. That is, all satellites above 620 nautical miles would continuously be within the line of sight of at least one of the TDRS satellites. In order to allow for a reasonable north-south drift during the mean mission duration of the TDRS elements, an initial inclination offset of 2.5 degrees is preferred. Thus, a 130-degree spacing is the optimum and 100 percent coverage capability is possible with satellites above 700 nautical miles.

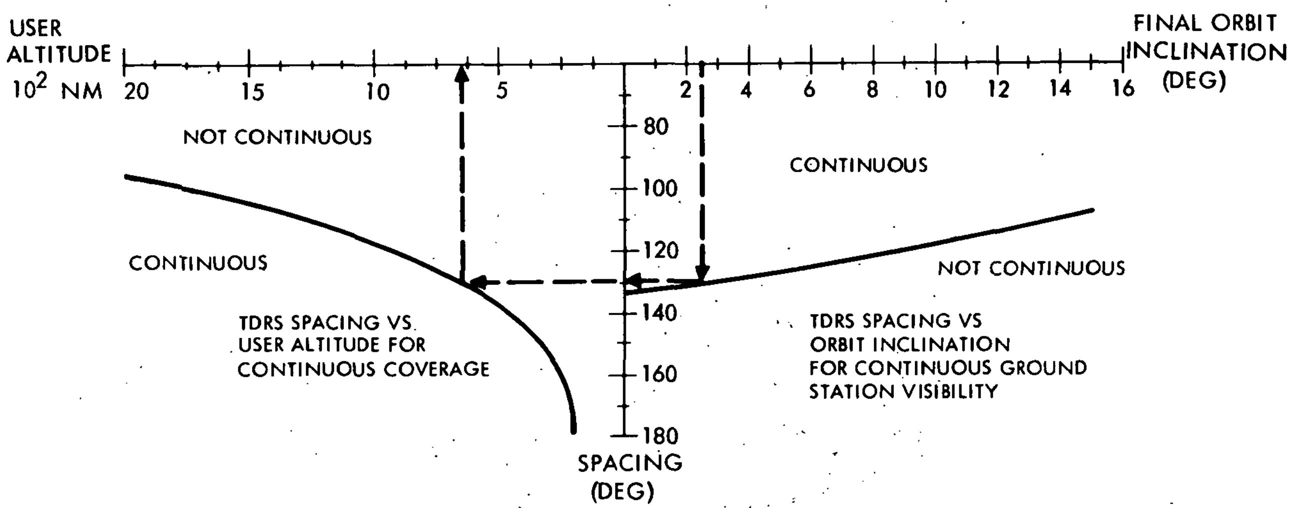

Figure 5.2-3. Optimized TDRS Spacing

One of the candidate TDRS concepts positions the TDRS elements at 11°W and 141°W longitude. This placement permits continuous contact from both elements to a ground terminal at Rosman, North Carolina. The resultant "cone of exclusion" of low earth orbiting satellites is depicted in Figure 5.2-4. Sensitivity of the exclusion zone to TDRS element spacing is also indicated. For the element placement selected the cone of exclusion extends from about the middle of India to the middle of Australia for satellites below an altitude of 100 nautical miles.

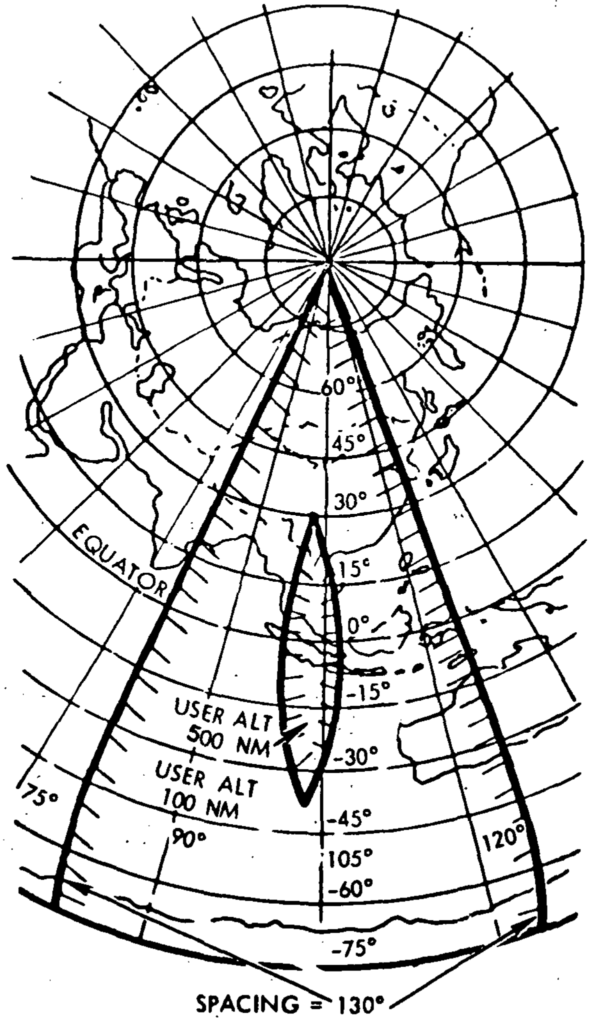

Figure 5.2-4. Cones of Exclusion

In order to fulfill the requirements of the TDRS, it is apparent that combining this function on platforms that are nominally spaced 90 degrees apart is impractical. The possibility of combining one of the TDRS elements with a Region III platform was considered. However, the TDRS concept also includes an on-orbit spare placed approximately at the mid-point between the two operational elements. Development of two TDRS elements of the same type and two different Region III platforms was not considered to be as economical as three identical TDRS elements and two identical Region III platforms. Therefore, in addition to the platforms identified for reasons of global coverage and sun outage problem, three additional platforms are required to fulfill the TDRS functions.

ORIENTATION CONSIDERATIONS

The baseline traffic model includes two classes of satellites that have unique operational characteristics. They are the astronomy-space physics and earth observation satellites. The astronomy-space physics (astro-physics) satellites are considered to be an integrated set of sensors for operational purposes that will require 4 π steradian pointing capability. All astro-physics satellites are positioned in Region IV (over the United States). The earth observation satellites considered in this grouping consist of integrated operational meteorology and earth resources activities. The observation functions must be conducted on a world-wide basis.

Astro-Physics

As all the astro-physics elements are in Region IV, the logical approach would be to group them with the Region IV data relay satellites. Even though the astro-physics satellites in the baseline traffic model are sequentially emplaced, they could be alternately grouped with one or the other of the data relay platforms. Thus, it would appear that grouping is feasible. However, there is a direct conflict in the desired pointing or orientation of the mission equipment between the data relay satellites and the astro-physics satellites.

The data relay function requires continuous local vertical orientation. Astro-physics sensors require multiple inertial orientations. In order to group the two types of satellites together, one section must be capable of three degrees-of-freedom rotational motion independent of the other section. If the mission equipment of either type of satellite were relatively light and comparatively small in size, such a pivotal platform would be feasible. However, the sizes and weights of the mission equipment of each type of satellite are large. In essence, a universal joint between two halves of the platform would be required.

It is not considered practical or even feasible to devise such a joint that would permit the pointing and stability requirements of astro-physics operations to be attained. The disturbance torques resulting from the constant relative motion between platform sections would preclude the required stabilization levels of less than one arc second. Therefore, astro-physics functions are not considered to be groupable with local vertically oriented functions.

Earth Observations

The majority of the sensors utilized for earth observations are designed for operation at 300 to 500-nautical mile altitudes. In order to achieve comparable resolution from geosynchronous altitudes, these sensors must operate in conjunction with a 1- to 2-meter telescope. The resulting instantaneous field of view is significantly less than the earth subtended angle of 17 degrees. A scan pattern must be included in the control concept of the telescope.

Although some meteorology sensors will have wide fields of view and "monitor" the entire visible region of the earth continuously, some of the related sensors will require the collimation of the telescope. Almost all earth resource sensors will require the telescope to achieve adequate resolution. Therefore, these two functions are candidates for grouping on a platform.

As mentioned previously, the observation function must be accomplished on a global basis. Therefore, at least four integrated earth observation platforms are required.

The earth observation functions/platforms are not groupable with the astro-physics functions for the same reasons as the data relay functions should not be grouped with the astro-physics functions; conflicting pointing requirements and stability. Grouping the earth observation functions with data relay functions presents similar problems. Data relay mission equipment requires a relatively constant local vertical orientation within ± 0.1 degree. The high resolution earth observation sensors must be programmed through a conical angle of 8.5 degrees about nadir. Stabilities of the order of 10 arc seconds are required. Thus, two continuously conflicting pointing requirements would require mechanical coupling between comparable large masses with arc second accuracy. This is not considered a practical design.

In addition, only one earth observation platform is required for each global region. Grouping this platform with one data relay platform in a region would still result in two unique designs per region, a data relay platform and a combined data relay-earth observation platform. It would appear to be more practical and economical to develop two identical data relay platforms for a region and a separate earth observation platform concept that would be the same for all four global regions.

DEVELOPMENTAL PAYLOADS

The continuously evolving nature of technology and system concepts makes it imperative that advanced planning include provisions for the identification and development of these technologies. Several classes of satellites in the baseline traffic model reflect this foresight. Included in this category are the following:

Type	Generalized Format
Applications Technology Satellites (ATS)	Evaluation of advanced communication, sensor, and system concepts
Small Applications Technology Satellites (SATS)	Evaluation of advanced solar, stellar, and earth observation sensors and sensing techniques
System Test Satellites (STS)	Evaluation of advanced communication system concepts
Prototype Synchronous Earth Observation Satellites	Evaluation of advanced meteorology and earth resource technology, sensors, and sensing techniques

The primary characteristics of all of the satellites in the developmental payloads category is that neither the mission equipment nor the performance parameters can be identified for the satellites proposed for the shuttle era. Obviously it is impossible to attempt to group developmental payload mission equipment under such circumstances. But even if the mission equipment were known or representative examples selected, it is doubtful if grouping would be reasonable. The nature of this class of payloads is essentially experimental. Relatively frequent modification, adjustment, and replacement of equipment will probably be required. Grouping this type of equipment with operational equipment such as data relay satellites that the world population has become dependent upon in their daily lives is not a preferred mode. The potential risk of interrupting nominal operations with experimental/development concepts is unacceptable.

Grouping of developmental payloads is not considered in the derivation of platform concepts. Only operational payloads will influence the platform configurations. The option could exist to adapt developmental payloads, when they are adequately defined, to be compatible with the platform concepts. Because the platforms must include on-orbit servicing capability, it may be feasible to utilize the basic platform structures and subsystems as an orbital evaluation facility. Developmental equipment could be cycled through the facility by on-orbit servicing techniques. Only mission equipment would require delivery/retrieval rather than an entire satellite.

SUMMARY

The above functional and operational analyses of the requirements of the satellites in the baseline traffic model indicated certain constraints on the grouping of mission equipment. Table 5.2-1 presents a summary of the minimum number of platforms required to fulfill the objectives of the baseline traffic model. (Consideration of equipment constraints including weight, power, volume, and electromagnetic interference will increase the number of astro-physics platforms to one each of four different types.) The development satellites listed in the baseline traffic model that are considered non-groupable add an additional 32 elements to the geosynchronous inventory.

Table 5.2-1. Minimum Platform Inventory

Functional/Operational Constraints	Types	Rationale	Inventory
Global coverage	1	Line-of-sight constraints Geographical dissimilarities	4
Sun outage	-	Disrupted communications	4
Low orbit satellite data relay	1	Longitudinal separation Single Conus contact	3
Orientation considerations Astro-physics	1	Local vertical versus inertial orientation	4
Orientation considerations Earth observations	1	Fixed versus scanning local vertical orientation	4
Totals	4		19

5.3 GEOSYNCHRONOUS PLATFORM REQUIREMENTS

Two distinct approaches to geosynchronous platforms were followed in this study. One approach was to derive a support module or utility platform that would be common for all satellites in the inventory (single function platform). The second approach was to group satellite functions and/or equipment into a minimum number of orbital elements (multifunction platforms).

With the utility platform approach, the total number of end item elements in a geosynchronous program would remain the same; but the potential cost reduction of such a program that utilized the same support systems, which are on-orbit serviceable, could be substantial. Also, this approach could be a practical compromise between a unique customized satellite program and a world-wide integrated multifunctional platform approach. National and international political, social, and economic considerations could preclude the coordination, integration, and control of centralized orbital facilities. In addition, the costs associated with the development of complete scientific and/or exploratory satellites could be prohibitive. Development of a common support module or "test bed" or utility platform could reduce an individual program's costs such that advanced geosynchronous technology and operations could be increased and expedited.

In this section, the requirements for both single function platforms and multifunction platforms are defined. The multifunction platforms that are discussed are classified into three groups: (1) data relay, (2) TDRS, and (3) observations. The data derived in the Satellite Inventory Analysis (Section 5.1) and Mission Objectives Grouping (Section 5.2) are used in conjunction with the traffic model itself to derive platform requirements. Because of the limited definition of observational requirements for geosynchronous orbit, a representative program is synthesized.

COMMON SUPPORT MODULE

The purpose of the common support module is to provide a utility platform for each of the individual satellite mission equipment complements of the traffic model. The primary drivers of the platform are the following utilities or subsystems functions:

- Electrical power
- Pointing
- Stability
- Data rate
- Impulse/propulsion

The performance characteristics of the satellites in the traffic model for each of these functions were either extracted from current literature and study reports or approximated based upon satellites of a similar nature/configuration.

Electrical Power

Figure 5.3-1 graphically presents the power requirements of the satellite inventory. The numbers on the abscissa refer to the number of satellites of a given type that have that particular power requirement. It can be seen that almost all the satellites require 1 kilowatt or less power. Also, about 75 percent of the satellites requires 500 watts or less power. Only five satellites have power requirements approaching 10 kilowatts. Synthesis of a single system that can accommodate from 200 watts to 10 kilowatts is not practical. A more realistic approach is to synthesize a one-kilowatt system that can be readily modularized/off-loaded to provide on the order of 500 watts.

It is recognized that upon grouping of various satellite functions and equipment, the power demand will increase. Modularized power systems should also consider demands greater than 1 kilowatt. The possibility exists that the common support module for satellites can also be used as the utilities source for platforms. The concept should include 1500-watt and 2000-watt systems. Therefore, four power levels are recommended for synthesis: 500, 1000, 1500, and 2000 watts.

Pointing

Establishment of a common support module pointing requirement must reflect hardware capability. Not only must sensor characteristics be examined, but the structural configuration of the satellite must be taken into account. Sensors range from simple horizon scanners to sophisticated star trackers. Accuracies correspondingly range from tenths of a degree to a few arc seconds. Even if sensors with less than arc second accuracies were available, structural alignment tolerances and thermal flexure would preclude such accuracies at the viewing instrument. Therefore, provisions must be included in the control system for a positioning input directly from the viewing sensor.

Figure 5.3-2 illustrates the spectrum of pointing requirements. Although a horizon scanner system would be adequate for most of the earth observational satellites and all of the data relay satellites, it would be inadequate for all the rest. In the interests of commonality of equipment, and to provide margin for the on-orbit changeout of sensors (realignment tolerances), a 10 arc second pointing accuracy requirement was selected. This basic capability, coupled with direct sensor inputs, will accommodate the most stringent pointing requirements.

Stability

Examination of Figure 5.3-3 indicates that the stability requirements are established by the observational satellites. Momentum exchange devices such as reaction wheels can obtain the desired stability. As all but one of the satellites require a value of 1 $\widehat{\text{sec}}$/sec or greater stability, the baseline requirement for the common support module is this value. Derivation of the control system should consider the capability of attaining 0.1 $\widehat{\text{sec}}$/sec stability.

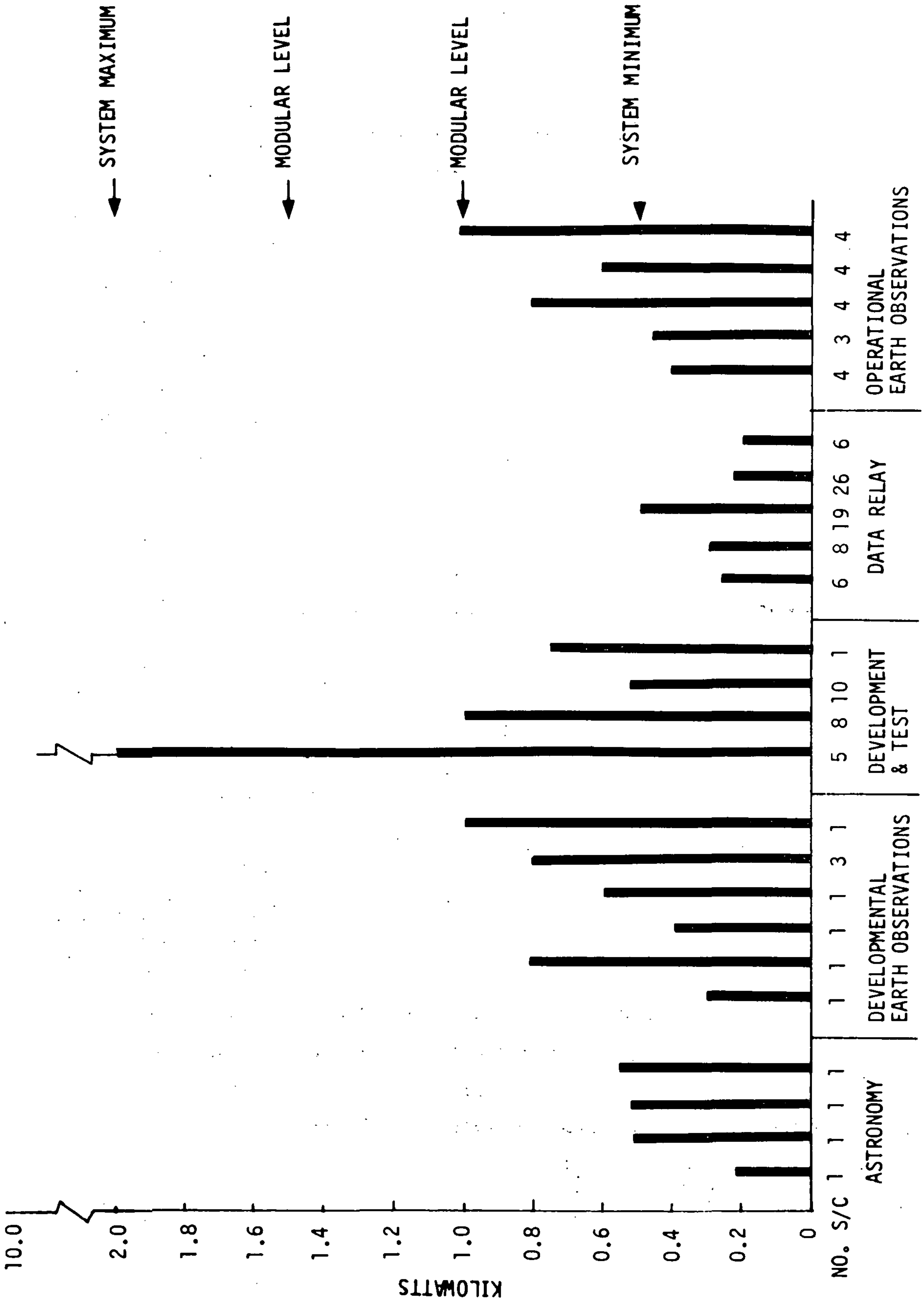

Figure 5.3-1. Geosynchronous Satellite Power Requirements

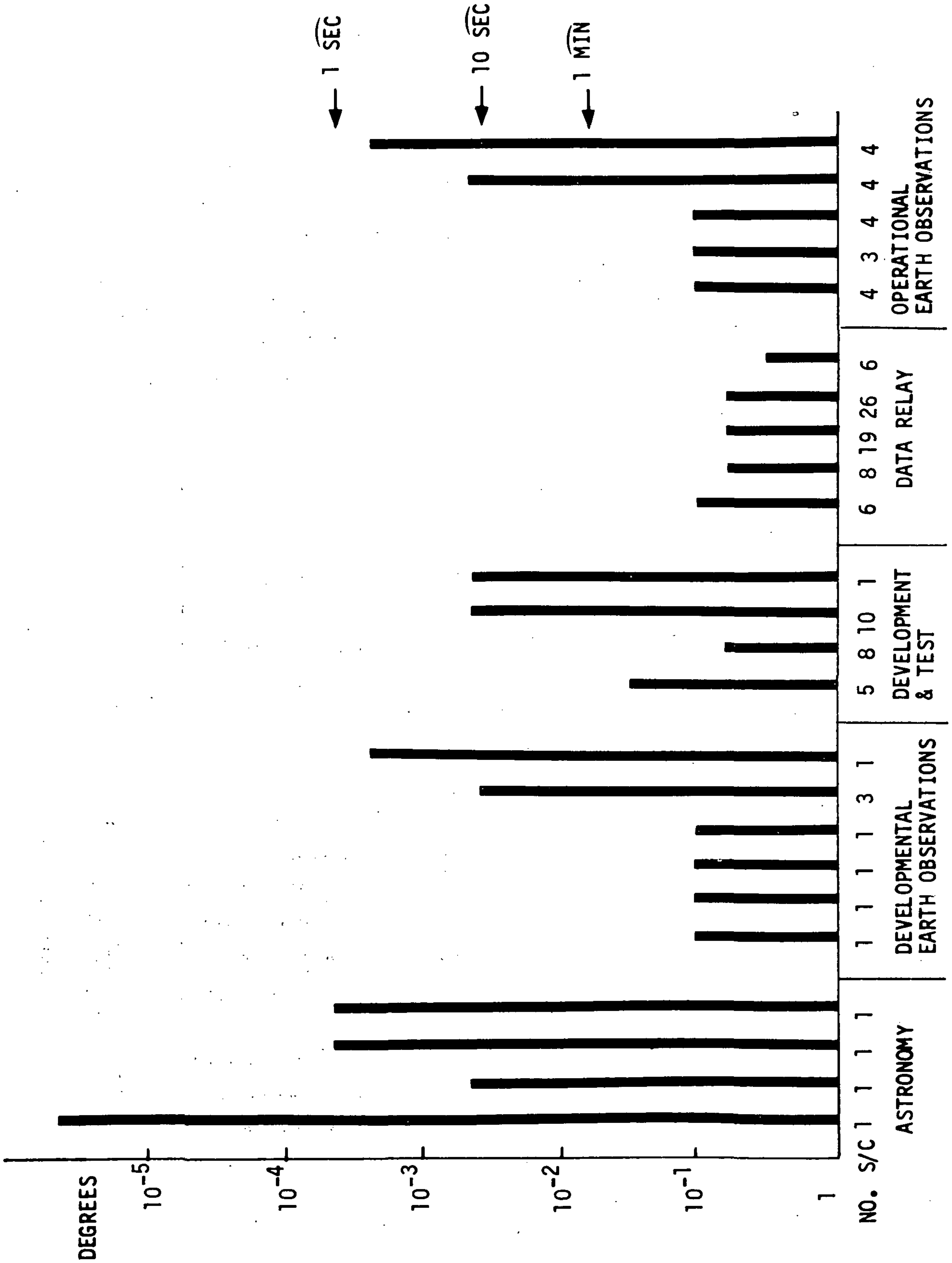

Figure 5.3-2. Geosynchronous Satellite Pointing Requirements

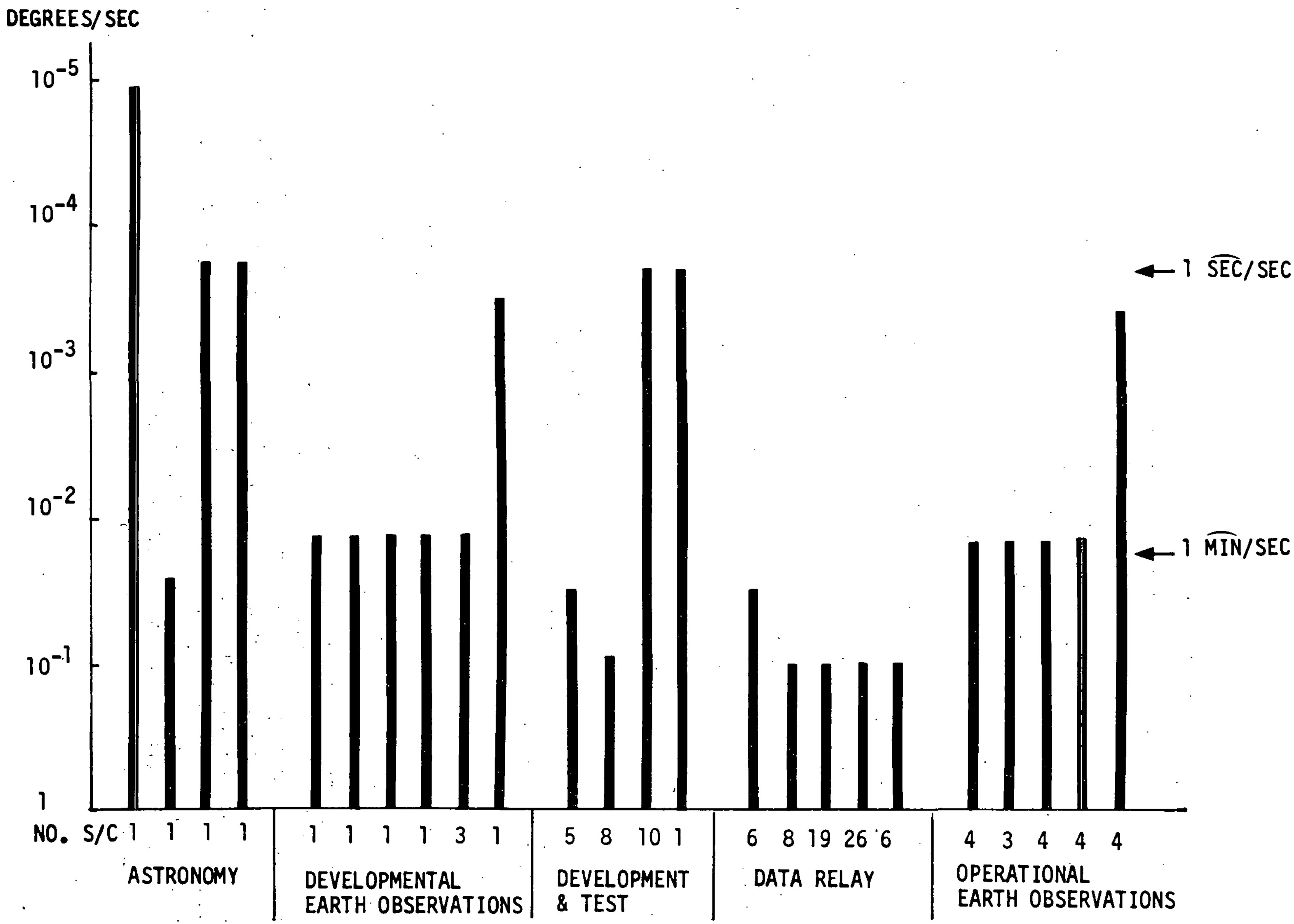

Figure 5.3-3. Geosynchronous Satellite Stability Requirements

Data Rate

The observational satellites require the transfer of large quantities of sensor data. By definition, the mission equipment of data relay satellites transfer data. Only housekeeping, telemetry and command data capability is required in the common support module of data relay satellites.

Figure 5.3-4 illustrates that the majority of the observational satellites requires data transfer rates of 50 megabits per second. This is the baseline requirement of the utility platform.

Propulsion

In establishing the propulsion requirements for the satellites, orbit insertion, apogee motor, and spinup requirements were not considered. It is assumed that all satellites will be three-axis stabilized and satellite emplacement will be accomplished by the tug logistics vehicle to within ±30 feet per second of the desired value.

Figure 5.3-5 illustrates the propellant requirements for the satellite inventory. All satellites were normalized to a hydrazine system with an I_{sp} of 220 seconds. The nominal operational lifetime of the satellites varies significantly. A unique characteristic is that, in general, the satellites requiring the largest propellant supply are planned for the shorter operational durations. The larger mass and number of required maneuvers of these satellites cause this situation.

The maximum requirement, 70 pounds, was selected as the baseline utility platform requirement. The excess capacity on the smaller satellites could conceivably extend their operational life.

Summary

The selected requirements for the satellite common support module reflect the most stringent requirements of the individual satellites within the projected 1980 technology level. Table 5.3-1 summarizes the values.

A common support module with the capabilities listed in Table 5.3-1 could support the mission equipment of all the satellites except a couple of developmental ones that require power levels of 10 kilowatts. Admittedly, in some cases, the performance margin is great. However, it is believed that the cost benefits that would accrue from commonality of hardware and potential extension of mission duration will warrant the over-design. If subsequent more detailed studies that include satellites in non-geosynchronous orbits indicate multiple plateaus of capability are more desirable, the basic concept of a common support module-utility platform would still be valid.

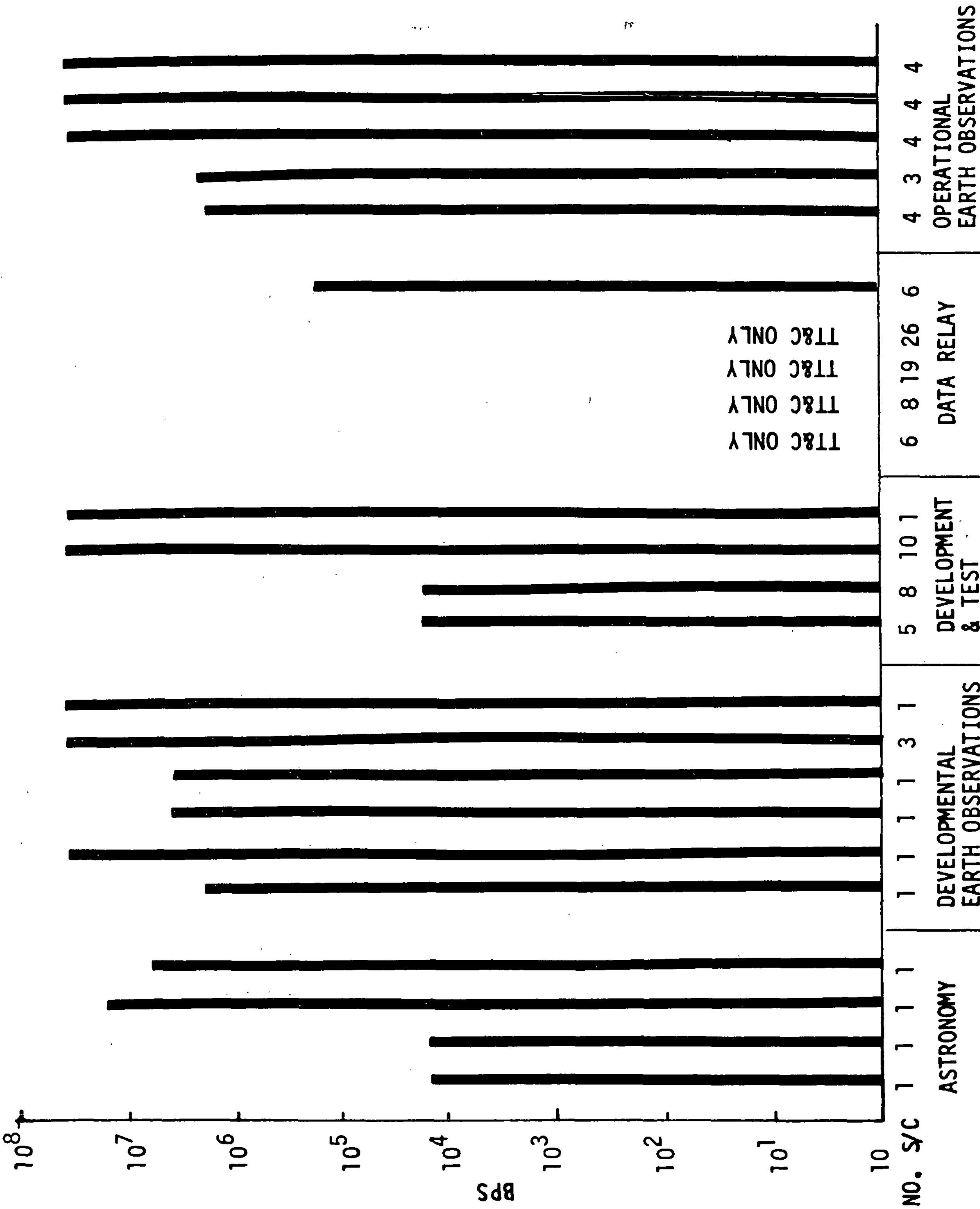

Figure 5.3-4. Geosynchronous Satellite Data Rate Requirements

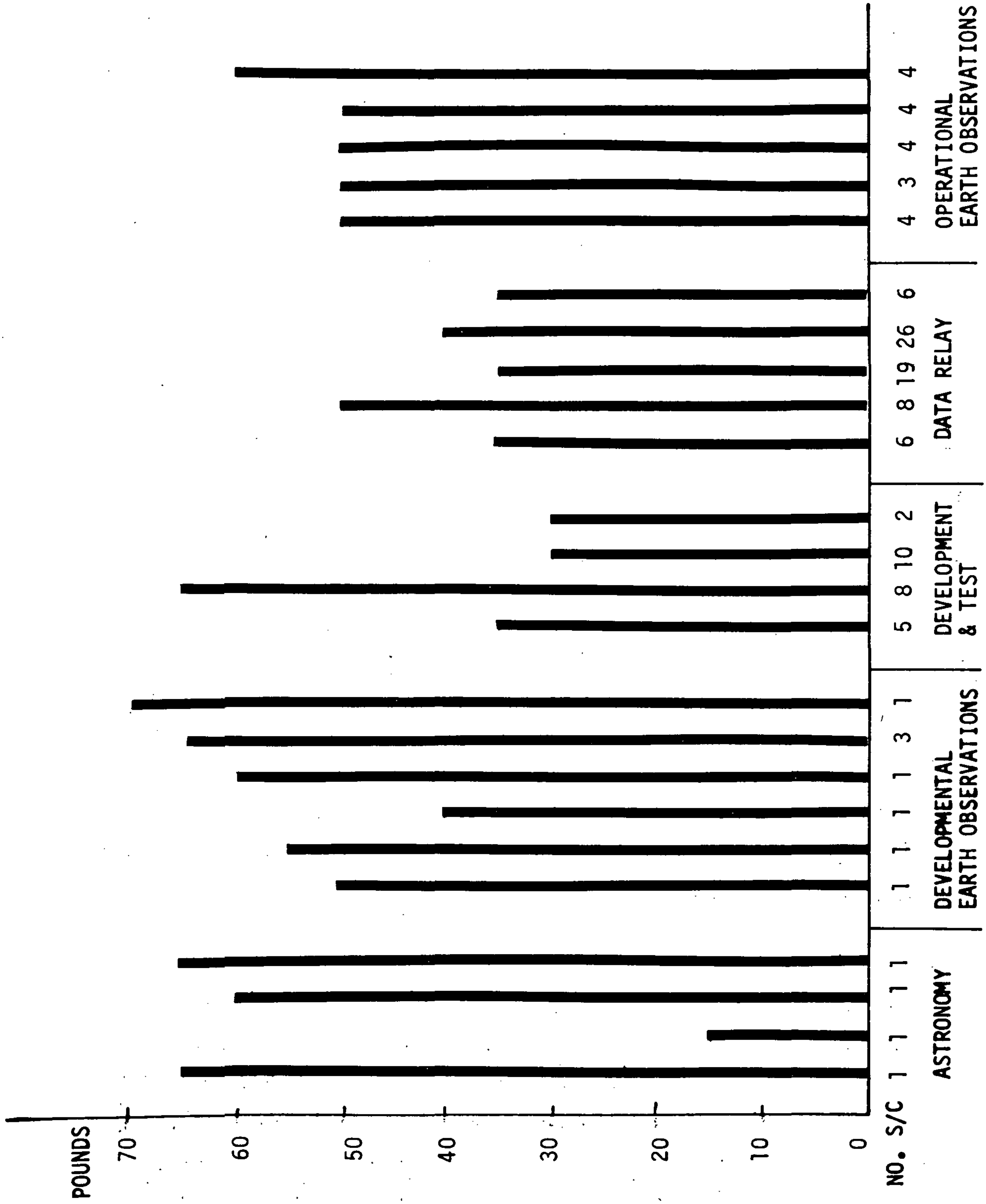

Figure 5.3-5. Geosynchronous Satellite RCS Propellant Requirements

Table 5.3-1. Common Support Module Subsystem Requirements

Function	Requirement	Comment
Power	2 kilowatts	500, 1 kw and 1.5 kw plateaus
Pointing	10 arc seconds	Provisions for sensor input
Stability	1 arc second/sec	0.1 arc sec/sec desired
Data rate	50 megabits/sec	Sensor and housekeeping
Propulsion	70 lb hydrazine	I_{sp} of 220 seconds

DATA RELAY PLATFORMS

In the baseline traffic model there are four types of data relay satellites defined: (1) U.S. domestic communications, (2) foreign domestic communications, (3) international communications, and (4) navigation and traffic control communications. The mission objectives grouping analysis (Section 5.2) indicated that the functions of the four types of data relay satellites could be grouped into four global regions with two identical platforms in each region. In this section, the operational and system level requirements of these platforms are defined.

<u>Pacific Ocean - Region I</u>

In order to minimize the required number of platforms, the idealized location of the Region I platform was selected as 172 degrees east longitude. Figure 5.3-6 illustrates the geographical coverage within communication line of sight for this platform location. Trans-Pacific Comsat and Pacific Ocean navigation and traffic control functions are readily accommodated from the Region I platform.

It is practical to provide Domsat service to some areas in the western sector of the region; namely, Japan, Southeast Asia, Philippines, Indonesia, Australia, and New Zealand. However, the domestic communication requirements for the East Asian-Australian sector of the world are not uniquely identified in the traffic model. A total of five 12-channel satellites was defined for serving Domsat functions for all of Asia and Australia. It was assumed that two of the satellites were for countries at the eastern extremity of Asia and Australia. Thus, the Domsat requirements for each Region I platform are 12 channels.

Trans-Pacific Comsat requirements were delineated in the traffic model as two 12-channel satellites. Each data relay platform must provide 12 channels for this function.

Trans-Pacific navigation and traffic control was also stipulated in the traffic model. Although only one satellite was specified for the region, it was not considered practical to subdivide the required capability between two platforms. The delta hardware and costs between half and full baseline

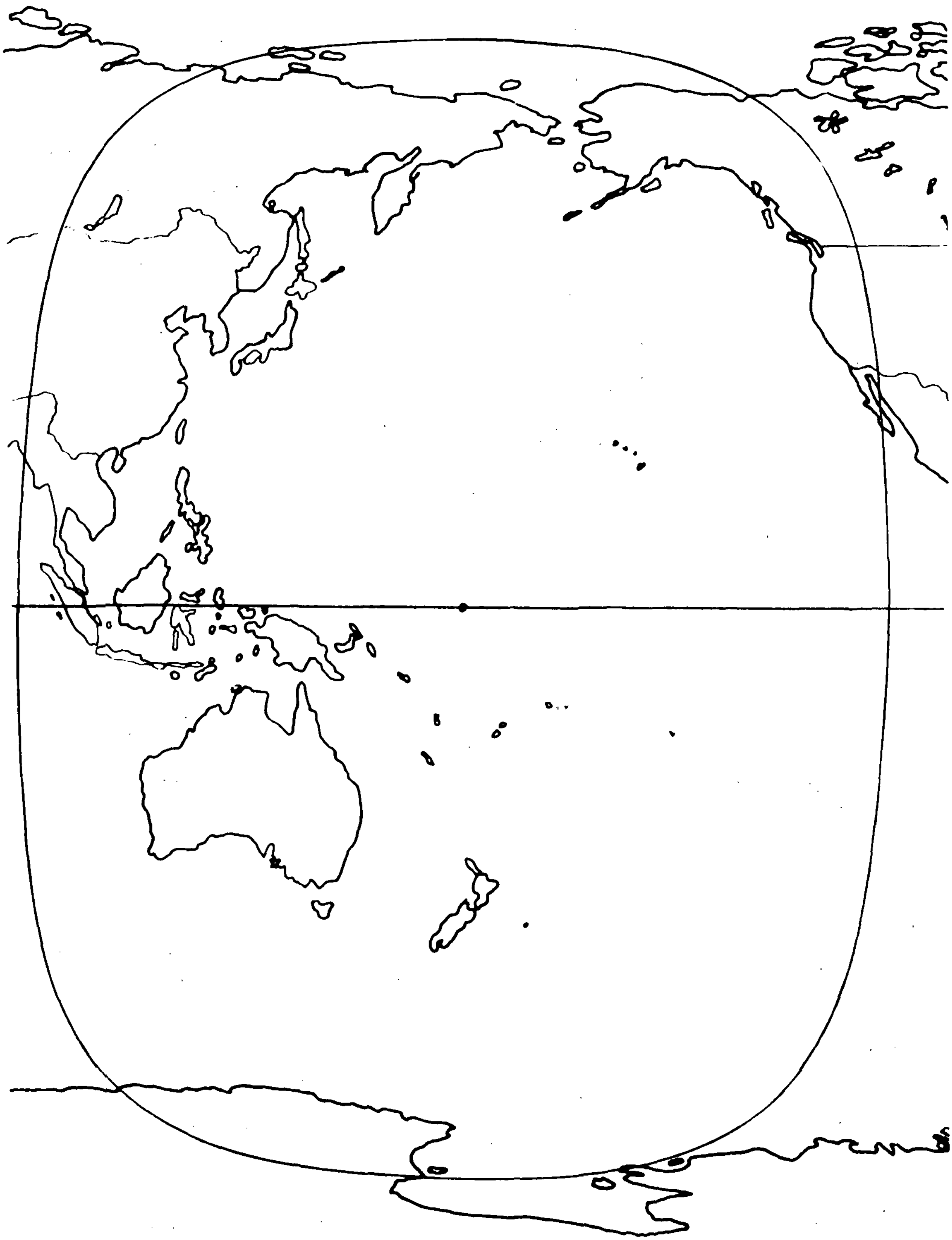

Figure 5.3-6. Region I Terrestrial Coverage

navigation and control capability on a platform were insignificant. Therefore, each platform duplicates the basic capability of the navigation and traffic control satellite in the traffic model. This same rationale applies to all four global regions. Therefore, the platform concept provides twice the navigation and traffic control capability stipulated in the traffic model.

The Region I requirements per platform are summarized in Table 5.3-2.

Table 5.3-2. Region I Data Relay Platform Requirements

Function	Locale	Channels
Domsat	East Asia/Australia	12
Comsat	Trans-Pacific	12
Navigation and traffic control	Pacific Ocean	250 kbps data rate

Asia/Africa - Region II

Region II (Figure 5.3-7) encompasses almost all of Asia, Africa, the Middle East, and most of Europe. The Domsat requirements specified in the traffic model were equivalent to five 12-channel satellites. As mentioned previously, two of these satellites were designated as servicing the eastern extremity of Asia and Australia. Therefore, only three 12-channel satellites are required to serve the central Asia area.

Although seven Domsat satellites were identified in the global sector of Europe and Africa, it was decided that all seven would be utilized to service Europe. Therefore, African Domsat requirements were assumed to be included in the three satellites in the Region II area.

Each platform in Region II is required to provide 18 channels for Domsat use. Areas to be included in the Domsat service include Africa, Middle East, central and eastern Russia, China, and India.

The traffic model identified two 12-channel satellites for Comsat purposes in this global sector. Comsat service should include links between Europe, Africa, Australia, Japan, and all countries within these regional extremes. Each Region II platform is required to provide 12 channels for Comsat purposes.

Navigation and traffic control was also specified for this global sector in the traffic model. For reasons delineated previously (sun outage), each platform in Region II is required to provide navigation and traffic control services. Also, as mentioned above, it is recommended that capability equivalent to the satellite capability be incorporated in each platform.

Table 5.3-3 summarizes the requirements of each Region II platform.

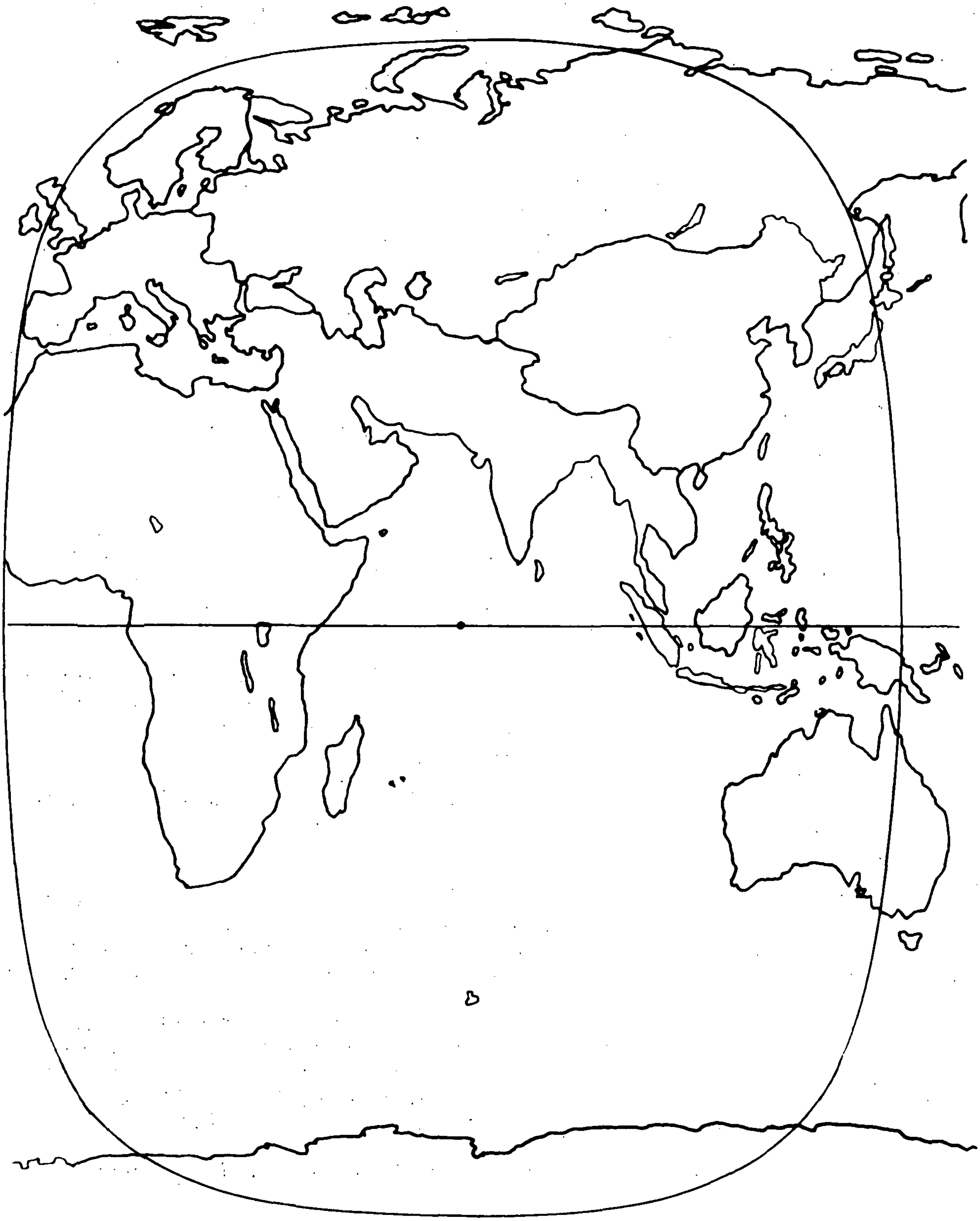

Figure 5.3-7. Region II Terrestrial Coverage

Table 5.3-3. Region II Data Relay Platform Requirements

Function	Locale	Channels
Domsat	Africa, Middle East, Central/ Eastern Russia, China, India	18
Comsat	Europe, Africa, Asia, Australia	12
Navigation and traffic control	Middle East, Russia, Asia, Indian Ocean, Africa	250 kbps data rate

Europe/Africa - Region III

As illustrated in Figure 5.3-8, Region III encompasses Europe, Middle East, Africa, South America, and portions of Asia and North America. Seven 12-channel Domsat satellites were identified in the traffic model for this global area. It is assumed that all seven satellites are used for European domestic services. Africa and the Middle East domestic needs are included in Region II platform requirements. South American requirements are met with Region IV platforms.

Four 12-channel Comsat satellites were defined in the traffic model for servicing this area. Communication links between South America, Europe, Africa, Middle East, and parts of Asia and North America must be provided. Each platform in Region III must provide 24 channels for Comsat functions.

Navigation and traffic control functions for the North and South Atlantic, Africa, Mediterranean Sea, North Sea, and Europe must also be provided by the Region III platforms. Although only one navigation and traffic control satellite in this region was identified in the traffic model, it is believed that air and ship traffic in this region will require at least the equivalent capability of two satellites. As the baseline concept for each regional platform includes the capability of a single navigation and traffic control satellite, the proposed expanded traffic demand can be accommodated.

Table 5.3-4 summarizes the requirements for each data relay platform in Region III.

Table 5.3-4. Region III Data Relay Platform Requirements

Function	Locale	Channels
Domsat	Europe	42
Comsat	U.S., Canada, South America, Europe, Africa, Middle East, India	24
Navigation and traffic control	Atlantic Ocean, North Sea, Mediterranean Sea, Europe, Africa	250 kbps data rate

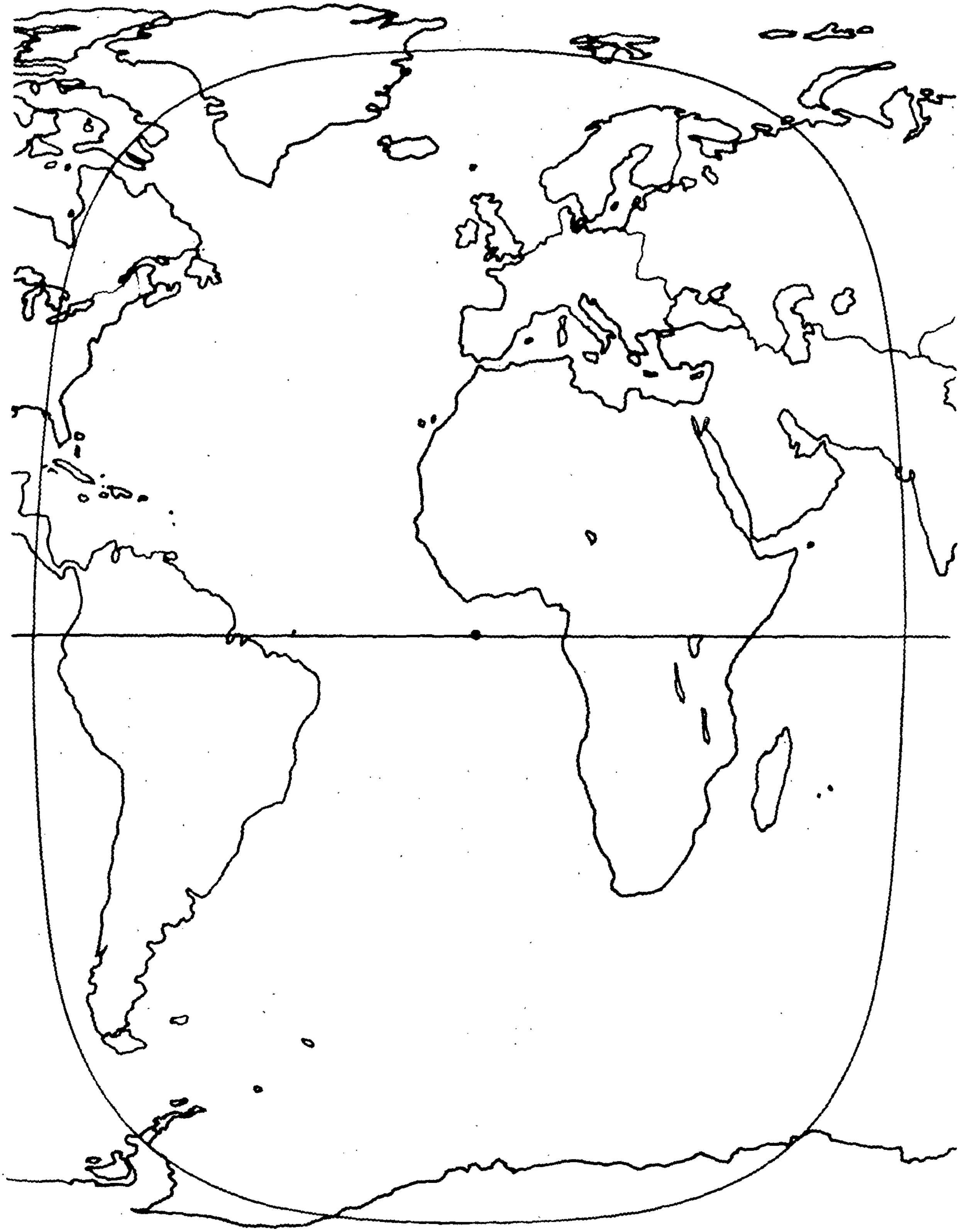

Figure 5.3-8. Region III Terrestrial Coverage

Western Hemisphere - Region IV

The satellite inventory analysis (Section 5.1) indicated that the U.S. Domsats had the capability of relaying 24 channels of data. In the shuttle era, a total of 10 satellites are considered to be in continual operation. Therefore, 240 channels or 120 channels per platform are required to serve U.S. domestic communication needs. Alaskan and Hawaiian service is included in the 240 channels.

Four 12-channel satellites were identified for foreign domestic service in the western hemisphere. It was assumed that 12 of the channels were for Canadian use, 12 for Central American and 24 for South American.

Navigation and traffic control functions for the Pacific Ocean were stipulated in the traffic model. However, it is impossible to obtain total coverage of the Pacific Ocean from one geosynchronous platform. The geographical coverage of Region IV platforms is illustrated in Figure 5.3-9. Both the east and southeast sectors of the Pacific Ocean are covered from these platforms serving the western hemisphere. Thus Region IV platforms, coupled with Region I platforms, provide complete coverage. The concept can also be used for traffic control throughout all sectors encompassed within the mask angle of Region IV platforms.

International or Comsat communications between countries in the western hemisphere were not included in the traffic model. A total of 12 channels were arbitrarily allocated to this function.

The total communication requirements for each Region IV data relay platform are summarized in Table 5.3-5.

Table 5.3-5. Region IV Data Relay Platform Requirements

Function	Locale	Channels
Domsat	United States Canada Central America South America	120 6 6 12 144
Comsat	Western Hemisphere	6
Navigation and traffic control	Eastern and Southeastern Pacific	250 kbps data rate

System Requirements

The system level requirements for all of the data relay platforms are the same. They pertain to pointing/stability, stationkeeping, and mission duration. None of the requirements impose stringent design requirements on the platform.

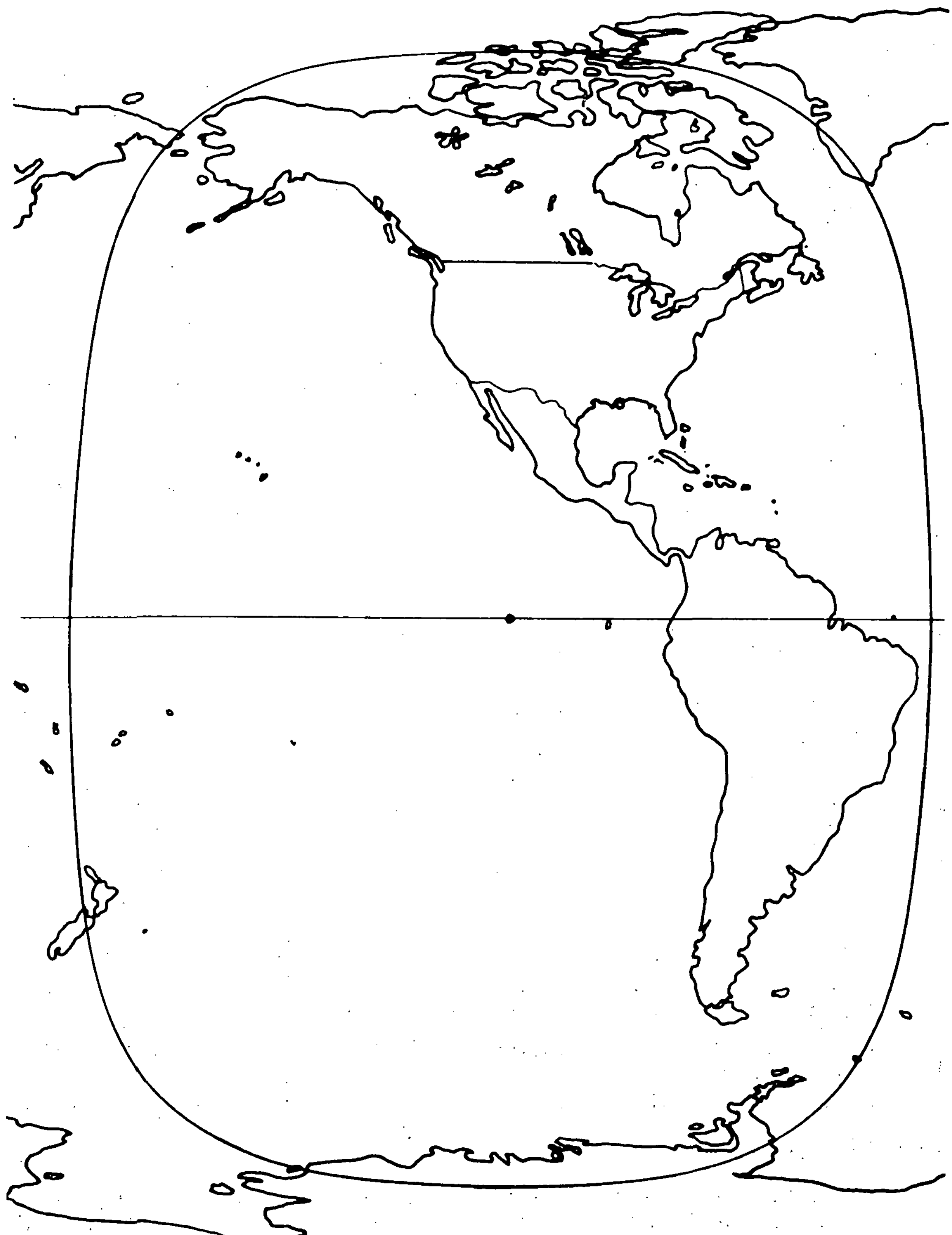

Figure 5.3-9. Region IV Terrestrial Coverage

Pointing/Stability

The selected ground station and platform antennas directly affect pointing/stability requirements placed upon the platforms. If the platforms have continuously tracking antennas, then requirements of the order of degrees could be tolerated. However, the complexity of continuously tracking antennas is not warranted; stabilities of tenths of a degree can readily be attained.

Fixed antennas do result in degradation of performance as a function of misalignment between the boresight of the platform and ground station antennas; but the degradation is not a step function as with most sensors. Normally, communication link margin calculations are based upon the half-power or -3 dB level of the antenna signal pattern. Depending upon the signal margin of the link, acceptable operations can be conducted well outside the 3 dB beam intercept. Operations at -6 dB and -12 dB are common. Thus, from a systems level standpoint, there are no stringent pointing/stability requirements. Nominal values of 0.1 degree pointing accuracy and 0.1 degree/second stability are selected as the baseline requirements. This will ensure that the desired ground station will always be within the -6 dB contour of the platform antenna beam.

Stationkeeping

East-west stationkeeping is mandatory. Depending upon the specific desired longitudinal location, if this type of stationkeeping were not provided, platform drift of up to 180 degrees in longitude would occur. Obviously, the platform would not service its intended global region. The rate of east-west drift is nominally 0.02 degree/day. The platform must include provisions for a periodic delta V to compensate for this drift. The yearly delta-V budget required to offset potential east-west drift is 7 feet per second per year.

North-south stationkeeping could impose a significant design constraint on the platforms. A yearly delta V of 150 feet per second would be required to compensate for a 0.9 degree-per-year drift rate. Slewing antennas on the platform and at the ground station can compensate for north-south drift. From a design standpoint, the steerable antenna is the preferred approach. However, an integrated total system (ground station, platform, logistics) economic analysis could show that north-south stationkeeping is preferred. Ground station sites would be significantly less expensive if tracking antennas are not required; but platforms sized for up to 10 years of this type of stationkeeping would be a marginal design because of the large propellant requirement. It appears that the trade to be conducted in a future study is to compare ground system costs with platform costs as a function of logistics resupply of propellants to data relay platforms.

For purpose of this study, only east-west stationkeeping is required. In addition, north-south stationkeeping capability that could be accomplished with the synthesized configuration is to be defined.

Mission Duration

The on-orbit servicing concept proposed for the platforms in this study essentially results in an open-ended mission duration. All equipment modules, including those with expendables, are to be designed such that they can either be replenished or replaced. However, in order to size various equipment, a nominal ten-year mission duration, which is comparable to advanced Domsat satellites, is selected as the baseline requirement for data relay platforms. This requirement will eliminate any constraints on servicing programmatic options.

Table 5.3-6 summarizes the system requirements for data relay platforms.

Table 5.3-6. System Requirements

Function	Requirement
Pointing	0.1 degree
Stability	0.1 degree/second
East-west stationkeeping	7 feet/second/year
North-south stationkeeping	Evaluate capability only
Nominal mission duration	10 years

TRACKING AND DATA RELAY PLATFORM REQUIREMENTS

The mission objectives grouping analysis (Section 5.2) indicated unique operational requirements for the tracking and data relay system platform (TDRS). In essence, the TDRS "platform" is functionally the same as the TDRS satellite. Configurations of the two are quite different. Instead of an expendable satellite the platform must facilitate on-orbit servicing. Instead of a customized design approach, commonality of hardware between the TDRS platform and other platforms synthesized in this study will be maximized. Therefore, the only unique requirements for the TDRS platform, as compared to the satellite, pertain to the configuration.

NASA Phase B TDRS contractual studies are currently in progress, and various communication system options are being evaluated. The subsequently presented data are intended to be representative of the TDRS. The concepts presented should not be construed to be the optimum or preferred configuration.

Operational Requirements

The TDRS shall consist of two geosynchronous platforms spaced approximately 130 degrees apart. A third platform shall be stationed approximately half way between the platforms. The third platform shall be considered an on-orbit spare and have the capability to transfer to the orbital position of either of the other two platforms.

The baseline positions of the two operational TDRS platforms shall be 11 degrees and 141 degrees west longitude. This positioning will permit compliance with the primary TDRS requirement of being able to communicate directly with

either or both platforms directly from one ground station. In the selected case the ground station could be Rosman, North Carolina.

System Requirements

Each TDRS platform shall be capable of relaying data between a ground station and low earth orbiting spacecraft. Up to 20 simultaneous low data rates (10K bits/second) must be accommodated by each platform. Two 50 megabits/second data rates must also be relayed by each TDRS platform. Figure 5.3-10 shows a summary of service links. The frequency plan is shown in Figure 5.3-11. Objective communication link parameters between TDRS platform and low earth orbiting satellites that are used in sizing the TDRS mission equipment are listed in Table 5.3-7. Pertinent TDRS to ground station link data are summarized in Table 5.3-8.

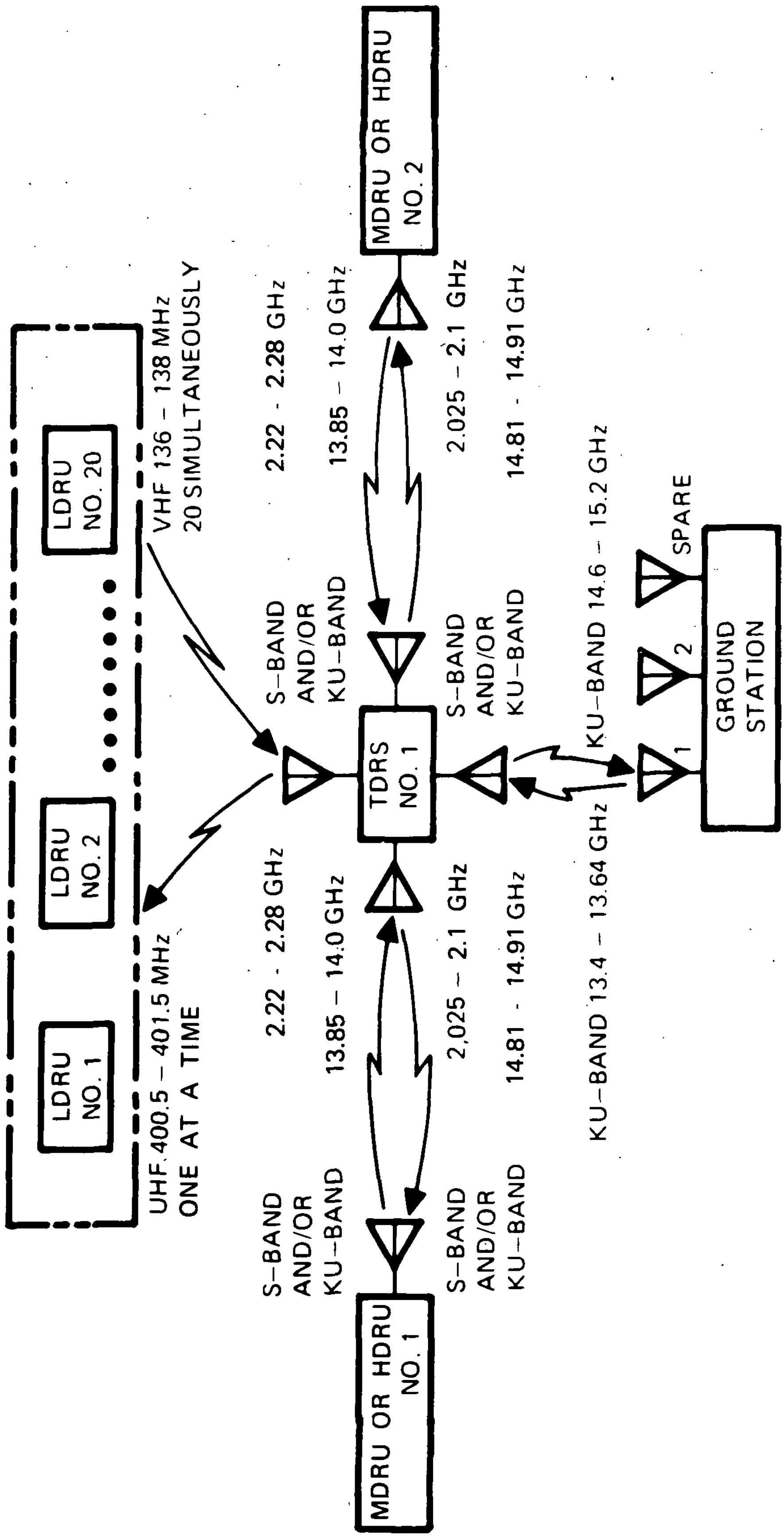

Figure 5.3-10. Telecommunications Service

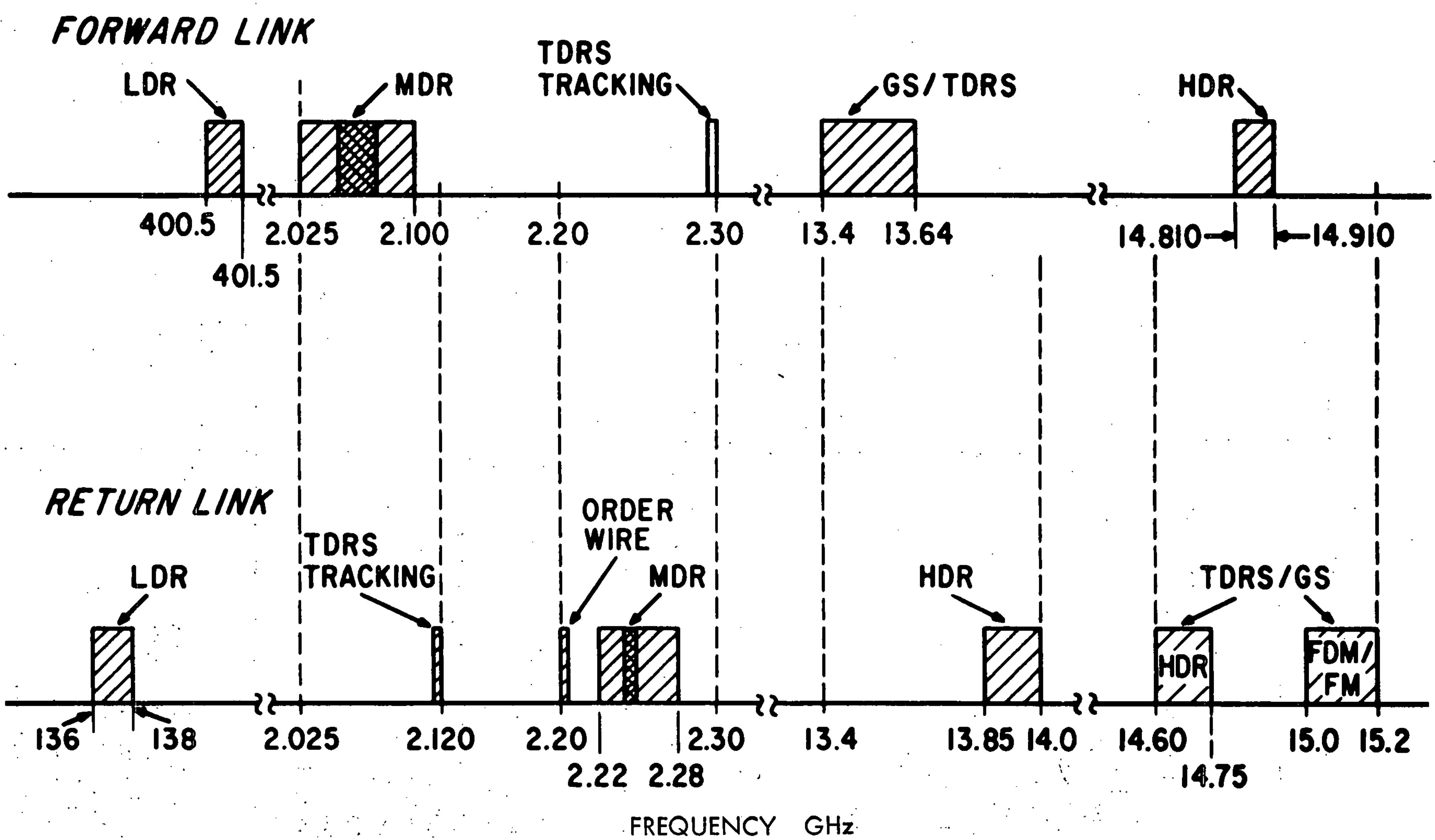

Figure 5.3-11. TDRS Telecommunication Frequency Plan

Table 5.3-7. TDRS-Spacecraft Link Characteristics

	VHF/UHF	Ku-Band
Forward Link (TDRS to Spacecraft)		
Transmission frequency	400 to 401.5 MHz	13.4 to 14.9 GHz
EIRP		52 dBw
Voice	30 dBw	
Digital	27 dBw	
Modulation		FM and PM
Voice	FM or PM	
Command	PM	
Return Link (Spacecraft to TDRS)		
Transmission frequency	136 to 138 MHz	13.8 to 15.2 GHz
Noise figure	6 dB	6 dB
Bandwidth	2 MHz	200 MHz
Antennas	16 dB end fire array; 26-degree cross-polarized	2 to 5 ft parabolic dishes; RH circular polarization

Table 5.3-8. TDRS-Ground Station Link Characteristics

	Ku-Band	
Forward Link (Ground Station to TDRS)		
Transmission frequency	13.4 to 13.64 MHz	
Bandwidth	240 MHz	
TDRS system noise temperature (degrees K)	33.6 dB	
Modulation	FDM/FM	
Required CNR	22.8 dB	
Antenna		
Type	Paraboloid/Cassegrain	
Beamwidth	≈0.8 degree	
Gain	46.4 dBi	
	FDM/FM	HDR
Return Link (TDRS to Ground Station)		
Transmission frequency	15.0 to 15.2 MHz	14.6 to 14.75 MHz
Channel bandwidth	250 MHz	150 MHz
TDRS system noise temp (deg K)	25.2 dB	
Modulation		
FDM/FM/FDM		
Required CNR	0 dB	17.1 dB
Antenna gain	47.1 dBi	47.1 dBi

OBSERVATIONAL PLATFORM REQUIREMENTS

Scientific Objectives

Definition of astronomy, physics, and earth sciences payloads in the baseline traffic model was insufficient to establish platform requirements or potential groupings. The NASA Blue Book, Space Station data, and open literature were researched to determine applicable operations. In consultation with Rockwell scientists, several unique or favorable advantages for the synchronous equatorial orbit were identified for various payload objectives. The unique advantages consist of:

1. View same earth region at all times
2. View entire earth hemisphere
3. Essentially communicate with the same ground station at all times
4. Constant specific relationship to earth global particles and field environments

Other advantages accrue from the relatively high altitude which reduces earth influence. These considerations are identified in Table 5.3-9 for earth disciplinary areas from which the candidates were selected.

A brief description of observational payloads was prepared from the baseline traffic model for geosynchronous orbit (GSO) and for low earth orbit payloads in the astronomy, physics, and earth sciences disciplines. Experiment characteristics were then reviewed with respect to the scientific value of performance at GSO. From a list of 28 candidates, 22 payloads were selected for further consideration. The description of each selected payload is as follows.

Earth Observations

In the general category of earth observations four satellites were felt to be representative of the objectives of earth sciences. These four payloads could accomplish the functions of meteorology, earth resources, and earth physics which are compatible with the synchronous equatorial regime (assuming adequate resolution and radiated power). Basic functional descriptions of these areas are:

1. Earth Observations: Although this term is used generally to cover all earth directed observations, it is here used more specifically to include the functions of earth geometry definition, description of surface characteristics, and other geophysical investigations.
2. Meteorology: Investigation of atmospheric phenomena such as thunderstorm activity, monitoring and prediction of weather, and observations to evaluate the effect of weather on earth resources.

Table 5.3-9. Scientific Benefits at Geosynchronous Orbit

Advantage (Over LEO)	Flight Mode	Benefitting Observation							
		Earth Resources	Earth Sciences	Solar Astronomy	Stellar Astronomy	Plasma Physics	Magnetospheric Physics	Hi-Energy Physics	Radio Astronomy
1. View same earth region at all times	Local Vertical	X	X				X		
2. View entire earth hemisphere at once	Local Vertical	X	X				X		
3. Communication with same ground station at all times	Local Vertical	X	X	X	X	X	X	X	X
4. Long viewing times--sun, stars, and planets	Inertial/Pointing			X	X			X	X
5. Local environment levels	Inertial or Local Vertical					X		X	
6. Relationship to global particle and field environments	Inertial or Local Vertical					X	X	X	
7. Quiet radio environment	Inertial/Pointing					X			X
8. Lower plasma cut-off frequency	Inertial/Pointing					X			X
9. Lower geomagnetic cut-off energy	Inertial/Pointing			X				X	
10. Avoid earth interference or influence	Inertial/Pointing			X	X	X		X	

3. Earth Physics: Atmospheric physics investigation through measurement of atmospheric altitude profiles or aurora and airglow aeronomy measurements.

4. Earth Resources: Recognition and identification of natural resources including ground moisture, mineral deposits, ocean life, and crop conditions.

Solar Astronomy

Solar information acquisition is also typified by four satellites, designed to improve knowledge of the stars as well as to increase understanding of the sun's influence on the earth.

1. Solar Orbiting Observatory: Solar ultraviolet and X-ray spectra and solar images (spectroheliograms) of spectral phenomena in high activity areas.

2. Photoheliograph: Magnetic field measurement and solar granulation structure profiles with white light, hydrogen-alpha, etc., observations.

3. Coronagraph: Research of phenomena of the inner and outer solar coronas.

4. Solar X-Ray Telescope: Grazing incidence observations of solar activity and phenomena.

Stellar Astronomy

Five satellites were chosen to encompass the objectives of increased knowledge of astronomical objects and the nature of the universe.

1. Optical Interferometer: Infrared studies of the nature and structure of gas and dust clouds, cool (class M) stars, and surveys of galactic or extragalactic IR sources.

2. Narrow Field Ultraviolet: UV imaging and spectrometry of nebulae, star clusters, and galaxies for examination of emission gas systems, spiral structure of galaxies, stellar evolutionary sequences, and interstellar dust particles.

3. Low-Energy Stellar X-Ray: High spatial and spectral resolution for correlation with UV observations, and investigation of X-ray sources in the medium energy range.

4. X-Ray Spectrometry/Polarimetry: Narrow-band investigation of super nova remnants, exploding galaxies, etc., in the high-energy range; measurement of flux and density.

5. X-Ray Low Background: High resolution of high-energy gamma ray sources to measure flux and spectra.

Plasma and Magnetospheric Physics

Six payload groups were selected for determination of the processes that are involved with the spatial and temporal plasma conditions of the magnetosphere.

1. Cometary Physics: Determination of the mechanism responsible for observed radicals and ions in comet molecular and atomic emission.

2. Meteoroids: Information on mass, velocity, composition and origin, to improve understanding of extraterrestrial objects, and establish more precise requirements for spacecraft protective design.

3. Magnetospheric Science: Study of chemical and energy processes of the thermosphere and of the phenomena of the magnetospheric substorm and auroral precipitation.

4. Wake Perturbations: Exploration of perturbation of ambient magnetospheric plasma around the spacecraft to avoid or correct for spurious effects.

5. VLF Wave-Particle Interactions: Observations of whistler-mode wave-induced phenomena to increase understanding of wave-particle interaction and potential magnetospheric plasma control.

6. Electron-Ion Beam: Study of plasma processes and magnetospheric configuration by electron and ion beam propagation and detection.

High Energy Physics

The study of high-energy cosmic radiation would extend knowledge of the universe such as its age and origin, and increase understanding of astrophysical phenomena such as the mechanisms responsible for various elements, and matter and magnetic field distributions. Two payloads were selected for representative coverage.

1. Nucleonic Antimatter: Estimation of the existence of antimatter bodies through the search and potential observation of negatively charged nuclei (especially those containing more than one nucleon) in primary cosmic rays.

2. Extra-Heavy Nuclei: Investigation of very high charge (extremely heavy) components of cosmic rays; gather data on the source and propagation mechanisms of these elements.

Radio Astronomy

The objectives for the study of low-frequency emissions include measuring of flux densities, mapping of sources, and recording of variations from selected sources. One payload was selected as a suitable representative.

Kilometer Wave Radio Telescope: Provide resolution and directional discrimination to measure flux densities and map cosmic noise background.

The specific GSO benefits of each payload are summarized in Table 5.3-10.

Compatibility Grouping Criteria

In considering grouping of payloads for integration into platforms, compatible requirements must be applied to ensure the most flexibility in combining payloads. Three levels of compatibility were identified, plus incompatibility, consisting of the following:

1. Common target or parameter
2. No interference
3. Time-sharing required
4. Incompatible

A matrix of the 22 candidate payloads, Table 5.3-11, defines the compatibility characteristics of each pair. In each case, the characteristics were considered at a gross level, including compatible observed targets, potential equipment interference, varied pointing or attitude requirements, etc. Based upon an analysis of the matrix, Table 5.3-12 was prepared to identify eight compatible groups. This summary also identifies payloads which would not interfere with the group, or which could be time-shared.

Table 5.3-10. Payloads Benefiting from Geosynchronous Orbit

No.	Payload Description	Same Region	Entire Hemisphere	Ground Station	Long View'g Stars/Planets	Long View'g Sun	Local Environment	Global Field	Radio Environment	Plasma Cut-Off	Magnetic Cut-Off	Earth Interference
1	Synchronous earth observations	X	X	X	X							
2	Synchronous meteorology	X	X	X								
3	Synchronous earth physics	X		X	X			X				
4	Synchronous earth resources	X	X	X	X							
5	Solar orbiting pair (A)			X		X					X	X
6	Optical interferometer			X	X							
7	Photoheliography			X		X						
8	Coronagraph			X		X						
9	Narrow-field ultraviolet			X	X							X
10	Low-energy stellar X-ray telescope			X	X							X
11	X-ray spectrometry/polarimetry			X	X							X
12	X-ray low-background stellar astronomy			X	X							X
13	Cometary physics			X			X					X
14	Meteoroids			X								X
15	Atmospheric/magnetospheric science	X	X	X				X				
16	Perturbations--wake			X			X	X				
17	VLF wave--Partical interactions			X			X		X	X		
18	Electron/ion beam			X			X					
19	Nucleonic anti-matter			X	X			X			X	X
20	Extra-heavy nuclei			X	X		X	X			X	
21	Solar X-ray telescope			X		X	X					X
22	Explorer kilometer wave radio telescope			X	X				X	X		

Table 5.3-11. Science Payloads Compatibility

Payload	Payload Number																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1. Earth observations	-	1	1	1	X	X	X	X	X	X	X	X	3	2	2	3	3	3	3	3	X	X
2. Meteorology		-	1	1	X	X	X	X	X	X	X	X	3	2	2	3	3	3	3	3	X	X
3. Earth physics			-	1	X	X	X	X	X	X	X	X	2	2	1	3	3	3	3	3	X	X
4. Earth resources				-	X	X	X	X	X	X	X	X	3	2	2	3	3	3	3	3	X	X
5. Solar orbit observatory					-	3	1	1	3	3	3	3	X	2	3	X	X	X	3	3	1	X
6. Optical interferometer						-	3	3	1	2	2	2	X	2	3	X	X	X	2	2	3	X
7. Photoheliograph							-	1	3	3	3	3	X	2	3	X	X	X	X	X	1	X
8. Coronograph								-	3	3	3	3	X	2	3	X	X	X	X	X	1	X
9. Narrow-field ultraviolet									-	1	1	1	X	2	3	X	X	X	2	2	3	X
10. Low-energy stellar X-ray										-	1	1	X	2	3	X	X	X	2	2	3	X
11. X-ray spectro-polarimetry											-	1	X	2	3	X	X	X	2	2	3	X
12. X-ray low-background stellar												-	X	2	3	X	X	X	2	2	3	X
13. Cometary physics													-	2	X	1	1	1	X	X	X	X
14. Meteoroids														-	2	2	2	2	2	2	2	2
15. Atmosphere/magnetosphere															-	X	X	X	2	2	3	X
16. Wake perturbations																-	1	1	X	X	X	X
17. VLF wave-particle interaction																	-	1	X	X	X	X
18. Electron-ion beam																		-	X	X	X	X
19. Nucleonic anti-matter																			-	1	3	2
20. Extra-heavy nuclei																				-	3	2
21. Solar X-ray telescope																					-	X
22. Explorer																						-

1 = Common target or parameter
2 = No interference
3 = Time-sharing required
X = Incompatible

Table 5.3-12. Grouping Requirements Summary

Compatible Payloads					
PL No.	Common Targets	PL No.	Non-Interference	PL No.	Time-Sharing Feasible
1 2 3 4	Earth observations Meteorology Earth physics Earth resources	14 15	Meteoroids Atmosphere/magneto-sphere	13 16 17 18 19 20	Cometary physics Perturbations--wake VLF wave--particle Electron/ion beam Nucleonic anti-matter Extra-heavy nuclei
5 7 8 21	Solar orbiting pair Photoheliography Coronagraph Solar X-ray telescope	14	Meteoroids	6 9 10 11 12 15 19 20	Optical interferometer Narrow-field UV Low-energy stellar X-ray X-ray spectro-/polarimetry X-ray low-background stellar astronomy Atmosphere/magneto-sphere Nucleonic anti-matter Extra-heavy nuclei
6 9	Optical interferometer Narrow-field UV	10 11 12 14 19 20 21	Low-energy X-ray X-ray spectro-/polarimetry X-ray low-background Meteoroids Nucleonic anti-matter Extra-heavy nuclei Solar X-ray telescope	5 7 8 15	Solar orbiting pair Photoheliography Coronagraph Atmosphere/magneto-sphere
9 10 11 12	Narrow-field ultraviolet Low-energy stellar X-ray X-ray spectro/polar. X-ray low-background	14 19 20	Meteoroids Nucleonic anti-matter Extra-heavy nuclei	5 7 8 15 21	Solar orbiting pair Photoheliography Coronagraph Atmosphere/magneto-sphere Solar X-ray telescope
13 16 17 18	Cometary physics Perturbations--wake VLF wave--particle Electron/ion beam	14	Meteoroids	1 2 3 4	Earth observations Meteorology Earth physics Earth resources
15	Atmosphere/magneto-sphere	14 19 20	Meteoroids Nucleonic anti-matter Extra-heavy nuclei		Groups I, II, III, IV
19 20	Nucleonic anti-matter Extra-heavy nuclei	6 9 10 11	Optical interferometer Narrow-field UV Low-energy stellar X-ray X-ray spectro/polar.	5 7 8	Solar orbiting pair Photoheliography Coronagraph
22	Explorer A-D	14 19 20	Meteoroids Nucleonic anti-matter Extra-heavy nuclei		

5.4 ON-ORBIT SERVICING

A significant issue in the design and implementation of a space system is the method for assuring its continued, trouble-free operation for a desired mission lifetime. This section discusses the use of maintenance to achieve this objective and the requirements associated with manned or mechanized methods.

On the basis of previous studies (e.g., "Impact of Low-Cost Refurbishable and Standard Spacecraft Upon Future NASA Space Programs," Final Report, LMSC-D157926, Lockheed Missiles and Space Company, Contract NASw-2312, 30 April 1972), maintenance is seen as cost effective because of the allowable design simplification (less redundancy) and reduction of reliability testing requirements.

MAINTENANCE DEFINITION

Periodic revisits to geosynchronous platforms will involve servicing, maintenance, and updating activities; where servicing is defined as replenishment of consumables, maintenance is defined as retention or restoration of functional capabilities, and updating means to exchange equipment to change a function, increase capacity or apply newer state of the art. In this study, no scheduled servicing requirements were identified except for contingency RCS fuel replenishment. Updating is assumed to be performed in the same manner as the selected maintenance concept.

First-level maintenance involves several functions in addition to removal and replacement. While this study was primarily concerned with the impact of remove-and-replace operations, the other functions were considered in the platform concepts selected. One of the functions, checkout and test, is considered to be worthy of an independent trade study. Table 5.4-1 identifies the conventional maintenance functions and the basic methods of accomplishment on-orbit, both manually and mechanically.

GEOSYNCHRONOUS SERVICING CONSIDERATIONS

Servicing and maintenance functions at geosynchronous orbit (GSO) exhibit both unique and common features when compared to similar low earth orbit (LEO) operations. The primary design driver in both orbits and the essentially common factor, is the methodology for removal and replacement of "black boxes" or equipment components. Since this study deals with platform definition, this aspect of servicing is addressed in depth with respect to the platform requirements. However, platform requirements cannot be adequately derived without consideration of unique GSO factors and the logistics interface with GSO platforms.

Table 5.4-1. Maintenance Functions

Function	On-Orbit Methodology	
	Manual	Mechanical
Gain access	Hatches, internal cover plates	External doors, segmented structure
Transport spares/tools	Hand-carry/mechanical aid	Mechanical device/ manipulator
Isolate unit functionally	Manual or remote valves/switches	Remote control
Break connectors	Plugs, quick-disconnects/B-nuts or self-breaking	Unit attached self-breaking disconnects
Remove fasteners	Standard (for zero-g)	Special latches
Remove/install	Manual	Mechanical device
Make connections	Reverse of above	Prealigned
Checkout and test	Ground, tug or portable test equipment	Ground or tug
Return on line	Manual or remote switch/valve	Remote control
Remove replaced unit, tools, and closeout access	Reverse of preparation	Reverse of preparation

The advantages and disadvantages of GSO operations when compared to LEO operations are presented in Table 5.4-2. All operations are predicated on the use of a shuttle and tug in that round-trip capabilities are required for the revisit mode. An assessment of the servicing missions was made to derive platform requirements. This assessment was based on capabilities and potential requirements to establish feasibility of selected modes in accordance with the following logic sequence:

1. Establish potential weight and quantity of modules to be exchanged.
2. Define gross weight levels of servicing systems.
3. Define logistic capabilities in terms of payload weight and mission time, and therefore, potential spares weight and platform visit time.
4. Prepare timelines for servicing concepts to assess compatibility with available time.
5. Prepare a gross mission timeline to ensure overall feasibility of revisit missions.

Table 5.4-2. Unique GSO Servicing Factors

Factor	Characteristics
Mission time	Less servicing time is available due to tug-shuttle separation and rendezvous operations, and increased phasing times over low earth orbits.
Payload size/weight	Spares and servicing system length and weight limited by shuttle-tug combined delivery capabilities, i.e., shuttle bay less tug length, shuttle weight to LEO less tug weight, and tug round trip delivery performance to GSO.
Remote (RF) checkout, trouble analysis, and command	Optimal ground link compared to LEO considering the capability of using a single station; minimal shuttle RF interface.

Spares Requirements

In order to establish the feasibility of the logistics of on-orbit servicing, some definition of spares was required. In-house reviews of various satellite concepts have shown that from 40 to 60 percent of the weight of a spacecraft consists of replaceable mission or subsystems equipment. The baseline satellite weights ranged up to 3500 pounds. Assuming a factor of two for platforms, their weight would be about 7000 pounds with 50 percent, or 3500 pounds, of replaceable units.

Selection of the replacement unit size is, in part, based on inherent capabilities and limitations in work capability of manual or mechanical servicing systems. A crewman in zero-g can maneuver masses ranging up to thousands of pounds. However, the size of the work area and thus the degree of required control will set an upper operational limit on the mass of replaceable modules. Special consideration to restraint systems is required if the module mass is equivalent to the mass of the crewman. The mass of current modular concepts (150 to 300 pounds) bracket the average weight of crewmen because of work space limitations, hatches, and passageways. The module size which meets these volume/access constraints (24 by 20 by 24-inch) weighs 150 to 300 pounds when the required subsystems assemblied are installed. Also, this range of weights is more amenable to ground handling and factory operations

The trends in going from smaller, lower level replacements to larger assemblies, modules, or total subsystems packages, is that the payload logistics weight increases, while replacement time decreases. Figure 5.4-1 shows the influence on mission time in terms of number of replacements performed, assuming an approximately equal time per unit regardless of size, and identifies system limitations.

If the 3500 pounds of replaceable units (RU's) averaged 175 pounds each, then it would require 20 modules to make up the mission and subsystems equipment; at 100 pounds each, 35 modules, etc. These ranges are considered later in connection with mission feasibility.

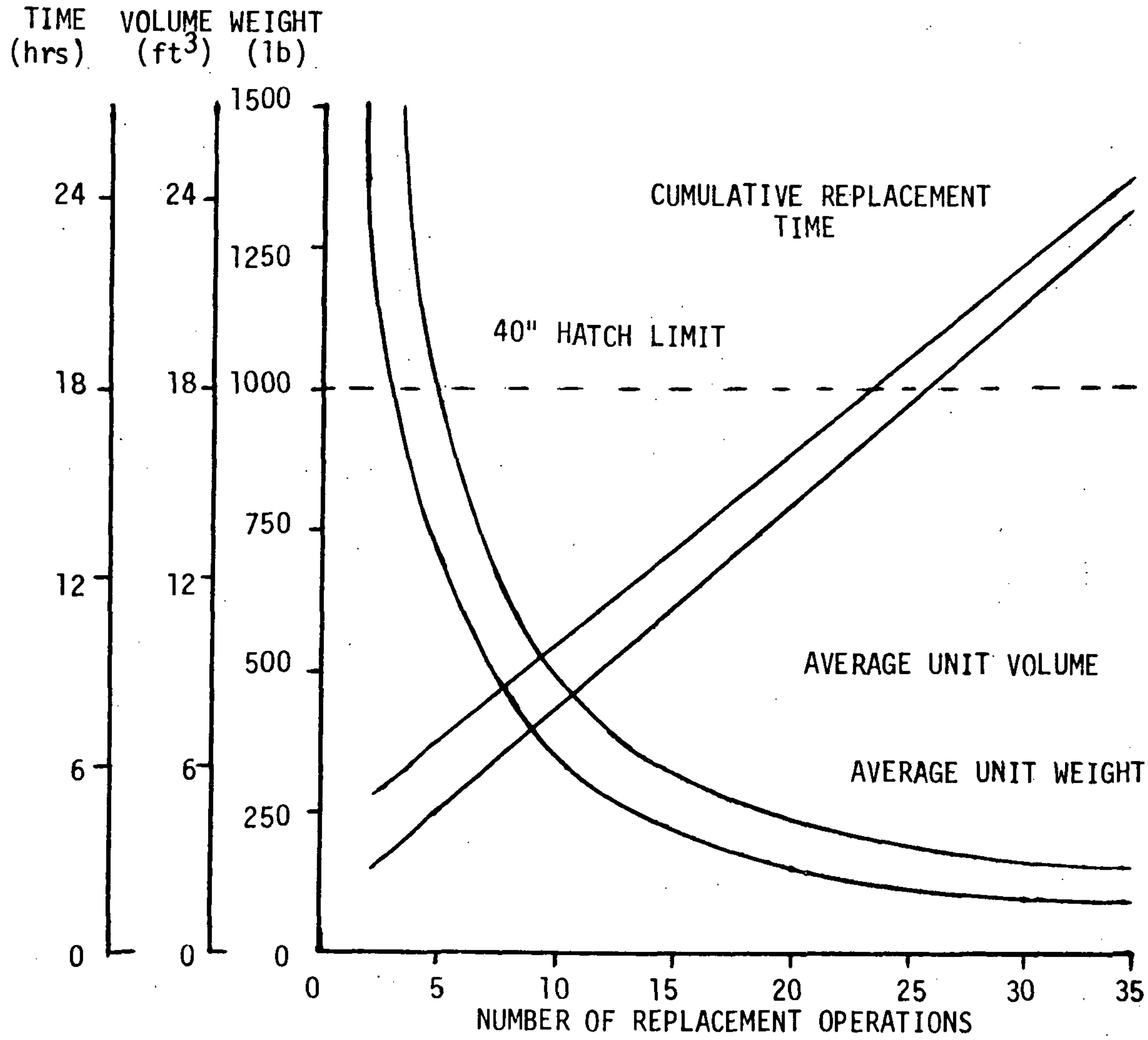

Figure 5.4-1. Trends in Replaceable Unit Factors

Servicing System Approaches

Several approaches for servicing geosynchronous platforms were established to aid in defining the interfaces between platforms and the servicing units. Their characteristic features and distinguishing trends have been compiled to provide the basis for establishing platform requirements related to servicing and man attendance. The three approaches treated are mechanical (automated) servicing, EVA/IVA man-attended, and shirtsleeve man-attended.

Conceptual features for each approach are illustrated in Figure 5.4-2, and are based on the following minimal requirements.

1. Each approach must carry spares to the platform.

2. Each approach must house the component exchange device or method.

3. Each approach must provide rigid attachment (docking):

   a. Mechanical, so as to ensure indexing and positive withdrawal or reinstallation forces

   b. Shirtsleeve, so as to provide environmentally safe crew transfer

   c. EVA, so as to preclude stationkeeping activities and to prevent separation, thus degrading crew safe return

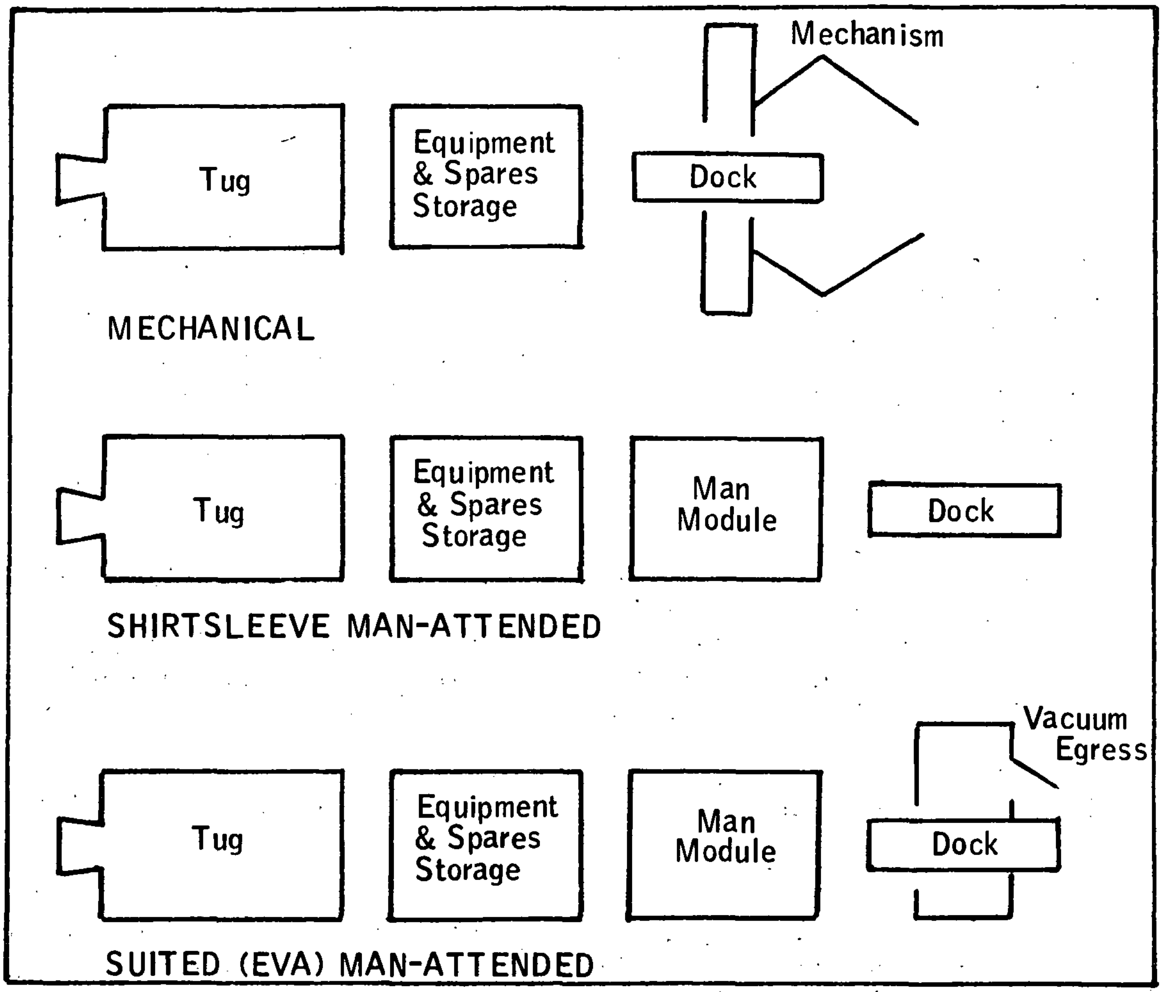

Figure 5.4-2. Servicing System Concepts

A review of analogous weights data for man modules (including data from Apollo, International Docking Module, and Sortie Laboratory) indicate that about 6000 pounds is a reasonable estimate, as follows:

	Pounds
ECLSS	500
Crew system	650 to 700
EPS	1000 to 1500
RCS	300
Expendables	600 to 700
Comm./data	150 to 300
Controls/displays	200
SCS	200
Structure	~2000
Total	5600 to 6400

A similar assessment for an unmanned (mechanical) system indicated a reasonable weight estimate of about 1500 pounds.

Logistics System Capabilities

The baseline shuttle and tug characteristics are depicted in Figure 5.4-3. The space shuttle cargo bay is 15 feet in diameter and 60 feet long. The payload weight capability to the transfer orbit is 65,000 pounds. The tug is 35 feet long; its performance characteristics are shown graphically. In the case of the tandem tug, which is required for the manned module because of its weight (exceeding 3225 pounds), the placement, round trip, and retrieval payload limits appear to be quite large. However, if the crew module is subtracted from the tandem tug capability curve, the servicing equipment payload is only about twice that associated with the auto-remote/single tug logistics concept.

A summary of tug capabilities (Table 5.4-3) identifies the available times and servicing payload weights for the single-mission visits to multiple geosynchronous platforms. Nominal 24-hour orbit transfer operations were assumed and platforms were separated 5 degrees in longitude. Weights data reflect increased delta-V propellant requirements for dual and triple platform visits.

The mission times are based on a seven-day space shuttle mission. Note that the available service times and spares weights are on a "per platform" basis.

Servicing Concept Timelines

Figures 5.4-4, 5.4-5, and 5.4-6, reflect servicing time estimates for each of the candidate modes: mechanical (remote) system, (manned) EVA system, and (manned) shirtsleeve. Each chart reflects time from docking to departure for a single platform, and the time block to replace a single module. The mechanical system requires the least overall time. The shirtsleeve mode is penalized by pressurization and verification tests of the platform after initial docking, while EVA is severely penalized by daily preparation time. In summary, these time estimates are:

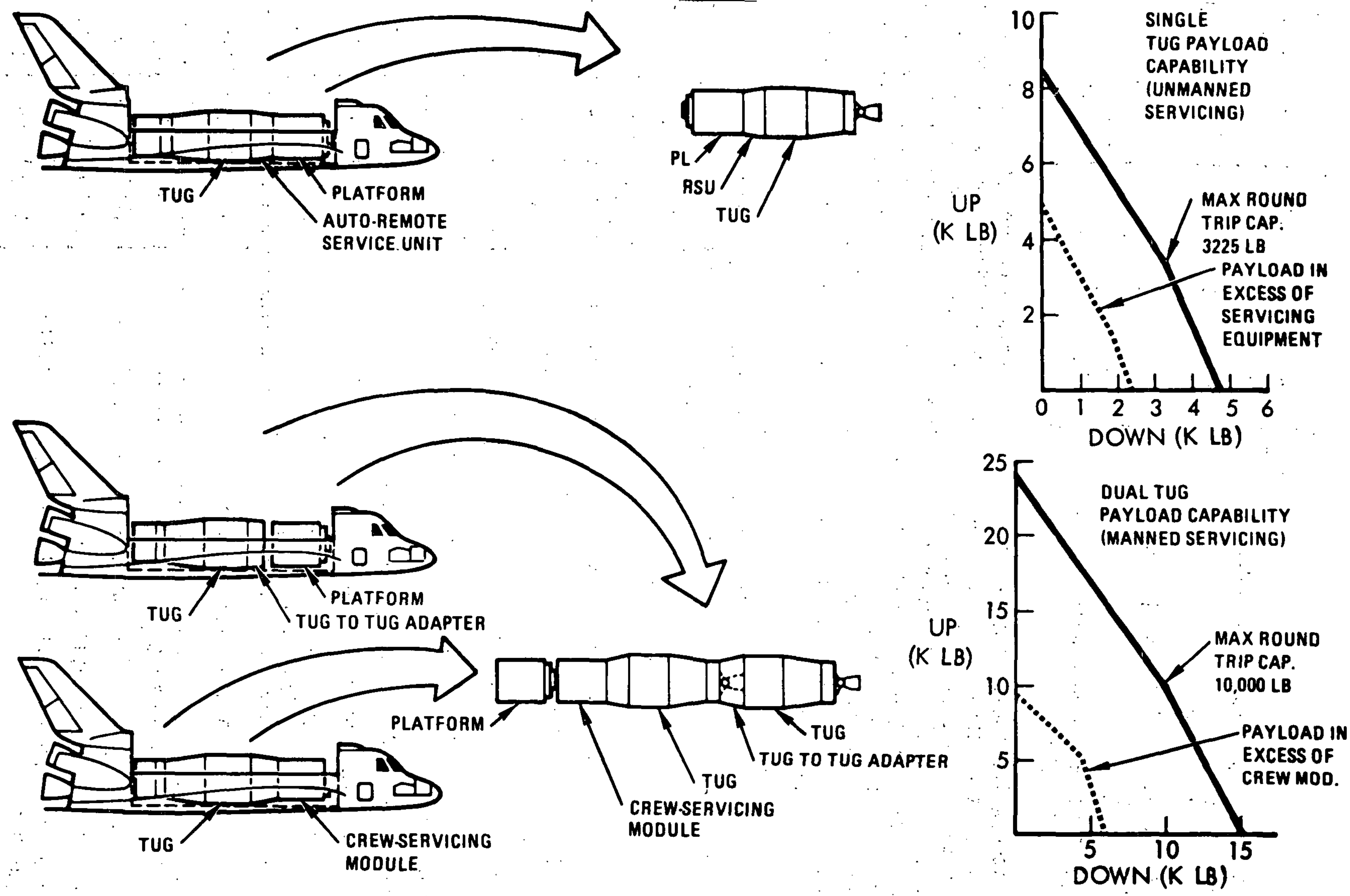

Figure 5.4-3. Logistics System Characteristics

	Remote	EVA	Shirtsleeve
Fixed time per platform visited-hours	3.5	6	7.5
Fixed time daily-hours EVA preparation plus crew personal time - hours	-	16	12.0
Exchange time per module-minutes	15	30	15

Integrating these data and the logistics systems capabilities into overall mission timelines, total available unit exchange times can be defined for each servicing approach. Figure 5.4-7 shows the total mission for each mode, for one, two, or three platform visits. For the remote servicing mode, it was assumed that ground crews worked two shifts (16 hours). EVA crewmen would be constrained to about 8 hours work plus airlock time. Shirtsleeve operations were based on a 12-hour workday. The purpose of this figure is to identify time available to replace modules so as to estimate the number of replacements that can be accomplished.

Table 5.4-3. Tug Servicing Mission Capability Summary

Major Phases	Platforms Visited		
	1	2	3
	(hr)	(hr)	(hr)
Shuttle lift-off to initial platform rendezvous and dock	24	24	24
Single orbital transfer (5 degrees) and rendezvous	-	24	-
Double orbital transfer (5 degrees each) and rendezvous	-	-	48
Transfer to shuttle through touchdown	24	24	24
Total time (exclusive of servicing)	48	72	96
Available time for servicing operations (per platform)	120	48	24
Launch Consideration	**Payload Capability (lb)**		
Single tug payload weight-to-orbit and return	3225	3160	3000
Pro rata spares weight available per satellite	1750	830	500
Dual tug available payload weight	10000	9850	9700
Pro rata spares weight available per satellite (manned)	4000	1925	1230

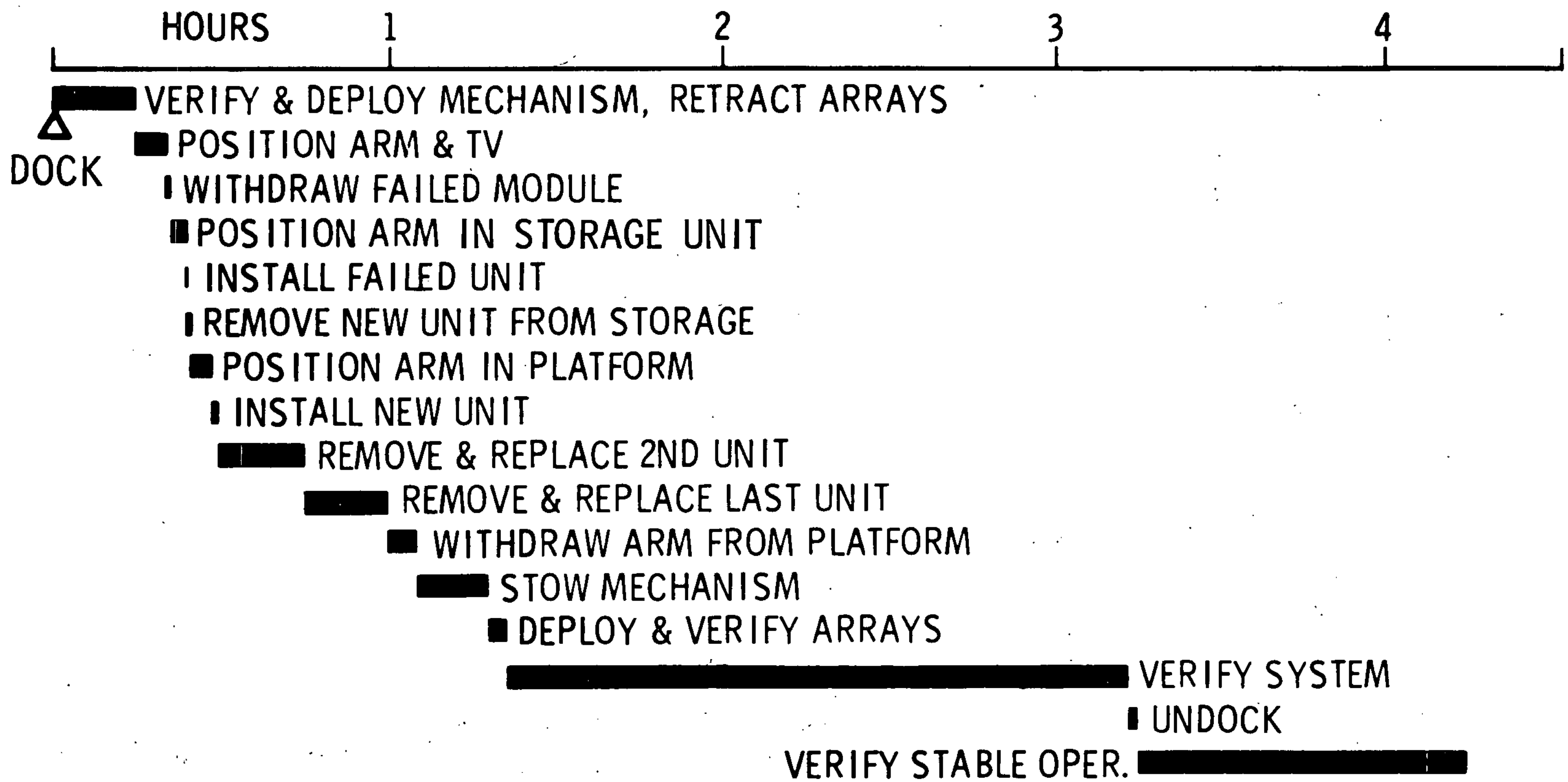

Figure 5.4-4. Remote Servicing Mode Module Exchange Timeline

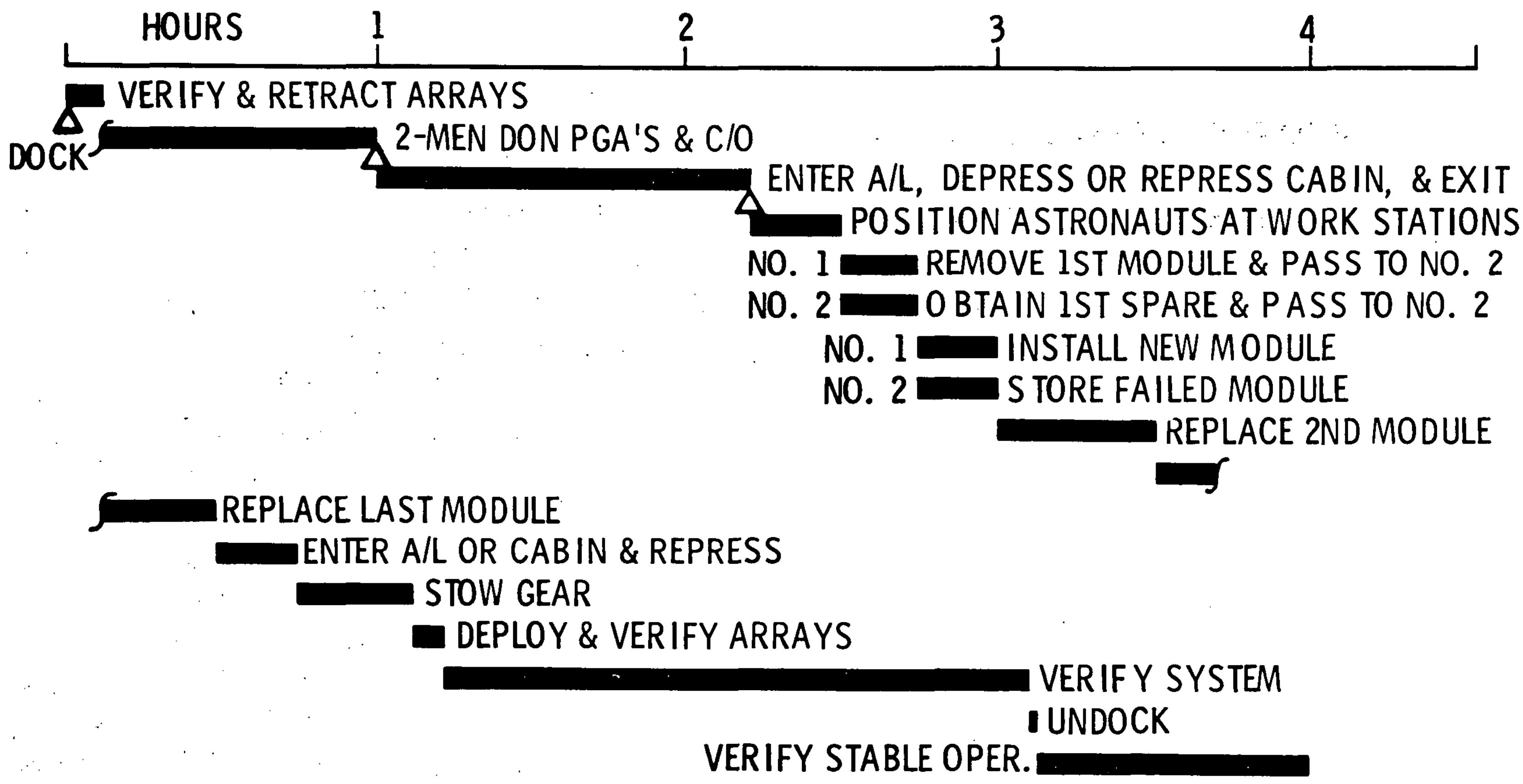

Figure 5.4-5. EVA Servicing Mode Module Exchange Timeline

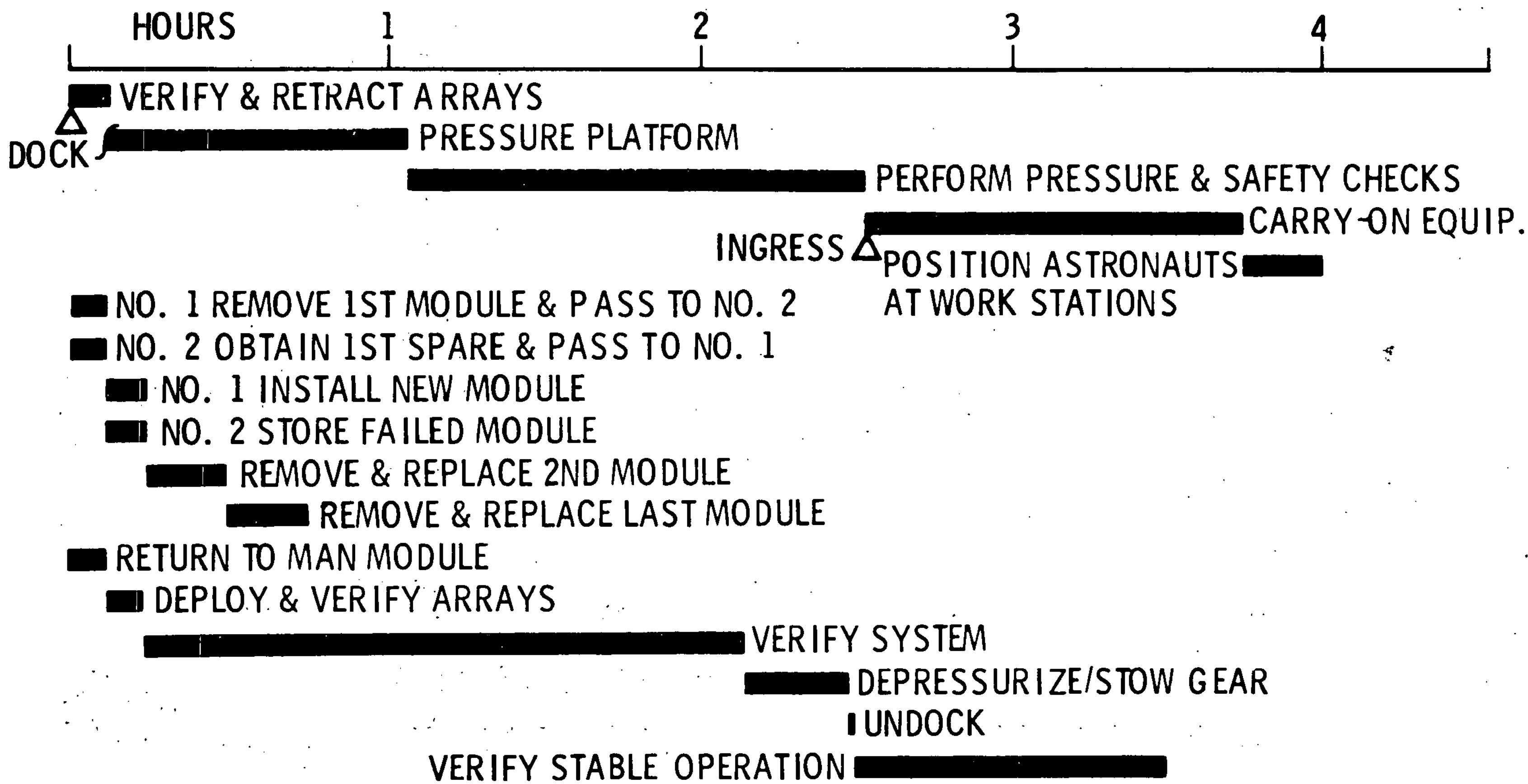

Figure 5.4-6. Shirtsleeve Servicing Mode Module Exchange Timeline

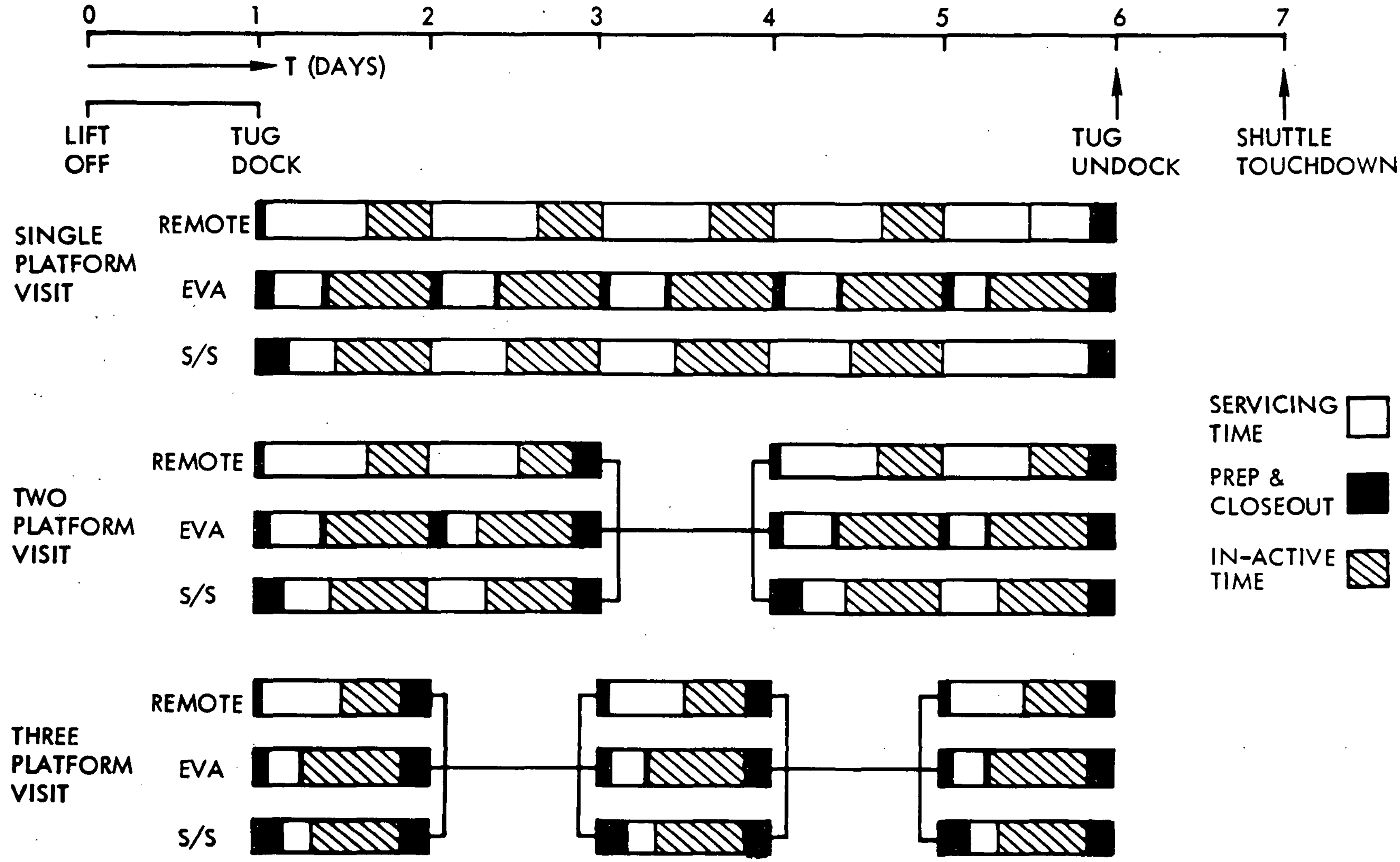

Figure 5.4-7. Platform Servicing Timelines

Servicing Capabilities

Based upon logistic system weight and time constraints and unit weight and replacement time estimates, servicing capabilities are summarized in Table 5.4-4. If 25 replaceable units are assumed for each platform, then each unit would weigh 140 pounds on a 7000-pound platform. This 140-pound value was used to establish maximum spares weight-to-orbit, and thus the number of spares. Weight of spares becomes the limiting factor in all cases except for the EVA, three-platform visit case. The lowest number of spares is 10, which is considered conservative on the basis of the average weight figure used. The lowest percent of changeout of a platform is 13, which is high enough to ensure feasibility and which is also considered conservative on the basis of overall platform sizing. It should also be noted that there are significantly greater spares capabilities for the unmanned mode by use of a dual tug.

SERVICING SYSTEM REQUIREMENTS

Each servicing system concept has a set of unique requirements for on-orbit operations. These requirements are summarized in Table 5.4-5, and are further described below.

Remote Servicing Unit (Mechanical) (RSU)

The mechanical servicing system would consist essentially of a manipulative device which is capable of removing failed or outdated equipment and of installing replacement units. The unit would be under remote (RF) control, most probably from a ground station, and could operate to any level of automation from manual (discrete) to fully automatic.

The RSU would house the mechanical device, control electronics, support subsystems, and the spares transported to orbit. The structure and support subsystems would provide for thermal-meteoroid protection, communication data links, electrical power, and/or other functions not available from the tug. Any platform signal, fluid, or power interfaces would be required to be completed mechanically during docking or remotely via radio link.

Manned Servicing Unit (MSU)

The manned servicing unit is essentially the same for either the shirtsleeve or suited mode of servicing. In general, it requires a manned module which includes all the necessary subsystems and crew provisions to accommodate the crew after separation from the shuttle, from low earth orbit to rendezvous and dock with a platform at GSO. The areas of potential difference between the two approaches include crew size and activities, atmospheric control system, and crew equipment.

Crew Size and Activities

In the shirtsleeve servicing mode, the operations after docking consist of verifying integrity of the mating, making connections (plumbing and electrical), applying and verifying atmospheric pressure to the platform

Table 5.4-4. Servicing Capabilities Summary (Conservative Values)

Servicing Approach	Max. Number 140-lb Units Exchangeable						Equivalent Percent of a 7000-lb Platform		
	1 Platform		2 Platforms		3 Platforms				
	Per Time	Per Wt.	Per Time	Per Wt.	Per Time	Per Wt.	1 Platform Visited	2 Platforms Visited	3 Platforms Visited
Mechanical - Remote									
1-shift ground crew	192		64		32				
2-shift ground crew	-	12	128	11	64	10	48	22	13
3-shift ground crew	-		-		96				
EVA	96	28	32	27	16	26	>100	54	21
Shirtsleeve	288	28	96	27	48	26	>100	54	34

Table 5.4-5. Summary of Servicing System Requirements Per Concept

Requirement	RSU	EVA	Shirt-sleeve	Requirement Driver
Crew size (minimum)	(ground)	2	2	Task/mission activities
Environmental protection	X	X	X	Thermal-meteoroid and pressure for crew; thermal-meteoroid for spares and equipment
Atmosphere and control		X	X	Life support system plus platform pressurization for shirtsleeve; plus repressurization for EVA
Stowage	X	X	X	Spares plus equipment and consumables
Docking	X	X	X	Common platform interface - spares transfer
Docking or side hatch		X	X	Crew transfer - shuttle or platform
External illumination	X or	X		Worksite lighting
Internal illumination	X	X	X	Crew lighting
TV viewing	X	X		Task activity
Data transmission	X	X	X	System status
Command reception	X			Operates mechanical system
Voice communication		X	X	Crew communication
Biomonitoring		X		EVA crew to man module
Mobility and restraint aids		X	X	Crew ingress, egress and transit
Personal hygiene and waste management		X	X	12 or 18 man-days
Food management		X	X	12 or 18 man-days
Mechanical and control units	X			For servicing operations
Tools		X	X	Crew task support
Sleep provisions		X	X	Time-shared with transit restraint
Crew equipment		X	X	General use or emergency
Tug interfaces (communications, attitude, G&C, etc.)	X	X	X	Per mission requirements
Electrical power	X	X	X	As noted

compartment, and then opening the MSU hatch and egressing to the platform. Two crewmen would be required for the manned module to provide redundancy, companionship during the six-day tug mission period, and task sharing during critical mission periods.

In the EVA support mode, crew activities after docking consist of connection and verification of interface functions followed by preparation for EVA, depressurization of the crew module, and egress procedures. Platform work time is impacted by the need to repeat the pressurization/depressurization activities associated with EVA for sleep periods and major meal periods.

Atmospheric Control System (ACS)

The shirtsleeve mode, as discussed above, requires an ACS not only for the manned module, but also for the platform, including an initial platform pressurization capability. Based on the initial review of logistic system capabilities, each revisit mission may include visits to as many as three platforms, thus requiring a capability for at least three pressurization cycles. For the suited mode, operations require a depressurization capability in the man module again for at least three cycles for a three-platform visit. If a six-day mission is for the servicing of a single platform, from 5 to 10 depressurization cycles would be required depending upon the duration of the work shift. Provisions for depressurization could consist of either cabin depressurization or a separate airlock. In order to minimize weight and length, the cabin depressurization mode was selected.

Crew Equipment

No unique servicing requirements were identified that would require pressure-suited activities. However, this is based on an assumed high reliability of antennas, solar arrays, and externally boom-mounted scientific instruments. If, in fact, maintenance activities were to be extended to these items, then the crew would require either an external manipulator or EVA capability.

Since pressure suits may be desirable for crew safety purposes, only a small weight and volume penalty would permit EVA for selected operational contingencies, including the capability to perform internal maintenance in the event that a platform becomes nonpressurizable for some reason. Consequently, no significant difference was seen in the EVA/IVA and shirtsleeve manned modules and their associated crew equipment.

Safety Factors

General

Safety of operations in the case of the unmanned servicing approach is essentially compatible with mission success of the tug-payload combination, and with the shuttle-imposed safety of operations during the mission phases involving the shuttle orbiter. No unique requirements can be seen to be imposed on the tug. The platforms must meet shuttle- or tug-imposed safety criteria during all interface operations. In general, these consist of:

1. Fail-safe on all systems/equipments
2. Remote (shuttle orbiter and/or ground) monitoring of systems status parameters
3. Command capability for shutdown of any functioning element
4. Structural integrity compatible with transporting vehicle flight regimes (e.g., thrust loads, no implosion, etc.)
5. Compatible design of high-energy or explosive devices with transporting vehicle design requirements

Tug, Man-Module

All the above criteria apply in the case of the man-module, and are, in fact, the only requirement for shuttle interface operations. However, there are special requirements for the tug, the platform, and for the man-module operations.

Tug. Tug systems and equipments may be impacted by manned operations. While it is not the function of this study to identify these design requirements, the safety objective must be to ensure safe return of the crew. While this objective may, in general, be achieved by measures taken to ensure mission success, special measures may be needed, including:

1. Redundancy in critical subsystem functions
2. Alternate methods for ensuring crew safe return

Platform. When docked to the man-module, the platform must provide assurance of crew safety at least equivalent to that which shuttle payloads provide the shuttle. In addition, the platform must meet operating safety criteria such as no design which might lead to blocked egress, thermal-meteoroid protection (at least shirtsleeve), fire/contamination control/warning, voice communication links, and some minimum caution-warning display and control of selected parameters or equipments. In addition, general design criteria must meet manned interface standards; e.g., no sharp protrusions, exposed wiring, etc.

Manned Module Operations. Some special considerations must be given to overall manned operations. The module itself must be a qualified, man-rated spacecraft, and it must have control or override capability over the tug, at least with respect to thrusting during powered flight, rendezvous, and docking. Attitude stabilization and guidance control are also required.

The crew has been sized at a minimum of two for operational purposes, as discussed previously. For both the EVA and shirtsleeve mode, the two men were considered to work concurrently. Neglecting operational efficiencies, two suited crewmen would still be baselined for the EVA mode in order to cope with time-critical emergencies. A detailed phase C level of failure and accident analysis might alleviate this requirement.

In addition, a preliminary consideration of safe operations indicates a probable need for a third crewman to remain in the crew module during EVA activities. If the EVA crewmen work for a continuous eight hours, a third crewman would monitor systems caution and warning, EVA crew life support, ensure that ground communication is enabled, assist in power on-off switching of the platform, and monitor EVA crew biomeasurements. A potential alternate would be for these functions to be performed by a ground station.

PLATFORM REQUIREMENTS FOR SERVICING

Servicing requirements imposed on the platform fall into two general categories: general configurational requirements and subsystem requirements. These requirements are established in subsequent paragraphs.

Configurational Requirements

Overall size, shape, and arrangement of the platform must provide for servicing access by the selected system. In the unmanned case, this means that the platform must allow a manipulative device to grasp, remove, and withdraw any replaceable unit and, subsequently, to insert and install its replacement. This could be accomplished by either removal external to the surface of the platform or through an annular structure (docking ring) which provides adequate clearance for the largest package and articulation motions of the manipulative device. Clearances must also consider possible use of portable (manipulator-mounted) lights and TV for remote operations. This concept also implies a manipulator end effector, which has sufficient accuracy and rigidity to grasp special latching mechanism for module interchange and actuation of electrical and plumbing quick disconnects.

For the manned approaches, clearance requirements for internal access must consider the man in a suited envelope, and his movement through passageways and docking ring with replaceable units, tools, etc. Package installation can be conventional ground-type, latches or disconnects, but with allowances for additional clearance and loss of dexterity due to a gloved hand. Typical clearances are shown in Figure 5.4-8.

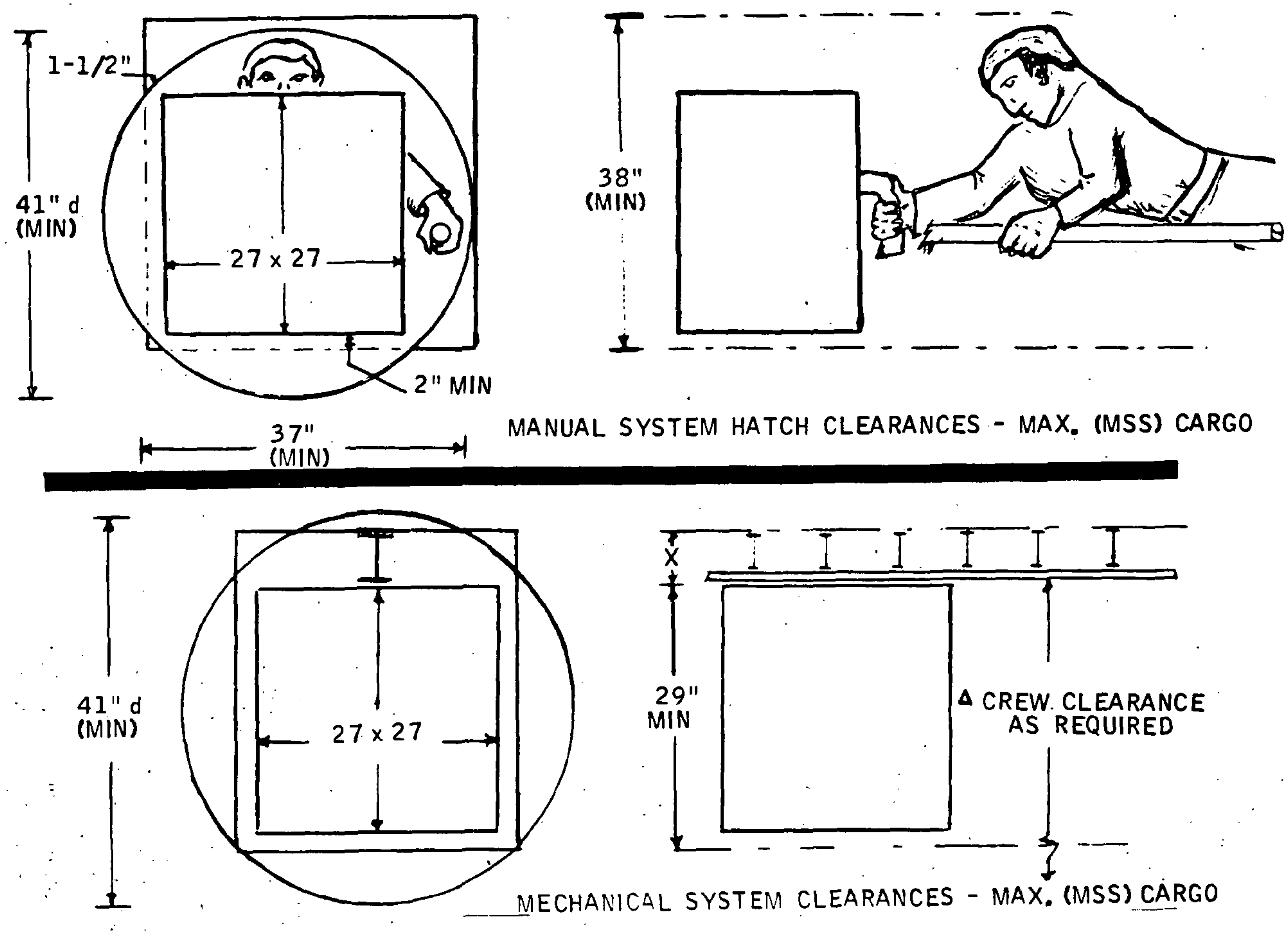

Figure 5.4-8. Typical Package Sizing and Clearance

Subsystems Requirements

The various requirements imposed on the subsystems differ with the servicing approach. Shirtsleeve servicing requires the greatest number of provisions including a pressurizable compartment, atmospheric control (or man-module interface), lighting, voice communication, crew aids and protective provisions. EVA/IVA requires similar but fewer provisions in that life support and environmental protection are furnished by the pressure garment assemblies. All concepts require a form of docking for rigid attachment, interface connections to the service unit, data links for trouble analysis and checkout, and a capability to deadface or shutdown systems are equipments undergoing replacement. For the manned modes, the latter could consist of manual switches and valves. For the remote mode, ground commands could be input via the service unit or directly to the platform.

Various schemes could be employed for diagnostics, test, and checkout. Status data to the level of the replaceable unit are required at the ground station prior to the servicing mission to ensure adequate delivery of spares. It would seem feasible that the ground station would periodically check out systems for trend data and confidence checks. The platform must, at a minimum, be compatible with these requirements with higher levels of built-in test capability optional for operational needs.

Various configurational subsystem and interface requirements are summarized in Table 5.4-6.

EVALUATION OF ALTERNATE ON-ORBIT SERVICING MODES

The advantages and disadvantages of the three on-orbit servicing modes considered in this study are discussed in the following paragraphs.

Required Maintenance Operations

If only scheduled maintenance operations are considered, the preferred servicing mode would be auto-remote. Man would not be exposed to the hazardous environment of space. Preplanned maintenance activities can normally be accommodated by automated or remote controlled devices. Inherent in an auto-remote maintenance concept is the relatively higher level of maintenance that is practical as compared to manned operations. Currently proposed packaging concepts for both mission equipment and support system assemblies are compatible with auto-remote servicing concepts.

The major disadvantage to the auto-remote servicing concept is its relatively restricted flexibility. In general, an auto-remote servicing concept can be developed to cope with any predictable or known contingency if sufficient development effort can be expended. The problem is coping with the unknown, the unexpected, and the unpredictable, especially in a short-time duration. Direct inclusion of men in the maintenance operation usually will permit timely resolution of the contingency.

Table 5.4-6. Summary of Platform Requirements Per Concept

Requirement	RSU	EVA	Shirt-sleeve	Requirement Driver
Crew size	(ground)	2	2	Servicing operations
Envir. protection			X	Thermal/meteoroid pressure hull
Atmos. and control			X	Shirtsleeve operations
Internal workspace			X	Equipment access and mobility
Stowage		X	X	Carry-on equipmeht
Internal access	X	X	X	Docking interface (tunnel)
External access	or X	or X		Per design concept
Illumination	X	X	X	Internal/external lighting
Voice communication		X	X	Platform to tug and to ground
TV transmission	X	X	X	Operations
Data transmission	X	X	X	System status and checkout
Mobility and restraint aids		X	X	Handholds, foot/waist restraints
Protective edges and surface		X	X	Crew and PGA protection
Release latch installations	X			Automated latch release
Docking mechanism	X	X	X	Rigid attachment for all concepts
Remote isolation of components	X	X	X	Electrical deadface and pressure/fluid flow shut-off
		or	or	
Manual isolation of components		X	X	
Service unit interfaces - power, communication/data, stability etc.	X	X	X	To tug and platform as required

Refurbishment and Repair Operations

The potential assembly level of equipment that could be involved in refurbishment and repair operations is considered to by significantly lower than for maintenance operations. Wire harnesses, connectors, equipment mounts, view ports, etc. could be involved. Attempting to accomplish this type of on-orbit service operations with auto-remote devices is impractical. Man attendance is the only reasonable approach for refurbishment and/or repair activities.

Logistics System Impact

Baseline values for the weight, volume,and number of replaceable units for geosynchronous spacecraft indicate that on-orbit servicing of multiple spacecraft on a single mission is feasible with all three servicing modes. However, the manned modes require a dual shuttle-dual tug logistics configuration. The per mission operational costs will be about twice as much for manned operations as for unmanned operations. However, these apparent increased costs for manned operations may be completely acceptable. Man's ability to cope with contingencies and perform detailed repair and refurbishment operations could be the difference between restoring a spacecraft to operational service or replacing the entire spacecraft. In essence, a net savings could result by inclusion of man attendance capability in the program.

Platform Impact

The majority of the requirements imposed upon the platform design by the three servicing modes are common. Even some of the requirements that are unique to a specific servicing mode are amenable to the other modes. For example, the replaceable unit attachment mechanism must be uniquely designed to interface with the auto-remote interchange device. A hand-held tool can be designed for use in the manned servicing mode. Also, free space requirements are generally larger for articulation of auto-remote mechanisms. This additional space can be advantageously used by man as work area and can facilitate dual manned operations.

The most significant platform requirement that is unique to a servicing mode is the need for a pressurizable volume and atmospheric control of that volume for shirtsleeve servicing operations. Assuming a cylindrical volume that is compatible with the space shuttle cargo bay, the additional weight of the pressure hull is about 50 pounds per foot of length. Manned servicing system accommodations for pressurization of a five foot long cylindrical platform would require about 1 cubic foot of storage space and weigh about 40 pounds.

Evolutionary Considerations

It appears that an evolutionary servicing concept is appropriate for a platform program. Initial module replacement can be achieved by the auto-remote concept. As the platform program progresses, repairs and refurbishment will probably be required and more complex and intricate operations will

be necessary. This type of activity is more amenable to man attendance. The projected development of the tug supports the evolutionary concept. Initial IOC of the shuttle and unmanned tug supports the early phase of on-orbit servicing of platforms at the modular interchange level. Approximately five years after initiation of platform operations, a man-rated tug is planned. This timing would support potential refurbishment of platforms.

In order to minimize total program development effort, it is recommended that the platform be designed to an integrated set of servicing requirements; a single concept that will accommodate remote, EVA, and shirt-sleeve servicing. In this approach, the servicing mode evolves, not the platform design.

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