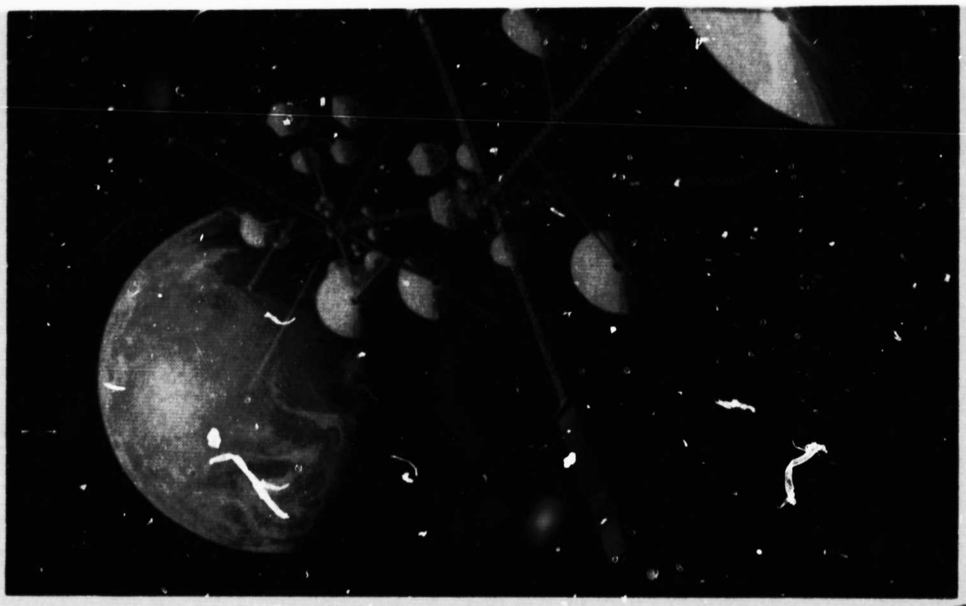
REPORT NO. GDC-GPP-79-006 (II)
CONTRACT NAS8-33527
JUNE 1980

GEOSTATIONARY PLATFORM SYSTEMS CONCEPTS DEFINITION STUDY

FINAL REPORT
VOLUME II TECHNICAL
BOOK 1 OF 3



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COMSAT

for the

National Aeronautics and Space Administration
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

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Submitted to
GEORGE C. MARSHALL SPACE FLIGHT CENTER
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812

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GEOSTATIONARY PLATFORM SYSTEMS
CONCEPTS DEFINITION STUDY
FINAL REPORT

VOLUME I	EXECUTIVE SUMMARY
VOLUME II	TECHNICAL ANALYSIS, TASKS 1 – 5, 3A
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This report is submitted in fulfillment of NASA/MSFC Contract NAS8-33527.

William T. Carey

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1 July 1980

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PREFACE

In today's world of expanding communication, military, and science satellite services, the geostationary orbit is rapidly becoming an extremely valuable and limited earth resource. Nations demand specific positions or "slots" in the orbit corresponding to their geographic longitude, seeking to maximize their territorial coverage and satellite performance. Sovereignty becomes an issue, with several nations at different latitudes and one longitude competing for the common longitudinal slot in the orbital arc. Common carriers within a developed nation demand equal rights for the best slots. Competition has been strong in the developed nations, and the developing nations are now voicing their concern.

At geosynchronous altitude, independent satellites operating at the same frequency must be separated by about 4 degrees of longitude to prevent RF interference (30 dB separation), dictated by the large beam widths of the small affordable ground antennas now in use. About 90 "slots" therefore exist around the world, with about 12 over the U. S. and our northern and southern neighbors.

The frequency spectrum is also a valuable and limited resource that is rapidly approaching saturation, particularly in those regions of low noise and freedom from atmospheric attenuation.

Both resources are now allocated worldwide by the International Telecommunications Union operating through subservient multinational and national agencies. Reallocation cannot solve our basic orbital arc and frequency saturation problems. Recent studies have shown projected traffic demands which will saturate both the geostationary orbital arc and the optimal frequency spectra in the near future. In the U. S. alone, current domestic satellite capacity is about 100 transponders. Projections indicate a five-fold increase in traffic demand for voice, data, and TV distribution in the next 10 years (by 1990); ten-fold by the year 2000. If video and audio conferencing expand as projected, the jump may be to 20 to 50 times the present traffic by 1990 and the year 2000, respectively.

Motivation for the rapid adoption of satellite communications services is primarily economic. Satellite communications provide lower service cost for certain fixed applications, economy of flexibility, and appreciable cost savings over terrestrial operation for mobile services direct to the users. Savings can be increased still further if the cost, complexity, and size of ground stations can be reduced by application of advanced communications and support technologies to a few satellites with expanded capabilities.

What is the solution to our orbital arc and frequency spectrum saturation problems, a solution that also lends itself to reduction of user costs?

One viable solution is the aggregation of many transponders, large antennas, and connectivity switches on board a small number of large orbital facilities. Such facilities, or platforms, can provide common power and housekeeping services to a number of coexistent communications systems, making maximum use of a single orbital slot. Large antennas with multiple spot beams and good isolation, bandwidth reduction, polarization diversity, and system interconnectivity can provide an equivalent transponder capacity over the U. S. at least an order of magnitude greater than the projected traffic demand for the year 2000.

In the public interest, NASA has initiated a program to encourage development of such geostationary platforms, anticipating the need for increased communications and other services in the near decades, at lower costs. In the past two years, initial NASA studies[1] have established the need and requirements for, and the feasibility of these platforms. NASA's George C. Marshall Space Flight Center has been authorized to carry out in-depth studies of geostationary platforms.

This report documents the results of the Geostationary Platform Initial Phase A Study, performed by General Dynamics Convair Division of San Diego with COMSAT Corporation of Clarksburg, Maryland, as subcontractor, under direction of the Marshall Space Flight Center. The performance period was from 1 June 1979 to 30 June 1980.

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[1] "Large Communications Platforms Versus Smaller Satellites," Future Systems, Inc., Report No. 221 February 1979, prepared for NASA HQ.

"Geostationary Platform Feasibility Study," Aerospace Corp., Report No. ATR-79(7749)-1, 28 September 1979, prepared for NASA/MSFC.

"Geostationary Platforms Mission and Payload Requirements Study," 30 October 1979, prepared for NASA/MSFC.

"18/30 GHz Communications System Service Demand Assessment," 30 June 1979, parallel studies by Western Union and ITT for NASA/LeRC.

"18/30 GHz Communications Service System Study," June 1979, parallel studies by Ford Aerospace & Communications Corp., and by Hughes Aircraft Co. for NASA/LeRC.

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GLOSSARY

ACOSS	Active Control of Space Structures
ACS	attitude control system
AFC	automatic frequency control
AIL	Avionics Integration Laboratory
APS	auxiliary power subsystem
APSK	amplitude and phase shift keying
APU	auxiliary power unit
ASE	airborne support equipment
ASU	acquisition and synchronization unit
BER	bit error rate
BFN	beam forming network
BOL	beginning of life
BOSS	baseline optical surveillance system
BSM	baseband switch matrix
CADSI	communications and data systems integration
C&W	caution and warning
CCC	central communications control
CER	cost estimating relationship
C/I	carrier/interference
CITE	cargo integration test equipment
CMG	control moment gyro
COMSAT	Communications Satellite Corporation
CONUS	Contiguous United States
CPS	customer premise services (same as DTU)
CQPSK	coherent quadriphase shift keying
CRT	cathode-ray tube
CSC	Computer Sciences Corporation
CTE	coefficient of thermal expansion
DARPA	Defense Advanced Research Projects Agency
DCU	distribution control unit
DDT&E	design, development, test and evaluation
DEU	Display Electronics Units
DHS	data handling system
DMS	Data Management System
DMSP	Defense Meteorological Satellite Program
DNSP	Defense Navigation Satellite Program
DoD	Department of Defense
DOD	depth of discharge
DoE	Department of Energy
DORA	double rolled array
DPS	Data Processing system
DQPSK	differential quadriphase shift keying
DSCS	Defense Satellite Communications System
DSN	deep space network

DTU	direct to user (same as CPS)
EHF	extra high frequency
EIRP	effective isotropic radiated power
EMC	electromagnetic compatibility
EMU	extravehicular mobility unit
EOL	end of life
EPC	electronic power conditioner
EPS	electrical power subsystem
ESA	European Space Agency
EVA	extravehicular activity
FCC	Federal Communications Commission
FDMA	frequency division multiple access
FDM/FM	frequency division multiplex/frequency modulation
FET	field effect transistor
FMECA	Failure Modes and Effects Criticality Analysis
FPR	flight performance reserve
FPT	flat plate trough
FRUSA	flexible rolled up solar array
FSI	Future Systems, Inc.
FSS	frequency selective subreflector
GDC	General Dynamics Convair Division
GDTTSS	General Dynamics Tetrahedral Truss Structure Computer Program
GEO	geostationary orbit
GFE	government-furnished equipment
GFP	government-furnished property
GN&C	guidance, navigation and control
GOICM	Ground Operations and Integration Cost Model
GP	Geostationary Platform
GPC	General Purpose Computer
GRARR	Goddard range and range rate
GSE	ground-support equipment
GSFC	Goddard Space Flight Center
G/T	gain-to-noise temperature ratio
HALO	High Altitude Laser Optics
HPA	high power amplifier
HVT	high volume trunking
ICL	intra-constellation link
I/F	interface
IF	intermediate frequency
IFSM	intermediate frequency switch matrix
IM	intermodulation
IMPATT	type of power-transmitting diode
IMU	inertial measurement unit
IOC	Initial Operational Capability
IOTV	Interim OTV

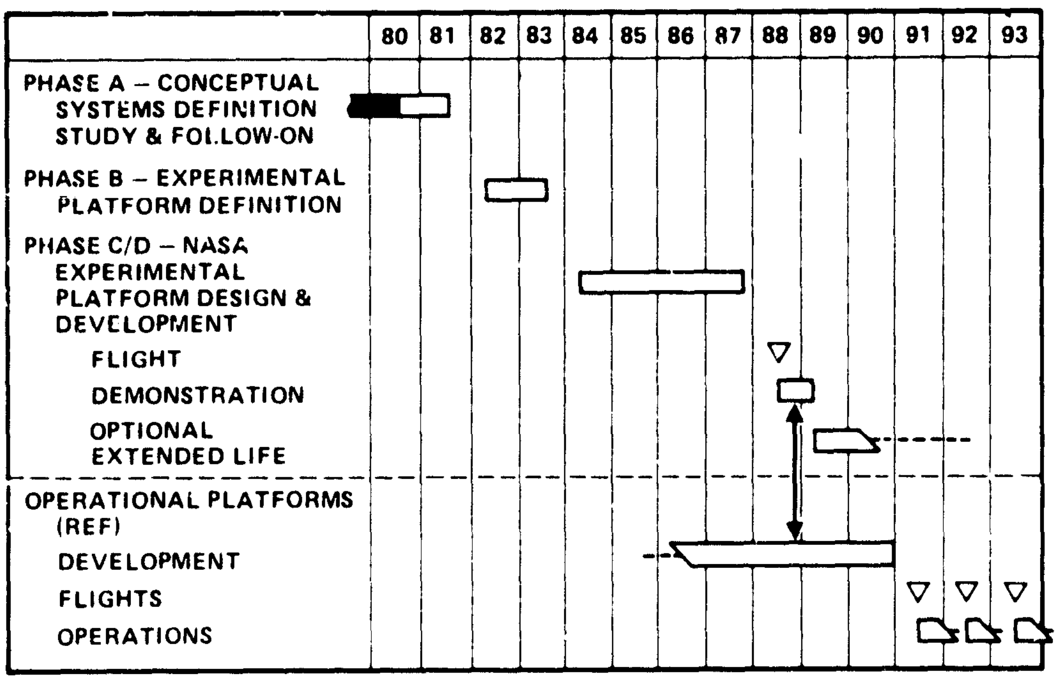
IPL	inter-platform link
IR	infrared
ISP	specific impulse
ITU	International Telecommunications Union
IUS	inertial upper stage
IVA	intravehicular activity
JPL	Jet Propulsion Laboratory
JSC	Lyndon B. Johnson Space Center
km	kilometer
KSC	John F. Kennedy Space Center
LaRC	Langley Research Center
LASS	Large Advanced Space System
LCC	life cycle cost
LEO	low earth orbit
LeRC	Lewis Research Center
LH_2	liquid hydrogen
LLLTV	low light level television
LO_2	liquid oxygen
LSS	large space structures
MBA	multibeam antenna
MBFRA	multiple beam frequency reuse antenna
MCC	Mission Control Center (at JSC)
MCDS	Multifunction Control and Display System
MDM	multiplexer-demultiplexer
MMP	Mission Mass Properties (program)
MMS	Multimission Modular Spacecraft
MMU	manned maneuvering unit
MOSFET	metal oxide silicon field effect transistor
MSFC	Marshall Space Flight Center
MSM	microswitch matrix
MTBF	Mean Time Between Failures
MUX	multiplex
NASA	National Aeronautics and Space Administration
nm	nautical miles
NPV	net present value
OBR	onboard regenerator
OLS	optical line scanner
OMJ	ortho-mode junction
OMS	orbital maneuvering subsystem
OOA	On-Orbit Assembly
OPF	Orbiter Processing Facility
OSR	optical solar reflector
OSS	orbital servicing system
OSS	Office of Space Science (NASA)
OSTA	Office of Space and Terrestrial Applications
OTV	orbital transfer vehicle

PCM	Pulse Code Modulation
PCR	payload changeout room
PDI	Payload Data Interleaver
PEP	power extension package
PETA	Parabolic Expandable Truss Antenna
P/L	payload
POP	perpendicular to orbit plane
PSP	payload signal processor
Q	quality factor (energy stored/energy lost)
QPSK	quadriphase shift keying
RAU	remote acquisition unit
RCS	reaction control subsystem
RF	radio frequency
RFI	radio frequency interference
RIU	remote interface unit
RMS	remote manipulator system
ROI	return on investment
RTOP	Research and Technology Operating Plan
SADA	solar array drive assembly
S/C	spacecraft
SCF	Satellite Control Facility
SCR	silicon controlled rectifier
SEP	solar electric propulsion
SGLS	space ground link subsystem
SPST	single pole single throw
SRT	supporting research and technology
SS	solid state
SSLCC	Space System Life Cycle Cost
SS-TDMA	satellite-switched time division multiple access
SSUS	spin-stabilized upper stage
STDN	space tracking and data network
STS	Space Transportation System
T&C	telemetry and command
TDMA	time-division multiple access
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TMS	Teleoperator Maneuvering System
T/R	transmit/receive
TRIAC	type of regulator tube
TSO	time-sharing option
TT&C	telemetry, tracking and command
T/W	thrust-to-weight ratio
TWT	traveling wave tube
TWTA	traveling wave tube amplifier
ULP	ultra-lightweight panel
USB	unified S-band

UV	ultraviolet
VCHP	variable conductance heat pipe
VPF	vertical processing facility
WAP	Work Authorization Plan
WBS	Work Breakdown Structure
Wp	weight of propellant
Wt	weight
X_o	X-axis of Orbiter
X_p	X-axis of payload
Y_o	Y-axis of Orbiter
Y_p	Y-axis of payload
Z_o	Z-axis of Orbiter
Z_p	Z-axis of payload
ΔV	delta (incremental) velocity

SUMMARY

The George C. Marshall Space Flight Center (MSFC) has the responsibility within the NASA for the geostationary platform - to initiate conceptual studies, develop feasible concepts, coordinate user needs and technology requirements, and promote activities aimed at system hardware solutions to the projected service demands of the 1990s. The schedule, as shown here, provides for a National Aeronautics and Space Administration (NASA) experimental platform in 1988 to validate required technology, and operational platforms with launch dates in the 1990s.



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Projected Development Schedule for Geostationary Platforms

On 31 may 1979, General Dynamics Convair was placed under contract to do the Initial Phase A Concepts Definition Study for the Geosta-ti[illegible]y Platform. NASA/MSFC's planned approach includes a review o[illegible]ommunications, military and science payloads, and mission models, development and analysis of operational and experimental platform concepts, identification of communications and platform technology requirements, and development of supporting programmatic data. Primary objectives of the study are to select and conceptually define operational geostationary platforms based on time-phased mission and payload requirements, and to develop attendant costs, schedules, and supporting research and technology (SRT) requirements. This data will be used as a basis for definition of the NASA experimental geostationary platform, which will be the subject of follow-on studies, although some preliminary precursor work on the experimental platform was done during this initial phase of the study.

Six tasks were defined in the Statement of Work (SOW) for this study:

Task 1 - Further Define Candidate Missions and Payloads.

Task 2 - Define Candidate Approaches/Concepts and Conduct Analyses and Trades Leading to Selected Concepts.

Task 3 - Define Selected Approaches and Concepts.

Task 4 - Define Supporting Research and Technology and Recommended Space Demonstrations.

Task 5 - Define Requirements On and Interfaces With STS Hardware Elements.

Task 6 - Define and Develop Cost and Schedule Data.

This document, Volume II of the final report, summarizes the technical and programmatic work performed in satisfying Tasks 1 through 5 of the Statement of Work and Study Plan requirements for these tasks. It contains in-depth discussions of the study elements, engineering data, and system and programmatic trades generated during the study. Parts 1 and 2 of this volume address operational and experimental geostationary platforms, respectively. Extensive data tables and drawings are documented in the appendixes (Volume II Supplemental Data), where appropriate.

Task 6, Cost and Schedules Data, is treated separately (Volume III of the Final Report), per data procurement document instructions.

A summary of Task 1 through 5 results follows.

In Task 1, candidate geostationary platform missions and payloads were identified from COMSAT, Aerospace, and NASA studies. These missions and payloads were cataloged; classified with respect to communications, military or scientific uses; screened for application and compatibility with geostationary platforms; and analyzed to identify platform support requirements. Two platform locations were then selected (Western Hemisphere - 110°W, and Atlantic - 15°W), and payloads allocated based on nominal and high traffic models considering communications payloads only, and considering communications plus secondary [Department of Defense (DoD) and science] payloads. In all cases, candidate payload requirements and characteristics were defined on three-page candidate payload data summary forms (Appendix E).

In Task 2, candidate platform concepts were defined and analyzed, and trade studies performed leading to recommendation of selected concepts. Of 30 Orbit Transfer Vehicle (OTV) configuration and operating mode options identified from data supplied by NASA/MSFC, 18 viable candidates compatible with the operational geostationary platform missions were selected for analysis. Each was considered using four platform operational modes - 8 or 16 year life, and serviced or nonserviced, providing a total of 72 OTV/platform-mode options. Standard platform concepts were defined for each of the 72 options for both the nominal and the high traffic models, and payloads reallocated to these 144 options based on OTV performance capability and payload weight and power. For final trade study concept selection, a cost program was developed considering payload and platform costs and weight; transportation unit and total costs for the Shuttle and OTV; and operational costs such as assembly or construction time, mating time, and loiter time. Servicing costs were added for final analysis and recommended selection.

The 144 candidate concepts were screened and the nine best options for combinations of launch and operating modes, transfer vehicles, and evolutionary buildup modes were analyzed. Four were recommended and selected by NASA for further study. Alternative #1 was designated for definition in Task 3. Alternatives #2, 3, and 4 were deferred to the follow-on study for further defintion.

Task 3 defines concept Alternative #1 as a data base for further geoplatform analyses in this study, in sufficient detail to identify requirements for supporting research and technology, space demonstrations, GFE interfaces, costs, and schedules. Alternative #1 consists of six platforms in geostationary orbit (GEO) over the Western Hemisphere and six over the Atlantic, to satisfy the total payload set associated with the nominal traffic model. Each platform is delivered to low earth orbit (LEO) in a single shuttle flight, already mated to its LEO-to GEO transfer vehicle and ready for deployment and transfer to GEO.

Although Alternative #4 was deferred to the follow-on study for further definition, it was looked at briefly in this initial study for comparison of configuration and technology requirements. Alternative #4 consists of two large platforms, one over the Western Hemisphere consisting of three docked modules, and one over the Atlantic (two docked modules), to satisfy a high traffic model. The modules are full-length orbiter cargo-bay payloads, mated at LEO to OTVs delivered in other shuttle flights, for transfer to GEO, rendezvous, and docking.

Alternatives #2 and 3, deferred to the follow-on study for definition, are respectively single-shuttle flight platforms docked at GEO and multiple-shuttle platforms in constellation at GEO.

Task 3 was expanded somewhat to include a preliminary feasibility study of an experimental platform to demonstrate communications and platform technologies required for the operational platforms of the 1990s. Six configurations were conceptually developed to consider a wide variation in payloads, structure, number of shuttle flights, and compatibility with available OTV performance characteristics. Results of this task (3A) are reported in Part 2 of this volume.

Task 4 identifies the SRT and space demonstrations required to support the 1990s Operational Platforms as typified by Concept Alternatives #1 and #4.

Task 5 identifies the requirements on and interfaces with STS hardware elements supporting the geostationary platform program, including the shuttle, orbital transfer vehicles, teleoperator, etc., to provide integrated support requirements to these programs.

The body of this volume concludes with a short preview of work to be accomplished on the follow-on study, in which operational platforms will be further characterized and concepts for an experimental geostationary platform further developed. Central to the further characterization of operational platforms will be the development of a multislot communications architecture using low-risk communications technology. Work on experimental geostationary platform concepts will concentrate on identifying affordable configurations compatible with potential upper stages.

PART I

OPERATIONAL GEOSTATIONARY PLATFORMS

SECTION 1

TASK 1: MISSIONS AND PAYLOADS DEFINITION

A prerequisite for the development of a geostationary platform system concept is the identification of missions and payloads suitable for inclusion in the system. Platform architecture is strongly influenced by payload configuration. If a large number of moderate size antennas are required, the structure must include many potential attachment points. Furthermore, the need to support several large multiple beam reflectors may severely limit structural design options.

Other important considerations are the locations of antennas/sensors and associated electronic units. Preamplifiers and transmitters need to be close to feed systems. Units with high heat dissipation must radiate to black space or be actively cooled by circulating fluids. Antennas radiating very narrow pencil beams will require high accuracy pointing, and a clear field of view.

Complex payload interconnection networks are needed for power distribution, command and control, communications, data management, and malfunction investigation. Payload design is an integral part of platform design and definition of the overall system concept is completely dependent on the character and requirements of the payloads selected for inclusion in the platform configuration.

The purpose of this task was to develop a comprehensive set of mission and payload requirements and present them in a form that would facilitate accomplishment of platform conceptual design.

Task 1 activities were separated into a sequence of subtasks, as illustrated in Figure 1-1. The object of this arrangement was to provide an orderly flow of data and analytical results from which to develop firm bases for mission/payload selection and allocation.

In the initial phase of Task 1, all missions considered to be potential candidates for platform installation were identified and cataloged according to origin and mission function, e.g., DoD, NASA, communications, observation, technology experiment, etc. Missions were further grouped in terms of required orientation and pointing accuracy.

In order to effectively size the payloads required to meet fixed point-to-point communications requirements, models of estimated demand for satellite communications during the years 1990 to 2000 were utilized to determine needed levels of domestic, regional, and transoceanic transponder capacity. These demand estimates covered the Americas, Western Europe, the Middle East, and Africa. The projected capacity levels incorporated voice, data, video distribution, and video conferencing services.

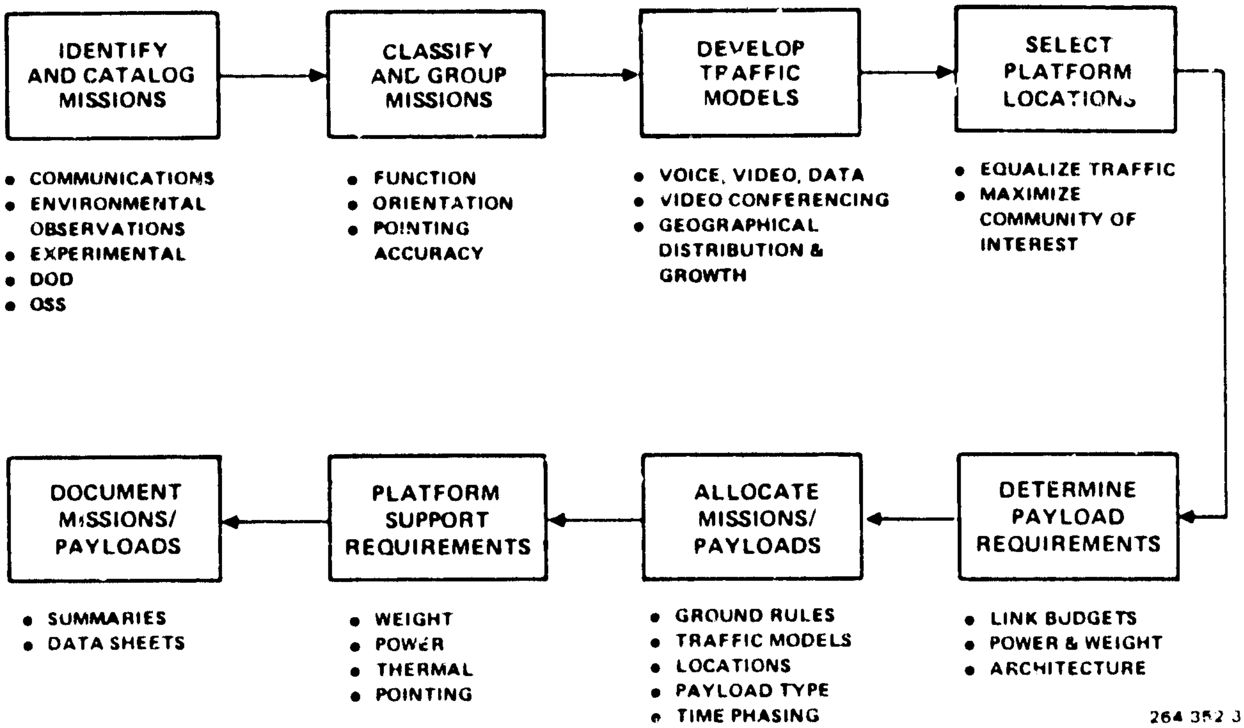


Figure 1-1. Task Objectives

Preliminary estimates of weight and power consumption were developed for communications and noncommunications payloads. These estimates were based on information derived from the input study material and limited discussions with potential payload sponsors.

The selection of candidate platform geostationary orbit locations was primarily based on communications user requirements. Two locations were selected. The location at 110°W provides full coverage of North, Central, and South America for domestic and regional communications. The field of view of the 15°W location includes Western Europe, the Middle East, and Africa. Thus, location also duplicates coverage of South America and the East Coast of North America to facilitate transoceanic communications.

Allocation of communications and noncommunications payloads to the two chosen orbit locations was based on user community grouping, balanced sharing of point-to-point communications traffic capacity, and the requirement for commonality of platform support equipment.

Primary payload characteristics, such as weight, power, thermal load, orientation and pointing accuracy were assessed in sufficient detail to permit estimates of the levels of support required from the platform subsystems.

All data generated and acquired in the performance of Task 1 has been documented. Relevant information includes payload data sheets, communications traffic models, link analyses, and summaries of payload characteristics. Data not contained in the body of the report can be found in the relevant appendix.

1.1 OBJECTIVES

The objectives of this task are to:

a. Develop a full and complete understanding of the individual and collective geostationary platform mission and payload requirements.

b. Identify and define additional missions that would be compatible with the platform concept.

c. Further define the missions and payloads selected by NASA as candidates for inclusion on a platform.

d. Collect, classify, and format all relevant mission/payload requirements data and document the material in easy reference form.

e. Coordinate payloads with platform locations in accordance with mission function and timing requirements.

1.2 INPUT DATA

Preliminary data on candidate missions and payloads considered suitable for inclusion in the geostationary platform configuration were supplied by NASA/MSFC at the commencement of the study program. These data included:

a. Specific requirements to be met by Task 1.

b. Ground rules under which the studies should be conducted.

c. Midterm reports from the 18/30 GHz service demand assessment and satellite communication system studies.

d. Midterm reports from the geostationary platform mission and payload requirements, and system feasibility studies.

e. Preliminary data on environmental sensing missions.

f. Preliminary data on DoD platform related missions.

A detailed listing of input data is given in Table 1-1.

The ground rules for mission/payload consideration in terms of allocation, priority, and time phasing were agreed as follows:

a. Communication payloads to be primary and noncommunication payloads secondary in priority of consideration.

b. Candidate payloads to be allocated to specific platform locations and time phased as appropriate.

c. Definition and analysis of platform support requirements at each location. First consideration to be given to communication payloads, followed by an assessment of the impact of accommodating the noncommunication payloads.

d. A minimum of two operational platform locations to be considered. These locations must meet the needs of the United States, Central America, South America, and Western Europe.

e. Commonality of equipment between subsystems elements and payloads to be a design goal.

f. Maximum use to be made of existing and projected technology for the time of frame of interest.

Table 1 1. Inpu Data

A. Marshall Space Flight Center

1. Interim and Final Reports, Geostationary Platform Mission and Payload Requirements Study NASA/MSFC Contract NAS8 33226 to COMSAT Corporation (1979)
2. Interim and Final Reports, Geostationary Platform Feasibility Study NASA/MSFC Contract NAS8-32881 to Aerospace Corporation (1979)
3. Preliminary Data on Candidate Science Payloads
4. Preliminary Data on Candidate Environmental Observation Payloads
5. Preliminary Data on Candidate DoD Payloads
6. Final Report, Geostationary Platform User Requirements NASA/MSFC Work Order H-3430B to Baker Development Corp. (1978)

B. NASA Hq. Office of Communications Program

1. Final Report, Large Communication Platforms Versus Smaller Satellites NASA/HQ Contract NASW-3212 to Future Systems, Inc. (1979)
2. Final Report, Application of Advanced On-Board Processing Concepts to Future Satellite Communications Systems, NASA/LERC Contract F19628-79-C-0001 to the MITRE Corporation (1979)
3. Final Report, 30/20 GHz Mixed User Architecture Development Study, NASA/LERC Contract NAS3-21933 to TRW Space Systems Division (1979)
4. Interim and Final Reports, 18/30 GHz Fixed Communications Systems Service Demand Assessment, NASA/LERC Contract NAS 3 834505 to Western Union Telegraph Co. (1979)
5. Interim and Final Reports, 30/20 GHz Fixed Communications Systems Service Demand Assessment, NASA/LERC Contract NAS3 21366 to U.S. Telephone and Telegraph Corp. (1979)
6. Interim and Final Reports, 18 and 30 GHz Fixed Service Communication Satellite System Study, NASA/LERC Contract NAS3-21367 to Hughes Space and Communications Group (1979)
7. Interim and Final Reports, Concepts for 18/30 GHz Satellite Communication System Study, NASA/LERC Contract NAS3-21362 to Ford Aerospace and Communications Corp. (1979)

In addition to the mission and payload data supplied by MSFC, projected satellite traffic models were received from NASA/LeRC and Future Systems, Inc. These models provided estimates of demand for satellite communications in the regions surrounding the Atlantic Ocean.

Additional input data were acquired and generated during the course of Task 1 as the need for additional material became apparent.

1.3 MISSION AND PAYLOAD IDENTIFICATION

A wide range of candidate missions and payloads has been identified from the input data supplied by NASA and DoD. A representative listing of 71 missions with their sponsors is shown in Table 1-2. The twelve operational communications missions were defined in the COMSAT and Aerospace studies. Data on the environmental observation missions and the RF interferometer were provided by NASA/MSFC. The experimental 30/20 GHz payload is being developed by NASA/LeRC.

Thirty-nine DoD space science and technology demonstration payloads were identified from the joint discussions of GDC, NASA, and Air Force Space Division. Information on fourteen additional space science payloads was provided by NASA HQ. Not all of these payloads need or can benefit from location on a geostationary platform. Some are not suited due to incompatibility, others present hazards to other payloads. Table 1-3 lists those payloads considered unsuitable with comments on the reasons for deletion.

A set of data sheets that contain currently available mission and payload information forms part of this report.

1.4 REQUIREMENTS DEFINITION

Three separate aspects of requirements definition were addressed during this phase of the study. Our basic approach was to consider 1) the basic user needs and concerns and relate them to the arrays of candidate missions and payloads identified in the previous section, 2) the specialized physical, electrical, and integration characteristics of each payload, and 3) the nature and degree of platform support needed to ensure satisfactory mission performance.

The optimum mission concept and platform configuration is a compromise between user requirements and system capabilities. The results of some exploratory discussions with organizations interested in the geostationary platform concept are shown in Table 1-4. During the course of the study, efforts were made to address some of the listed concerns. Social considerations were addressed through development of credible traffic models and identification of needed and potentially profitable services. An effort was made to ensure that all listed technical and economic concerns were included in the platform configuration trade studies.

Table 1-2. Candidate Missions

Payload No.	Mission/Payload	Sponsor
1	Direct to User (DTU)[1]	NASA (Aerospace and COMSAT Studies)
2	Domestic and Regional Trunking	
3	TV Distribution	
4	Tracking and Data Relay	
5	Educational TV	
6	Direct to Home TV	
7	Air Mobile	
8	Sea Mobile	
9	Land Mobile	
10	Transoceanic Trunking	
11	Intersatellite Links	
12	Data Collection	
17	Lightning Mapper	NASA/OSS
18	System 85 VISSR Atmospheric Sounder	NASA/MSFC
19	Visual and IR Radiometer } Severe Storm Research	
20	Microwave Radiometer } Severe Storm Research	
26	Experimental 30/20 GHz System	NASA/LeRC
27	RF Interferometer	NASA/MSFC
31	DMSP Data Relay	DoD
32	Advanced OLS Cloud Imager	
33	Materials Exposure/Unrecovered	
34	ACOSS/HALO Demonstration	
35	HALO Mirror Control Experiment	
36	Advanced Onboard Signal Processor	
37	Pulsed Plasma Millipound Thruster	
38	Aerosol and Cloud Height Sensor	
39	Solar Flare Monitor	
40	Solar Flare Isotope Monitor	
41	Energetic Proton Heavy Ion Sensor	
42	Global UV Radiance	
43	Magnetic Substorm Monitor	
44	Charged Particle Monitor	
45	Materials Exposure/Recovery	
46	Solar UV Irradiance	
47	Cosmic Ray Monitor	
48	Mini-HALO	
49	MSP	
50	Space Based Radar	

[1] Synonomous with "Customer Premise Services" (CPS)

Table 1-2. Candidate Missions, Contd

Payload No.	Mission/Payload	Sponsor
51	Cryogenic IR Radiator	DoD
52	BOSS Evaluation	DoD
53	GEMINI Evaluation	DoD
54	EHF System	DoD
55	Aircraft Laser Relay	DoD
56	Fiber Optics Demonstration	DoD
57	Space Sextant Demonstration	DoD
58	Passively Damped Structure	DoD
59	Thermally Stable Structure	DoD
60	ECCM Processing TDMA (Subset of 54)	DoD
61	Lasercom Space to Ground	DoD
62	Enhanced IR Emissions	DoD
63	AIRGLOW Far-UV Radiometers	DoD
64	Particle Beam Emission System	DoD
65	Particle Beam Ionospheric Effects	DoD
66	Particle Beam Plasma Precipitation	DoD
67	Dynamic Power System	DoD
68	Battlefield Illumination	DoD
69	Battlefield Cloud/Fog Dissipation	DoD
71	Optical Telescope	NASA/OSS
72	Particle Beam Injection	NASA/OSS
73	Chemical Release Module	NASA/OSS
74	Plasma Diagnostics	NASA/OSS
75	Spectrometric Observatory	NASA/OSS
76	Interferometer/Photometer	NASA/OSS
77	IR Occultation Instrument	NASA/OSS
78	Cryogenically Cooled Limb Scanner	NASA/OSS
79	Low Light Television	NASA/OSS
80	Plasma Wave Injection	NASA/OSS
81	Microwave Sounder	NASA/OSS
82	Soft X-ray Telescope	NASA/OSS
83	Hard X-ray Telescope	NASA/OSS
84	Bistatic Forward Scatter Radar	NASA/OSS

Table 1-3. Deleted Missions

No.	Mission/Payload	Comment
35	HALO Mirror Control Experiment	Technical Objectives Met by Mission #53
36	Advanced On-Board Signal Processor	Incorporated in Mission #53
37	Pulsed Plasma Thruster	Candidate Platform Subsystem
45	Materials Exposure (Recovered)	Low Earth Orbit Preferred
46	Solar UV Irradiance	Low Earth Orbit Preferred, Need Frequent Recalibration
47	Cosmic Ray Monitor	Low Earth Orbit Preferred, Incompatible
48	Mini HALO	Precursor to Mission #53
49	MSP	Precursor to Mission #53
50	Space Based Radar	Requires Dedicated Satellite
57	Space Sextant	Candidate for 1985 Demonstration
58	Passively Damped Structure	Candidate Platform Subsystem
59	Thermally Stable Structure	Candidate Platform Subsystem
60	ECCM Processing TDMA	Subset of Mission #54
61	Lasercom	Requires Highly Elliptical Orbit
62	Enhanced IR Emissions	Requires Shuttle Support
63	AIRGLOW for UV Radiometers	Requires Low Earth Orbit
64	Particle Beam Emission	RFI and Space Charging Hazard
65	Particle Beam Effects	RFI and Space Charging Hazard
66	Particle Beam Plasma Effects	RFI and Space Charging Hazard

Table 1-3. Deleted Missions, Contd

No.	Mission/Payload	Comment
67	Dynamic Power System	Radioactive Hazard
68	Battlefield Illumination	Requires Dedicated Satellite
69	Cloud and Fog Dissipation	Requires Dedicated Satellite
72	Particle Beam Injection Facility	RFI Hazard
74	Plasma Diagnostic Satellite	Related to Mission #72
80	Plasma Wave Injection	Related to Mission #72

1.4.1 MISSION/PAYLOAD GROUPINGS. To facilitate requirements analysis, missions and payloads were functionally grouped according to mission application, Table 1-5. The ordering of the groups also reflects priority of consideration. The criteria used for determining the order included: social benefit, return on investment, importance to national security, and degree of public support. Communication missions already have a high degree of acceptance and public support and can provide a substantial return on investment. Observational missions can have important applications to military security and public welfare but limited financial returns. The benefits of scientific experiments and technology demonstrations are generally long term with no immediate social or economic benefit.

Missions and payloads were also grouped according to orientation requirements. A geostationary platform will normally be oriented toward the earth to accommodate its primary mission of earth/space communications.

In Table 1-6, candidate missions and payloads are categorized by orientation requirements. Earth oriented mission groups include: communications, environmental observation, position location, and data relay. Sun and outer space oriented missions need autonomous tracking mechanisms that can follow the designated targets.

Many candidate payloads have very precise pointing requirements. It is generally difficult to control platform attitude to better than $\pm 0.1°$. Payloads requiring tighter tolerances must be individually stabilized. Table 1-7 indicates the levels of pointing accuracy required by the various payload groups.

Table 1-4. Platform Participant Concerns

Participant Function	Concerns			
	Technical	Economic	Legal/Political	Social/ Environmental
User	Performance Utilization Capacity Redundancy Servicing Connectivity Reliability Flexibility Interference 30/20 GHz	Undersea Cable Analogy Saturation Condominium Analogy Market for Platform Services	Competition versus Monopoly FCC Policy Platform versus Terrestrial	Message Quality Traffic Growth Projections
Regulator	Support for Shuttle	Cost to Consumer	Regulation Policy	Operator Training and Support
Management	Motivation and Priority	Demonstrate Cost Effective	Program Priorities	Public Image Health Hazards
Investor	Proven Technology Flexibility in OPS	High Return on Investment	Consortium of Users/Investors	High User/Public Acceptance
Insurer	Reliable Performance	Need for Insurance	Period of NASA Involvement	Risk to Taxpayers and Investors

Table 1-5. Mission Functional Classification with Payloads

---

1. Point-to-Point Communications
   - Direct to User Networks (No. 1)
   - Domestic and Regional Trunking (No. 2)
   - Transoceanic Trunking (No. 10)
   - Interplatform Links (No. 11)

2. Broadcast and Relay
   - TV Distribution (No. 3)
   - Tracking and Date Relay (No. 4)
   - Educational TV (No. 5)
   - Direct to Home TV (No. 6)
   - Data Collection (No. 12)

3. Mobile Communications
   - Air Mobile (No. 7)
   - Sea Mobile (No. 8)
   - Land Mobile (No. 9)

4. Environmental Observations
   - Lightning Mapper (No. 17)
   - VISSR Atmospheric Sounder (No. 18)
   - Visual and IR Radiometer (No. 19)
   - Microwave Radiometer (No. 20)

5. RF Interferometer (No. 27)

6. 30/20 GHz Communications (No. 26)

7. DoD Communications
   - DMSP Data Relay (No. 31)
   - EHF System (No. 54)
   - Aircraft Laser Relay (No. 55)

8. DoD Earth Observation
   - Advanced OLS Cloud Imager (No. 32)
   - Aerosol and Cloud Height Sensor (No. 38)
   - Global UV Radiance (No. 42)
   - BOSS Evaluation (No. 52)

9. DoD Solar Observation
   - Solar Flare Monitor (No. 34)
   - Solar Flare Isotope Monitor (No. 40)
   - Energetic Proton Heavy Ion Sensor (No. 41)
   - Charged Particle Monitor (No. 44)

Table 1-5. Mission Functional Classification with Payloads, Contd

10.	DoD Passive Exposure Material Exposure (No. 33) Magnetic Substorm Monitor (No. 43) Fiber Optics Demonstration (No. 56)
11.	DoD Technology Demonstrations ACOSS/HALO (No. 34) Advanced On-Board Signal Processor (No. 53) Cryogenic IR Radiator (No. 51) GEMINI Evaluation (No. 53)
12.	NASA/OSS Space Science Experiments Cryogenically Cooled Limb Scanner (No. 78) Soft X-Ray Telescope (No. 82) Hard X-Ray Telescope (No. 83)
13.	NASA/OSS Earth Observation Optical Telescope (No. 71) Chemical Release Module (No. 73) Spectrometric Observatory (No. 75) Interferometer/Photometer (No. 75) IR Occultation Instrument (No. 77) Low Light Television (No. 70) Microwave Sounder (No. 81)

Table 1-6. Mission Orientation

Mission Group	Orientation
Point-to-Point Communications (except Interplatform Links)	
Broadcast and Relay	
Mobile Communications	
Environmental Observations	Earth Pointing
RF Interferometer	
30/20 GHz Communications	
DoD Earth Observation	
NASA/OSS Earth Observation	
DoD Solar Observation	
NASA/OSS Space Science Experiments	Space Pointing
DoD Technology Demonstrations	
DoD Passive Exposure	

Table 1-7. Mission Pointing Accuracy Requirements

Mission Group	Pointing Accuracy
Environmental Observations NASA/OSS Space Science	$\leq 0.0003°$
DoD Communications DoD Earth Observation	$\leq 0.001°$
DoD Technology Demonstrations Point-to-Point Communications	$\leq 0.01°$
Broadcast and Relay Mobile Communications	$\leq 0.1°$
DoD Solar Observation DoD Passive Exposure	$\leq 1.0°$

1.4.2 TRAFFIC MODEL DEVELOPMENT. The power and weight requirements of the fixed point-to-point communication payloads are directly dependent on estimates of future traffic demand. To make such estimates, it is necessary to develop traffic models based on economic and demographic projections. Models must be developed on a country-by-country basis using forecasts of domestic, regional, and intercontinental communication requirements. The standard approach is to analyze trends in population growth and distribution and combine the data with forecasts of local and worldwide economic conditions. Population densities provide an indication of potential demand for communications, while the economic data indicate the extent to which the potential may be realized. The demand data thus developed must be further analyzed to determine the proportion that is subject to capture by satellite systems.

Parallel studies of the market for telecommunications services in the United States were recently completed by Western Union and the International Telephone and Telegraph Corporation. The studies were sponsored by the NASA Lewis Research Center in Cleveland. In the course of these studies, projections were made of: geographical distribution of traffic, traffic volume as a function of urban area size, and forecast traffic demand.

The demand for voice, data, and video services was forecast for the period from 1980 to 2000. Two types of forecast were made: 1) a baseline forecast predicated on an orderly growth of present services, and 2) an impacted baseline forecast modified by possible events such as widespread adoption of fiber optics technology and replacement of business travel by video conferences. In both cases, assessments were made of the amount of traffic subject to capture by satellite facilities. Preliminary estimates indicated a need for approximately 1100 standard satellite transponders in orbit over the U.S. by the year 2000. This figure was consistent with capture percentages of 25, 60, and 60 for voice, video, and data traffic respectively.

Similar traffic forecasts were developed for NASA Headquarters Office of Communication Programs by Future Systems, Inc. These forecasts differed in that they also covered forecasts for Atlantic Ocean Region international traffic.

It should be noted that the numbers quoted here and in the traffic models are sensitive to a number of variables, including: 1) fiber optics technology used as a means to extend satellite trunking systems to users; 2) fiber optics competition for long-haul transmission; 3) increasing sophistication of voice and video encoding equipment; 4) growth of packet switching as it affects efficiency of data transmission; and 5) impact of the energy shortage on business travel.

Future Systems, Inc., provided a substantial portion of the basic data and computer analyses used by Western Union and ITT and were also subcontractors to INTELSAT for international and foreign domestic satellite traffic projections. Because of their specialized knowledge in this area, FSI was asked to provide support to GDC in Task 1 by developing point-to-point satellite traffic projection models for the Americas, Western Europe, the Middle East, and Africa.

The model projections developed by FSI include forecasts for the basic voice, data, and video communication services. New and specialized services such as electronic mail video conferencing, electronic banking, etc., were also considered.

Traffic demand is routinely expressed in number of two-way voice circuits. A standard 40 MHz bandwidth satellite transponder can accommodate up to 1000 one-way voice circuits, 2 video transmissions, or 64 megabits of data. Thus, for the purpose of sizing communication payloads, it is convenient to express satellite traffic demand in numbers of equivalent 40 MHz transponders.

Conservative traffic projections based on current forecasts by telephone and telegraph agencies and common carrier organizations indicate a substantial increase in demand for satellite services by the year 2000. The five-year increases from 1990 to 2000 for the regions surrounding the Atlantic Ocean are shown in Table 1-8. The region designated Atlantic refers to East-West and West-East intercontinental communications. As might be expected, demand is highest in the developed regions of North America and Western Europe. Even with conservative rates of growth, either hemisphere will require well over 1000 transponders in orbit by the year 2000. These estimates make only a small allowance for the growth of new services. One area of communications which may experience spectacular expansion before the end of the century is video conferencing. Travel will become increasingly more expensive and inconvenient if the energy shortage continues and oil prices maintain their steep climb. There will be pressure for a reduction in government and business travel and more reliance on communication. This trend will increase the demand for efficient, economical and wideband communication links for telephony, facsimile transmission, and video conferencing. A combination of fiber optic technology, digital switching, and geoplatform communications can provide an integrated system of worldwide low cost wide band communications.

Table 1-8. Projected Voice, Data and Video Traffic in Equivalent 40 MHz Transponders, Nominal Traffic Model

Region	1990	1995	2000
North and Central America	550	700	870
South America	120	200	310
Western Europe	440	570	690
Middle East	130	220	320
Africa	40	60	100
Atlantic	160	240	480
Totals	1440	1990	2770

Since video conferencing can be considered as a substitute for travel, it is legitimate to use airline passenger statistics as a basis on which to forecast video conferencing requirements. Video conferenceing traffic estimates were made by FSI under the following assumptions: 5 percent of North American business air travel to be replaced by video conferencing in 1990. This factor will increase to 10 percent by the year 2000. Corresponding factors for the other regions are 1 percent in 1990 and 3 percent in 2000. The expected median demand for video conferencing based on this model is shown in Table 1-9. A further assumption is that 6 one-way video transmissions can be accommodated in a 40 MHz bandwidth. Note that the video conferencing estimates far exceed the demand for traditional services. This aspect of the model is highly controversial and dependent on a substantial reduction in video conferencing costs.

Table 1-9. Projected Video Conferencing Traffic in Equivalent 40 MHz Transponders

Region	1990	1995	2000
North and Central America	1470	2740	4270
South America	70	170	300
Western Europe	300	770	1270
Middle East	70	170	300
Africa	--	20	40
Atlantic	50	100	300
Totals	1960	3970	6480

The requirements listed in Table 1-8 were designated as the "nominal traffic model" to reflect their conservative nature. A "high traffic model" was also developed by adding half of the video conferencing traffic to the nominal traffic model, Table 1-10.

A detailed discussion of the geographically distributed traffic requirements and the population data from which they were derived is given in Appendix A. A preliminary analysis of video conferencing requirements over the same period (FSI report) is also provided, Appendix B.

1.1.3 PLATFORM LOCATIONS. Selection of locations for geostationary platforms is dependent on a number of factors. One must consider number and size of payloads, service areas, platform size, transportation costs, available orbit locations, equipment commonality, operating agencies, and user communities. Since a geostationary platform is inherently multimission and multipurpose, its location will be a compromise between the conflicting requirements of the various payloads. If platforms are located to serve specific regions, e.g., North America, South America, Western Europe, Atlantic, Africa, etc., each platform will have a different orbit location. However, the wide variations in traffic demand and

Table 1-10. Projected Voice, Video, Data and Video Conferencing Traffic in Equivalent 40 MHz Transponders, High Traffic Model

Region	1990	1995	2000
North and Central America	2020	3440	5140
South America	190	370	610
Western Europe	740	1340	1960
Middle East	200	390	620
Africa	40	80	140
Atlantic	210	340	780
Totals	3400	5960	9250

communication payloads support requirements will cause the platforms to differ substantially in power and weight characteristics (compare Western Europe and Africa). A more desirable approach is to equalize platform physical characteristics by choosing service areas with approximately similar traffic demands.

Regions listed in Table 1-8 and 1-10 have been consolidated into two groups designated Western Hemisphere and Atlantic respectively. The corresponding traffic demand forecasts are combined accordingly, Table 1-11. Total traffic projections for the Americas are roughly comparable with those forecast for Africa, Western Europe, and the Middle East. Two separate orbital locations were chosen to provide coverage of these two regional groups. Figures 1-2 and 1-3 show coverage corresponding to an earth station antenna elevation of 5°. The field of view for a platform located at 110°W, as shown in Figure 1-2, covers the Western Hemisphere with the exception of the Canadian far north and the northwest tip of Alaska. The field of view for a platform located at 15°W, Figure 1-3, covers Western Europe, Africa, the Middle East, South America, and the east coast of North America. The overlap between the two coverage patterns is designed to facilitate integration of domestic, regional, and transoceanic communications. Selection of these orbital locations takes advantage of the natural community of interest within the two groupings, and assists in the equalization of payload weight and power requirements. The physical characteristics of the platforms to be placed at these locations have yet to be determined. Their size and number will be a function of Shuttle and orbital transfer vehicle (OTV) payload capabilities, overall transportation costs, and mission requirements. In the event the payloads are divided amongst a number of smaller platforms, the need to maximize equipment commonality and provide for platform interchangeability will remain.

The nominal traffic model was the primary driver in orbital location selection. Inclusion of the video conferencing projections is likely to change the overall traffic distribution but should not affect coverage requirements.

Table 1-11. Multiregional Traffic in Equivalent 40 MHz Transponders for the Year 2000

Area	Nominal Traffic Model	High* Traffic Model
Western Hemisphere – 110°W (includes North, Central, and South America)	1180	5750
Atlantic – 15°W (includes Western Europe, Middle East, Africa, and Transocean)	1590	3500

*Includes Video Conferencing

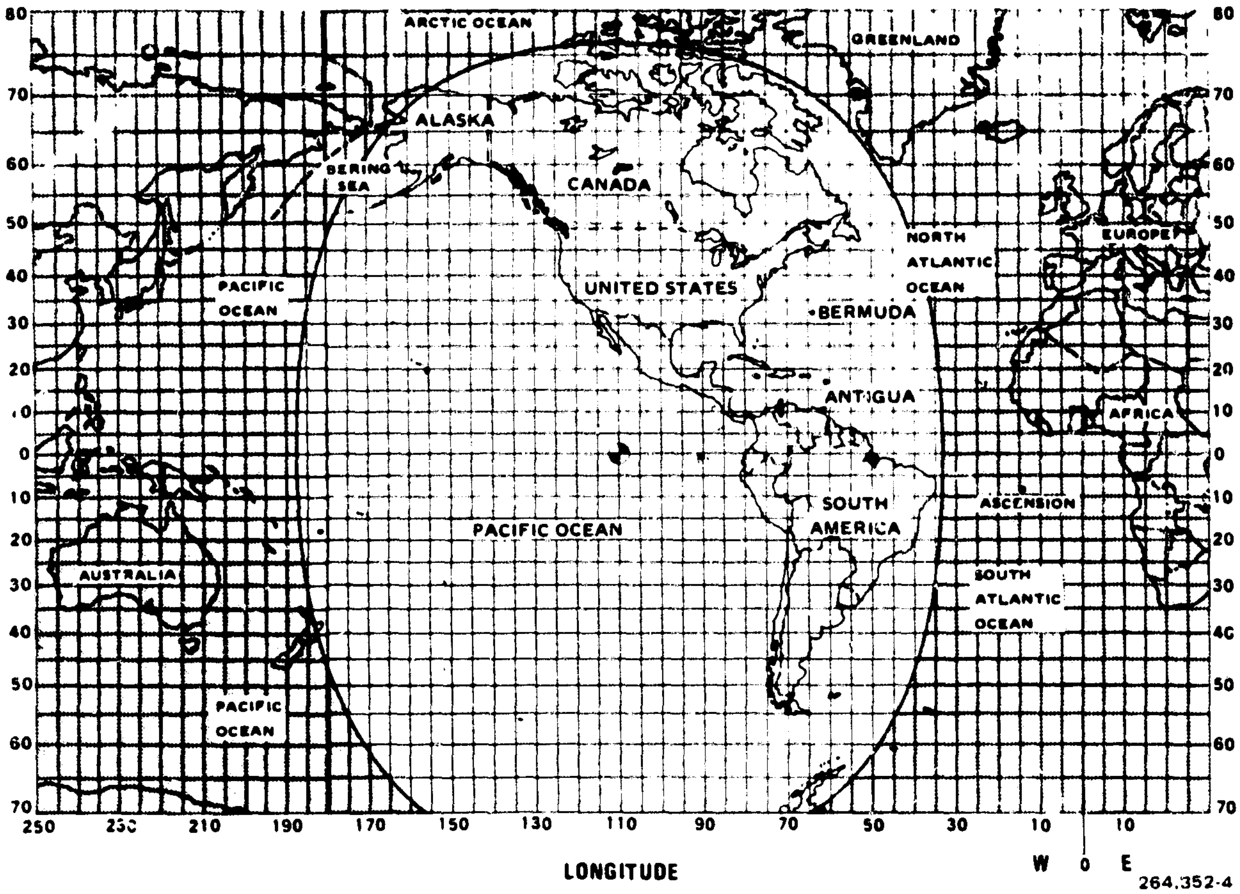


Figure 1-2. Western Hemisphere Coverage from 110°W, 5° Elevation Angle

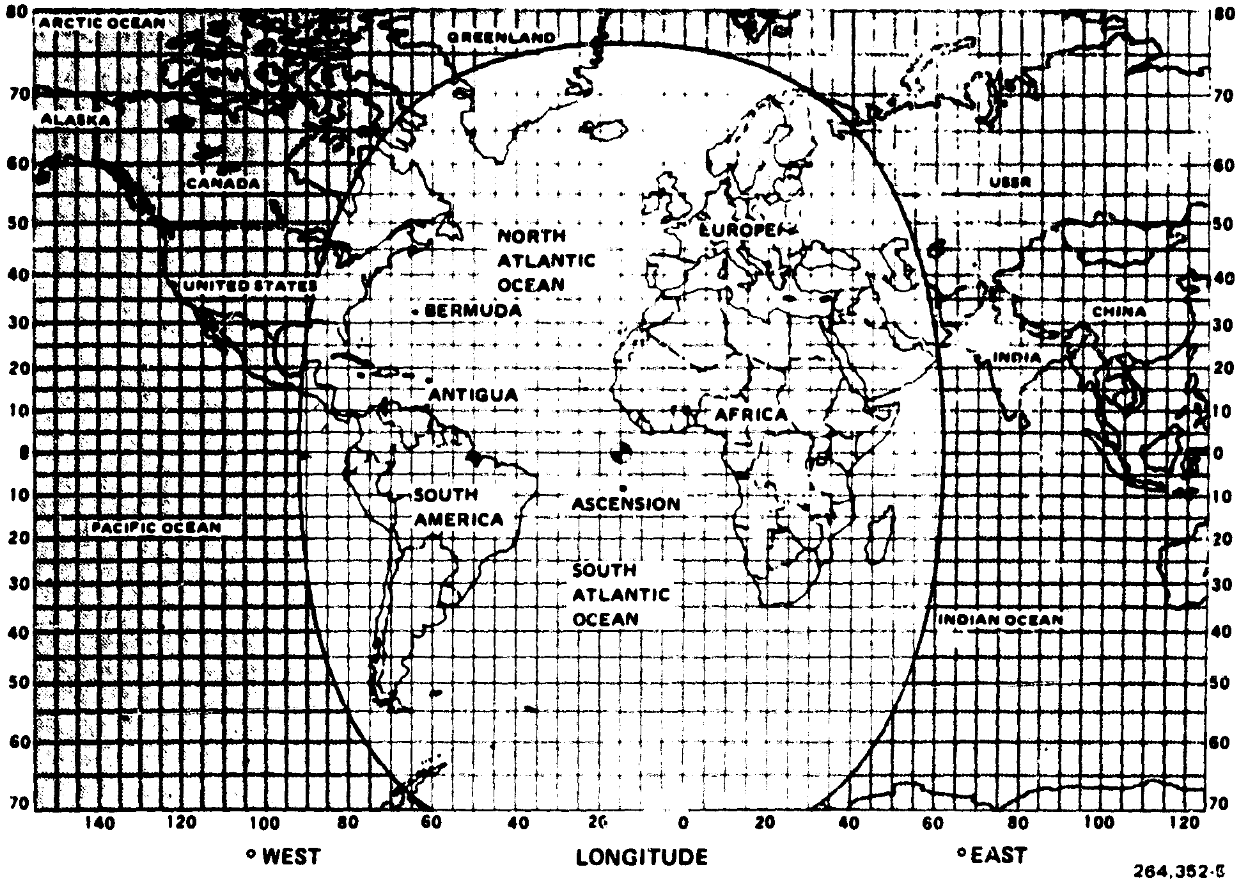


Figure 1-3. Atlantic Region Coverage from 15°W, 5° Elevation Angle

1.4.4 PAYLOAD ARCHITECTURE. The majority of the missions listed in Table 1-5 can be served by payloads that are not significantly affected by changes in the ground segment. The characteristics of the NASA and DoD payloads are determined primarily by the nature of the mission and the type of information required. The NASA and DoD missions are observational or experimental and payload architecture is determined by data output requirements, instrument sensitivity, and payload environment. Except for experimental communications payloads, output data will most likely be transmitted via the platform TT&C system or relayed through one of the point-to-point operational communications payloads.

The architecture of the eleven operational communications payloads is strongly influenced by the amount and character of the traffic to be handled. The fixed point-to-point communications payloads must be designed to meet the requirements of the traffic models described in Section 1.4.2. In this case the architecture is determined by coverage, bandwidth, power density, and ground segment characteristics. TV distribution and broadcast payload architecture are governed primarily by number of video channels needed and service area coverage. The majority of the ground stations are low cost receive-only units whose number and distribution have limited impact on payload architecture. Mobile communications payload architecture is relatively simple due to the small number of narrow band channels and the low level of traffic. Projections for aeronautical and maritime communications traffic are given in Appendix A. Estimated channel requirements are several orders of magnitude less than for fixed satellite communications. For data collection and relay payloads, the architecture depends on the amount of data to be handled and the number and frequency of accesses. The architecture of the TV, mobile communications, and data relay payloads is described in the final reports of the COMSAT and Aerospace studies. Summaries of payload primary characteristics are provided by the payload data sheets contained in Appendix E.

The fixed point-to-point communications payloads have been found to make the heaviest demands on platform weight and power support capabilities. The approach to point-to-point communications payload architecture is based on the recommendations contained in the report on the Geostationary Platform Feasibility Study conducted by Dr. Fred Bond of the Aerospace Corporation under contract to the Marshall Space Flight Center. Two basic types of service are envisioned: a direct-to-user (DTU) or customer premise service (CPS) system, and a high-volume trunking (HVT) system. The existence of two systems provides potential customers with options that can be related to technical and economic needs.

The architecture outlined above was developed to represent an extreme case in which all point-to-point services are provided from a single orbital slot, resulting in the need for highly advanced technology. Follow-on studies will look at alternative architectures using more than one slot with lesser demands on technology development.

The DTU or CPS system is based on contiguous coverage of the service area and service to large numbers of widely dispersed small to medium earth terminals with a range of capacities and transmission rates. The HVT system supplies coverage to selected high capacity earth terminals located in the vicinity of high population density urban areas to support and complement the existing terrestrial plant. Both systems employ dual frequency band operation. DTU traffic occupies uplink frequencies within the ranges 14.0 to 14.5 GHz and 27.5 to 28.7 GHz and downlink frequencies in the ranges 11.7 to 12.2 GHz and 17.7 to 18.9 GHz. HVT traffic occupies uplink frequencies in the ranges 5.925 to 6.425 GHz and 28.8 to 30.0 GHz and downlink frequencies in the range of 3.7 to 4.2 GHz and 19.0 to 20.2 GHz. Frequency allocations to specific earth terminals are based on traffic demand and local atmospheric propagation conditions. In general, service will be provided at the lower frequency bands with excess demand to be met by supplementary operation at the higher frequencies.

1.4.4.1 Direct to User System. The basic parameters of the DTU or CPS system are listed in Table 1-12. The system is designed to provide a maximum capacity of 1000 standard transponders. Contiguous coverage is provided over populated

Table 1-12. High Capacity Direct to User Payload Parameters To Meet Year 2000 Nominal Traffic Model

Description	Operating Frequencies 14/12 GHz	30/20 GHz
Spectrum Bandwidth	500 MHz	1200 MHz
Satellite Antenna Size	6m (3)	4m (3)
Antenna Configuration	Offset Cassegrain with Multiple Feed Array	Offset Cassegrain with Multiple Feed Array
Antenna Weight	100 kg	75 kg
Beamwidth	0.35°	0.35°
Beam Pointing	0.03°	0.03°
No. of Beams/Clusters	260	100
Dual Polarization	Yes	Yes
Transponder Bandwidth	40 MHz	40 MHz
Transponder Power	2 watts	5 watts
No. of Transponders	400	400
Transponders/Beam (Maximum)	8	20
Transponder DC Power (Unit/Total)	6/2500 watts	15/6000 watts
Transponder Weight (Unit/Total)	1.8/900 kg	2.2/1100 kg
Bit Rate per Transponder	64 Mbps	64 Mbps
Access	SS-TDMA/FDMA	SS-TDMA/FDMA
Modulation	QPSK	QPSK
Matrix Switch Size	400 x 400	400 x 400
DC Power	4000	4000
Weight	240 kg	240 kg
Earth Terminal		
Antenna Size	4.5/7m	4.5/7m
Transmit Power	200 watts	200 watts
Noise Temperature	225K	400K

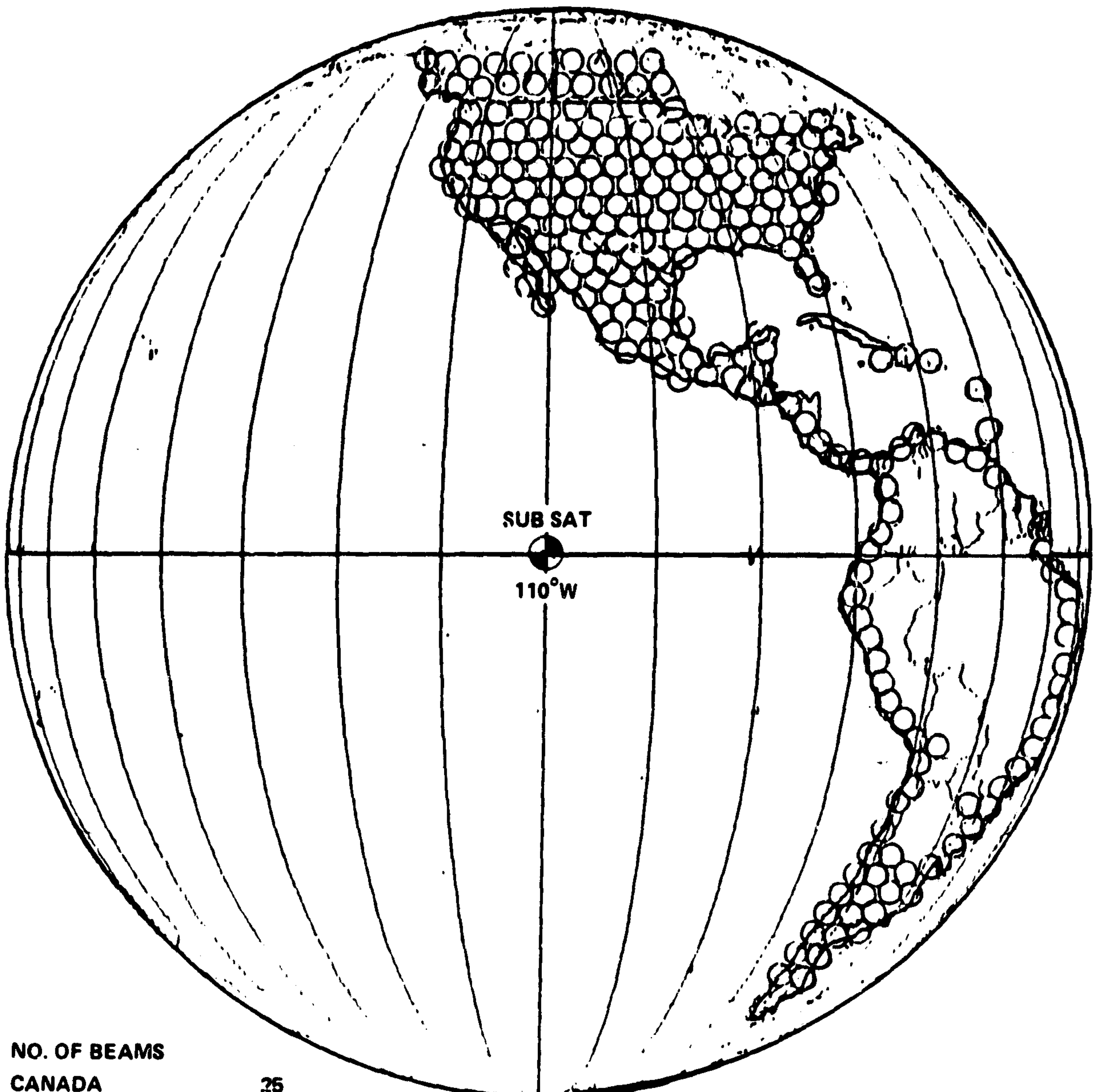
1. Antennas provide contiguous spot beam coverage of populated areas.
2. Dual frequency or single frequency earth stations can be used.
3. Estimated traffic capacity is 800 equivalent 40 MHz transponders.
4. Higher level (more bandwidth efficient) modulation may be required in high density traffic areas.
5. Detailed link analyses are provided in Appendix D.

areas in North, Central, and South America as shown in Figure 1-4. Adjacent beams use separate segments of the available spectrum. At Ku-band, the 500 MHz spectrum is split into three 160 MHz subbands. At Ka-band, a 1200 MHz segment of the available spectrum is split into 400 MHz subbands. A representative three-frequency plan for CONUS is shown in Figure 1-5. Beams radiating at the same frequency are spaced 2 beamwidths apart. A minimum of three multiple beam antennas are provided at Ku-band and also at Ka-band. Beam patterns are interlaced to minimize side lobe interference and maximize gain at the beam crossover points.

Traffic distribution for the DTU system is based on population density. An estimate of population distribution for contiguous cell sizes of approximately 0.35° is shown in Figure 1-6. The highest population concentration is in the northeast with approximately 8 percent of the total in the cell surrounding the New York area. This figure translates into a forecast maximum demand of 28 standard transponders per cell. Assuming use of dual polarization and QPSK modulation at both Ku and Ka band frequencies, a maximum of 28 transponders is available to meet this demand.

The contiguous beam configuration tends towards an excess of transponder capacity in thinly populated areas if a minimum of one transponder per cell is required. An alternative approach would be to replace groups of fixed beams by scanning beams tailored to local traffic patterns, and earth terminal distributions. Note that the scanning patterns must be synchronized to TDMA burst assignments and payload switch timing. Also, if a large number of locations are scanned by a single beam, a high burst rate is required with a corresponding increase in ground station complexity and cost. Because of the heavy demand concentration, NE area earth terminals are likely to be more sophisticated and expensive than those located in more sparsely populated regions.

1.4.4.2 High Volume Trunking System. The basic parameters of the HVT system are listed in Table 1-13. This system is also designed to provide a maximum capacity of 1000 standard transponders. Its purpose is to connect a limited number of terminals located at points of high traffic concentration. The key objective is to provide full frequency reuse to designated urban centers within the coverage areas specific to the Western Hemisphere and Atlantic orbital locations. Both C-band and Ka-band frequency spectrum allocations are utilized via 0.35° spot beams. In most cases beam separation is sufficient to permit full frequency reuse. In areas with closely spaced urban centers (less than two beamwidths) frequency subbands are allocated to adjacent or overlapping beams. Beams utilize single or dual polarization depending on capacity needs. Wideband transponders are employed to accommodate high burst rate transmissions from the earth segment. Additional capacity in high density areas is provided by going to higher level modulation schemes. A summary of capacity levels as a function of frequency band, polarization, and modulation is shown in Figure 1-7.



NO. OF BEAMS	
CANADA	25
U.S.	120
MEXICO	40
CENTRAL AMERICA	15
SOUTH AMERICA	60
TOTAL	260

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Figure 1-4. DTU Coverage, Western Hemisphere

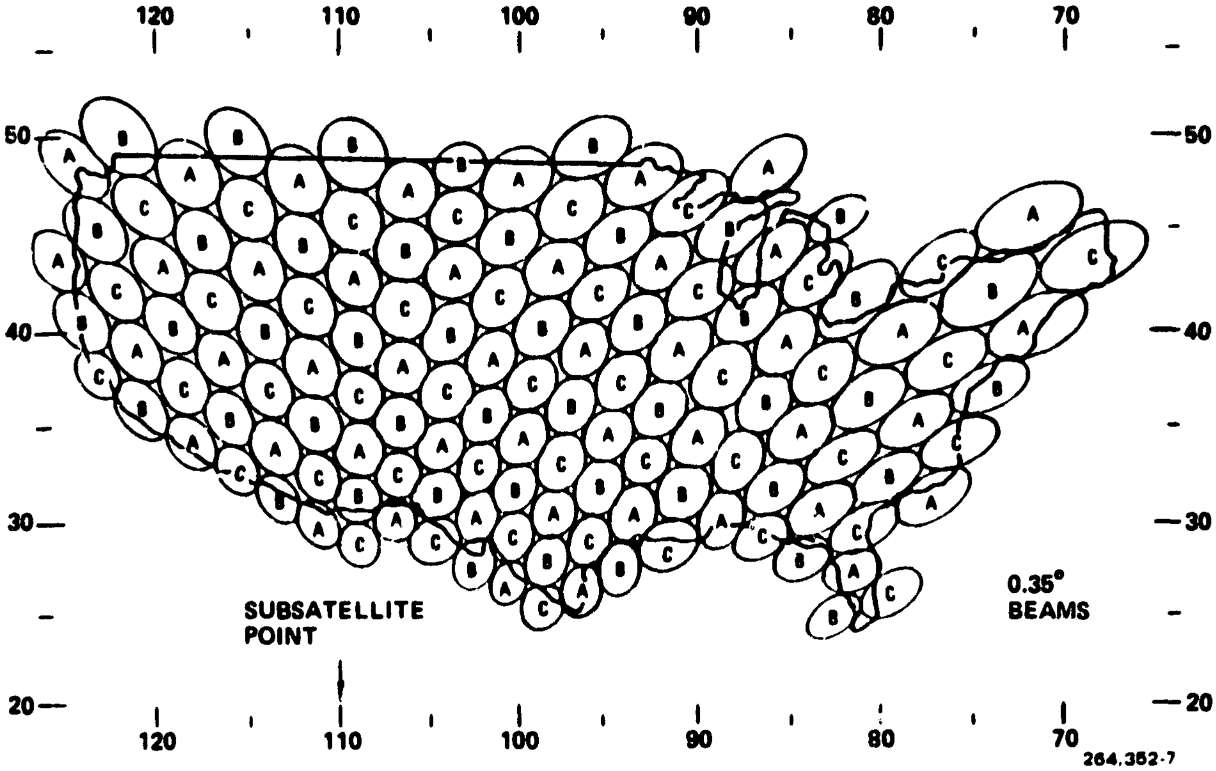


Figure 1-5. 0.35° Beam Footprint and Frequency Band Distribution

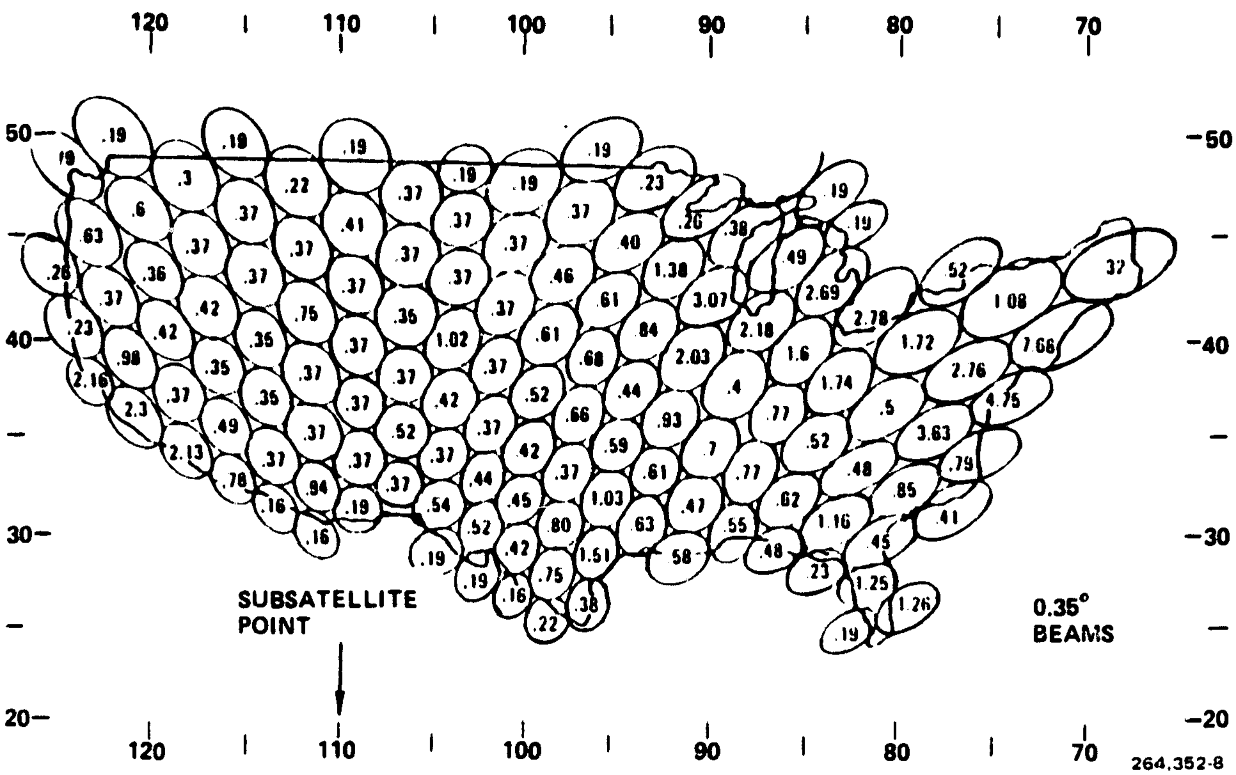


Figure 1-6. Percent Population Distribution

Table 1-13. High Volume Trunking Payload Parameters To Meet Year 2000 Nominal Traffic Model

Description	Operating Frequency 6/4 GHz	30/20 GHz
Spectrum Bandwidth	500 MHz	1200 MHz
Satellite Antenna Size	15m	4m
Antenna Configuration	Centerfed Cassegrain with Multiple Feed Array	Offset Cassegrain with Multiple Feed Array
Antenna Weight	100 kg	30 kg
Beamwidth	0.35°	0.35°
Beam Pointing	0.03°	0.03°
No. of Beams	65	35
Dual Polarization	Yes	Yes
Transponder Bandwidth	160 MHz	200 MHz
Transponder Power	1.0 watts	10 watts
No. of Transponders	125	100
Transponders/Beam (Maximum)	6	12
Transponder DC Power (Unit/Total)	3/400 watts	30/3000 watts
Transponder Weight (Unit/Total)	2.2/275 kg	2.7/270 kg
Bit Rate per Transponder	256 Mbps	256 Mbps
Access	SS-TDMA-FDMA	SS-TDMA/FDMA
Modulation	QPSK/16 APSK	QPSK/16 APSK
Matrix Switch Size	125 x 125	100 x 100
DC Power	250 watts	200 watts
Weight	30 kg	30 kg
Earth Terminal		
Antenna Size	12m	12m
Transmit Power	50 watts	300 watts
Noise Temperature	174K	478K

1. Antennas provide individual spot beams pointed at major traffic nodes that generally correspond with major urban centers. Beams are spaced at least two beamwidths apart to permit full frequency reuse.
2. Estimated traffic capacity is 800 equivalent 40 MHz transponders.
3. Weather outages at 30/20 GHz are compensated by site diversity.
4. Higher level modulation required in very high density traffic areas.
5. Detailed link analyses are provided in Appendix D.

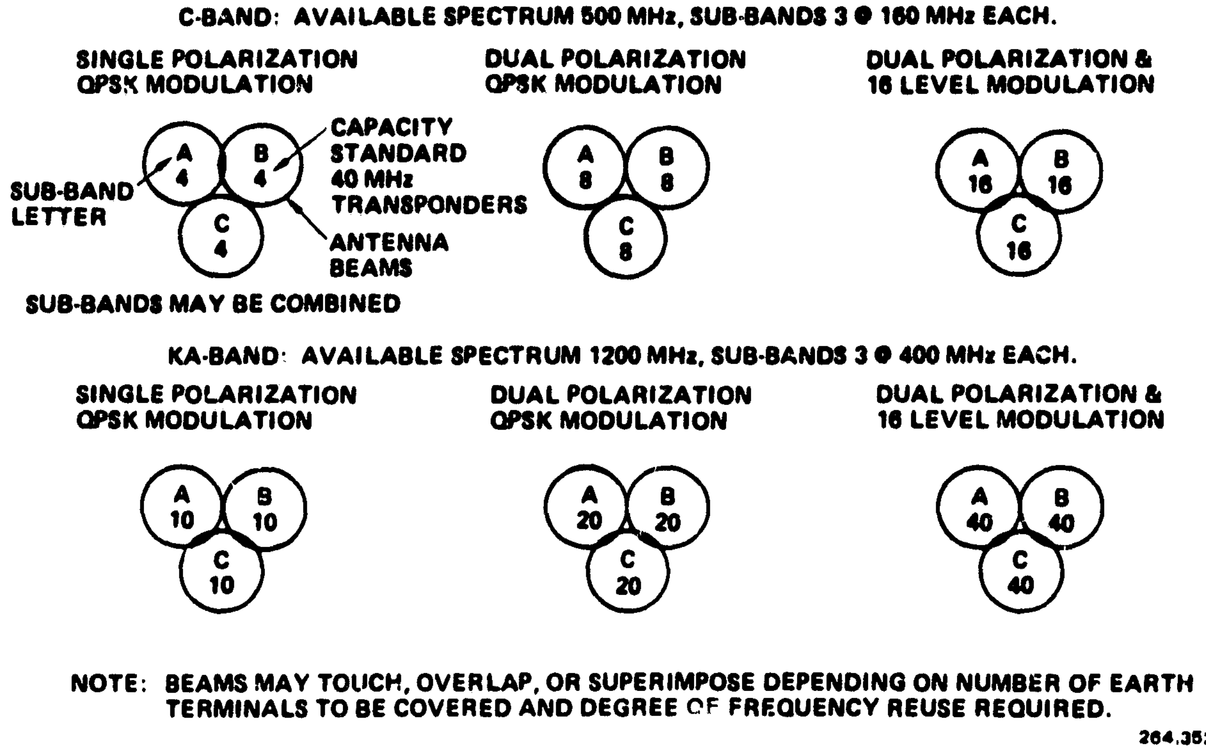


Figure 1-7. High Volume Trunking Payload Frequency Band and Capacity Distribution

A proposed multiple-beam, high-volume trunking coverage pattern for the Western Hemisphere is shown in Figure 1-8. C-band coverage from the 15-meter antenna would be provided at all the indicated locations with supplementary coverage at Ka-band, as required by traffic demand.

CONUS presents the most difficult coverage problems in the Western Hemisphere because of the high population density and concentration of urban centers in the northeast. Table 1-14 shows the traffic distribution in standard transponders for the 25 largest cities in the U.S. (representing 32 percent of the total population). The cities are ranged in order of population. Traffic requirements are proportional to the number of circuits over 500 miles long.

Table 1-15 shows the same 25 cities grouped geographically. There are four groups of cities that are too close to rely on frequency reuse through spatial separation of the beams. In these cases, the frequency bands must be split into subbands and dual polarization must be used to provide the required isolation. The most difficult case is the northeast corridor, from Boston to Washington, D.C.

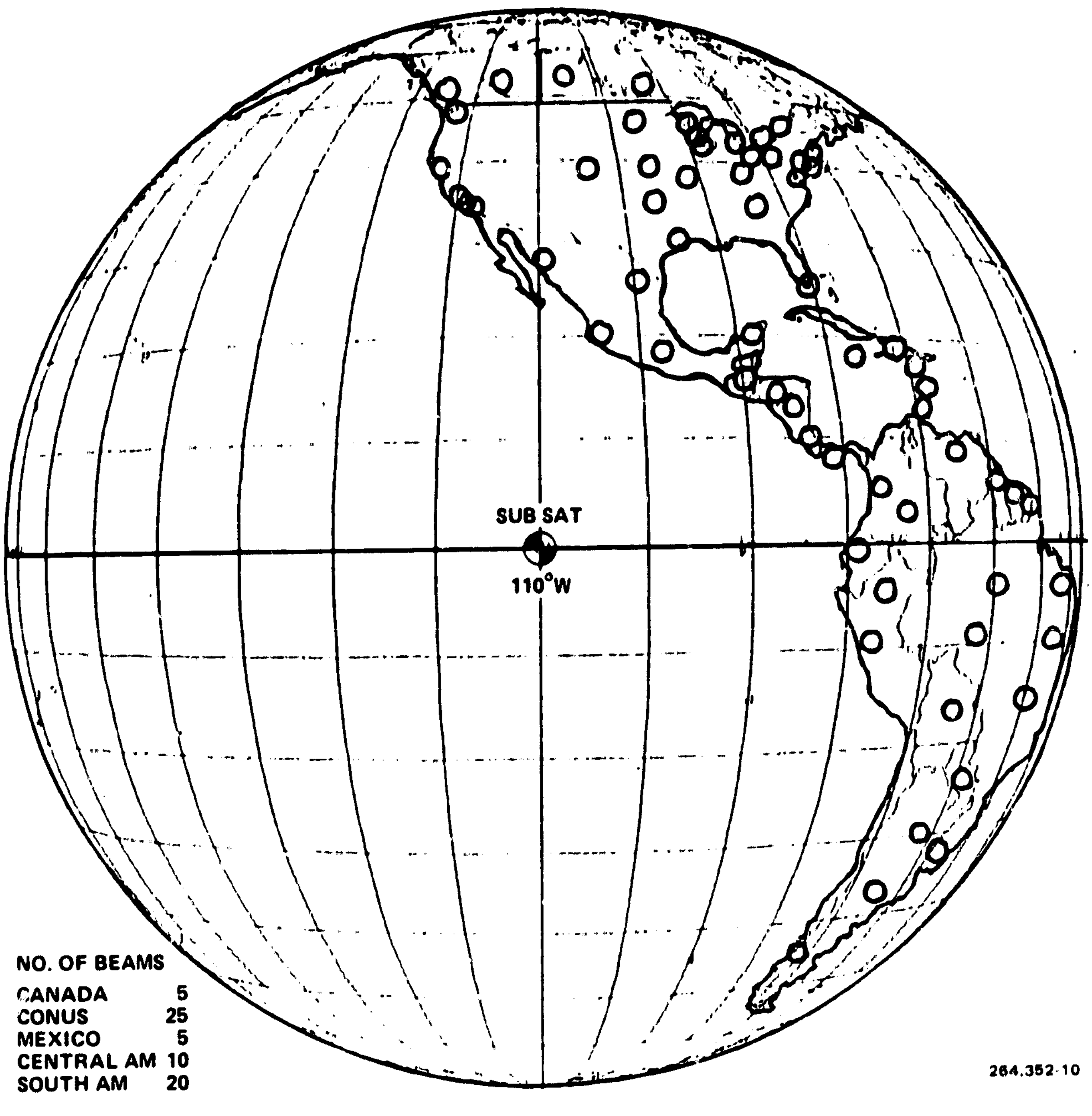


Figure 1-8. HVT Coverage, Western Hemisphere

Table 1-14. High Volume Trunking Traffic Distribution Over CONUS

Cities in Order of Population Density	Estimate of Standard Transponders Required
1. New York	75
2. Los Angeles	54
3. Chicago	31
4. Philadelphia	21
5. Detroit	23
6. San Francisco	19
7. Washington, D.C.	12
8. Boston	12
9. Pittsburgh	12
10. St. Louis	12
11. Baltimore	10
12. Cleveland	10
13. Houston	10
14. Minneapolis	9
15. Dallas	9
16. Seattle	8
17. Anaheim	6
18. Milwaukee	6
19. Atlanta	6
20. Cincinnati	6
21. San Diego	5
22. Buffalo	5
23. Miami	6
24. Kansas City	5
25. Denver	5

Table 1-15. HVT Payload Capacity Distribution

Traffic Node Location	Equivalent Transponders Required		Frequency Band	Beams Used	Subbands Used	Polarization Use	Modulation Type	Equivalent Transponders Available	
New York	75								
Philadelphia	21	118	C	3	3	Dual	16 APSK	48	168
Baltimore	10		Ka	3	3	Dual	16 APSK	120	
Washington, D.C.	12								
Boston	12		C	1	1	Dual	QPSK	8	28
			Ka	1	1	Dual	16 APSK	10	
Pittsburgh	12								
Cleveland	10		C	5	3	Dual	QPSK	40	90
Cincinnati	6	56	Ka	5	3	Single	QPSK	60	
Buffalo	5								
Detroit	19								
Chicago	31	37	C	3	3	Dual	QPSK	24	54
Milwaukee	6		Ka	3	3	Single	QPSK	30	
Los Angeles	54		C	3	3	Dual	QPSK	24	84
Anaheim	6	65	Ka	3	3	Dual	QPSK	60	
San Diego	5								
San Francisco	19		C	1	3	Dual	QPSK	24	
St. Louis	12		C	1	3	Dual	QPSK	24	
Houston	10		C	1	3	Dual	QPSK	24	
Minneapolis	9		C	1	3	Dual	QPSK	24	
Dallas	9		C	1	3	Dual	QPSK	24	
Seattle	8		C	1	3	Dual	QPSK	24	
Atlanta	6		C	1	3	Single	QPSK	12	
Miami	6		C	1	3	Single	QPSK	12	
Kansas City	5		C	1	3	Single	QPSK	12	
Denver	5		C	1	3	Single	QPSK	12	

Figure 1-9 shows one possible scheme for meeting the 20 year projected demand within the NE corridor. The beam footprints are for 0.35° beams from a platform at 110°W. The matrix accompanying each footprint indicates what specific frequency subbands and polarizations are used within that beam. The modulation scheme is also indicated, as well as the total number of equivalent transponders within the beam. For each of the major trunking modes within the corridor, the projected traffic demand is indicated, followed by the capacity of the beams to which it has access. New York City, for example, is projected to have a requirement for 75 equivalent transponders. It lies within four overlapping beams, two of which have capacities of 56 transponders and two of which have 20. This gives New York City access to 152 equivalent transponders. The excess capacity is shared with other cities as shown. Considerable margin for traffic growth exists. This scheme depends, of course, on foreseeable advances in technology. Improved linear amplifiers with distortion cancellation will lead to practical 16-level APSK. Message coding and redundancy will reduce depolarization and rain fade. Active sidelobe cancellation will improve isolation between beams spaced about 2 beamwidths apart.

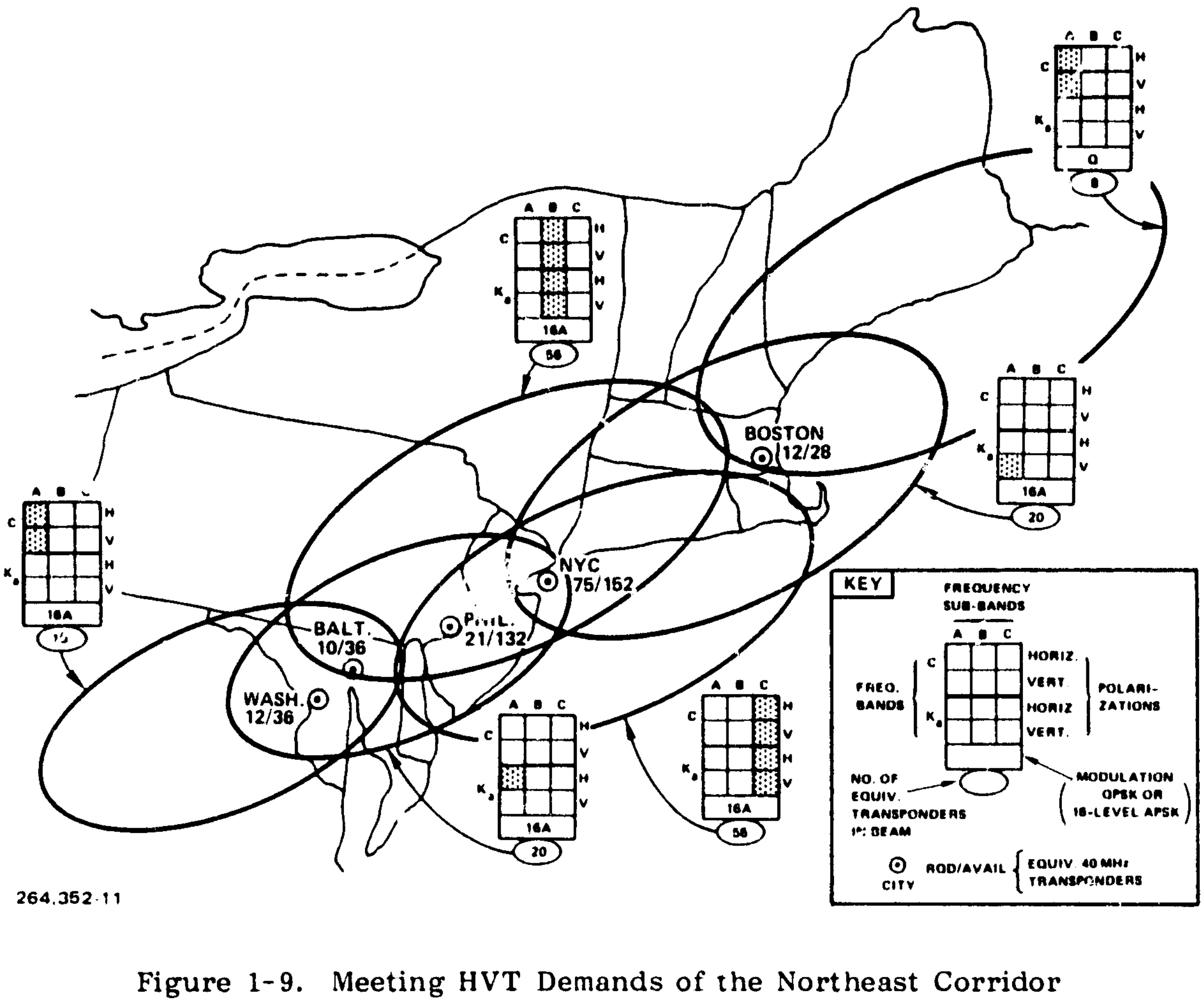


Figure 1-9. Meeting HVT Demands of the Northeast Corridor

1.4.4.3 Video Conferencing Services. As evidenced by the data in Tables 1-8 and 1-9, the impact of an expanding market for long-haul video conferencing services could substantially increase point-to-point communications payload capacity requirements. The demand would be greatest in the developed areas of North America with as much as a 5-fold increase in traffic. To meet these requirements, some changes to the baseline DTU and HVT payload architectures are proposed. It is assumed that the geographical characteristics of the nominal and high traffic models will be similar.

Tables 1-16 and 1-17 show the degree of payload upgrading needed to meet Western Hemisphere projected video conferencing requirements. Beamwidths have been reduced to 0.10° to meet the need for a substantial increase in capacity. Fixed and scanning spot beams are employed to ensure comprehensive and flexible coverage of both high density and thin route traffic. Earth station parameters are assumed to stay fairly constant with traffic growth to take advantage of the economics of large scale production.

1.4.4.4 Technology Requirements. Implementation of the communications payloads discussed in the previous sections will require significant state-of-the-art advances in a number of highly technological areas. These areas include:

a. Large aperture multiple beam frequency reuse antennas.

b. Large spaceborne switching/processing complexes.

c. High capacity interplatform links.

d. On-board signal regeneration and processing.

Two basic types of payload system configuration are likely to be employed. Figure 1-10 shows the baseline concept for a high volume trunking system. Each uplink beam carries an RF signal modulated with TDMA burst rates in the range of 240 Mbps to 320 Mbps. The bit streams are demodulated and processed to identify message destinations. Data from the received bit streams are switched to the appropriate downlinks by the base band switch matrix. The switch is programmed to interconnect given receive and transmit beams in accordance with a prearranged time and duration pattern. This pattern can be altered as required by the controlling ground station. Transmitted bit streams are modulated onto downlink carriers using burst rates similar to those on the uplinks. The principal requirement on a high volume trunking payload is maximum throughput between a limited number of high density traffic nodes serving complex terrestrial local distribution networks. This requirement implies numbers of well isolated narrow spot beams with full frequency reuse capability connected to wideband regenerative receivers and transmitters via a large baseband matrix switch capable of nanosecond switching times and controlled by a high speed logic operating system.

Table 1-16. High Capacity Direct-to-User Payload Parameters To Meet Year 2000 High Traffic Model

Description	Operating Frequency 14/12 GHz	30/20 GHz
Spectrum Bandwidth	500 MHz	1200 MHz
Satellite Antenna Size	20m	10m
Antenna Configuration	Centerfed Cassegrain with Phased Array Feed	Offset Cassegrain with Phased Array Feed
Antenna Weight	200 kg	100 kg
Beamwidth	0.1°	0.1°
Beam Pointing	0.01°	0.01°
No. of Beams	TBD	TBD
Dual Polarization	Yes	Yes
Transponder Bandwidth	40 MHz	40 MHz
Transponder Power	2 watts	5 watts
No. of Transponders	500	500
Transponders/Beam (Maximum)	8	20
Transponder DC Power (Unit/Total)	6/3000 watts	20/10,000 watts
Transponder Weight (Unit Total)	2/1000 kg	2.2/1100 kg
Bit Rate per Transponder	128 Mbps	128 Mbps
Access	SS-TDMA/FDMA	SS-TDMA/FDMA
Modulation	16 Level APSK/QPSK	16 Level APSK/QPSK
Matrix Switch Size	500 × 500	500 × 500
DC Power	4000 watts	4000 watts
Weight	240 kg	240 kg
Earth Terminal		
Antenna Size	4.5/7	4.5/7
Transmit Power	200 watts	200 watts
Noise Temperature	225K	400K

1. Antennas provide a mixture of contiguous spot beams, and scanning beams to match traffic distribution patterns and provide maximum frequency reuse.
2. Dual frequency or single frequency earth stations can be used.
3. Estimated traffic capacity is 2000 equivalent 40 MHz transponders.
4. QPSK modulation used where traffic volume does not justify higher levels.

Table 1-17. High Volume Trunking Payload Parameters To Meet Year 2000 High Traffic Model

Description	Operating Frequency 6/4 GHz	Operating Frequency 30/20 GHz
Spectrum Bandwidth	500 MHz	1200 MHz
Satellite Antenna Size	60m	10m
Antenna Configuration	Centerfed Cassegrain with Phased Array Feed	Offset Cassegrain with Phased Array Feed
Antenna Weight	500 kg	100 kg
Beamwidth	0.1°	0.1°
Beam Pointing	0.01°	0.01°
No. of Beams	TBD	TBD
Dual Polarization	Yes	Yes
Transponder Bandwidth	160 MHz	200 MHz
Transponder Power	1.0 watts	10 watts
No. of Transponders	125	100
Transponders/Beam (Maximum)	6	12
Transponder DC Power (Unit/Total)	3/500 watts	30/3200 watts
Transponder Weight (Unit/Total)	2.5/160 kg	3/300 kg
Bit Rate per Transponder	512 Mbps	512 Mbps
Access	SS-TDMA/FDMA	SS-TDMA/FDMA
Modulation	16 Level APSK/QPSK	16 Level APSK/QPSK
Matrix Switch Size	125 × 125	100 × 100
DC Power	400 watts	400 watts
Weight	30 kg	30 kg
Earth Terminal		
Antenna Size	12m	12m
Transmit Power	50 watts	300 watts
Noise Temperature	147K	478K

1. Antennas provide fixed and scanning spot beams directed at traffic nodes that generally correspond with urban centers. High density nodes are served by fixed beams; low density nodes are grouped and served by scanning beams. Beams are spaced to permit full frequency reuse.
2. Dual or single frequency earth stations can be provided at node locations.
3. Estimated traffic capacity is 2000 equivalent 40 MHz transponders.
4. Weather outages at 30/20 GHz are compensated by site diversity.
5. QPSK modulation used where traffic volume does not justify higher levels.

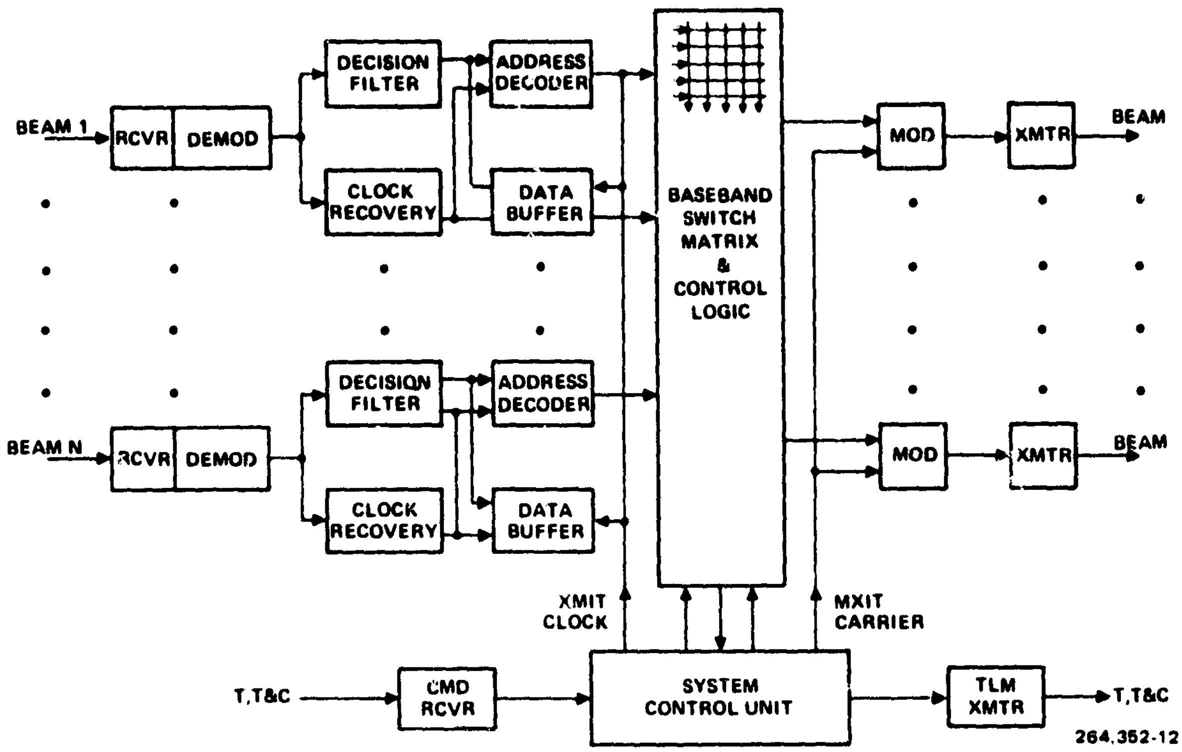


Figure 1-10. Baseline Concept for HVT Multiple Beam Circuit Switched TDMA Communication System

The configuration for a representative DTU (CPS) communications system is shown in Figure 1-11. In contrast to the HVT system, this approach uses a combination of TDMA and FDMA. Each uplink beam can serve several groups of small earth stations. The beam may be fixed or steerable depending on traffic density and geographic distribution. Frequency multiplexed TDMA carriers are received on the uplinks demodulated and temporarily stored in the input interface buffers. The data is shifted into receiver memories and processed to determine message destinations. Message data is then transferred to appropriate transmit stores by a time slot interchange technique similar to that used in terrestrial digital central offices. Data in the transmit memory is shifted into the output buffer over a parallel bus interface and formatted into several TDMA bit streams. The bit streams are modulated onto frequency multiplexed downlink carriers. The receiving earth stations pick off messages from the appropriate time slots for delivery to the required destination. The incremental message delay added by buffering and processing should not exceed 1/10 of the earth/space propagation delay (25 ms). Voice and picture transmissions are not noticeably affected.

Since it is desirable to interconnect all communications payloads for maximum flexibility and path redundancy, a common digital interface and interconnect bus system should be provided. It is anticipated that most major platform payloads will employ digital communications. Those that do not will require

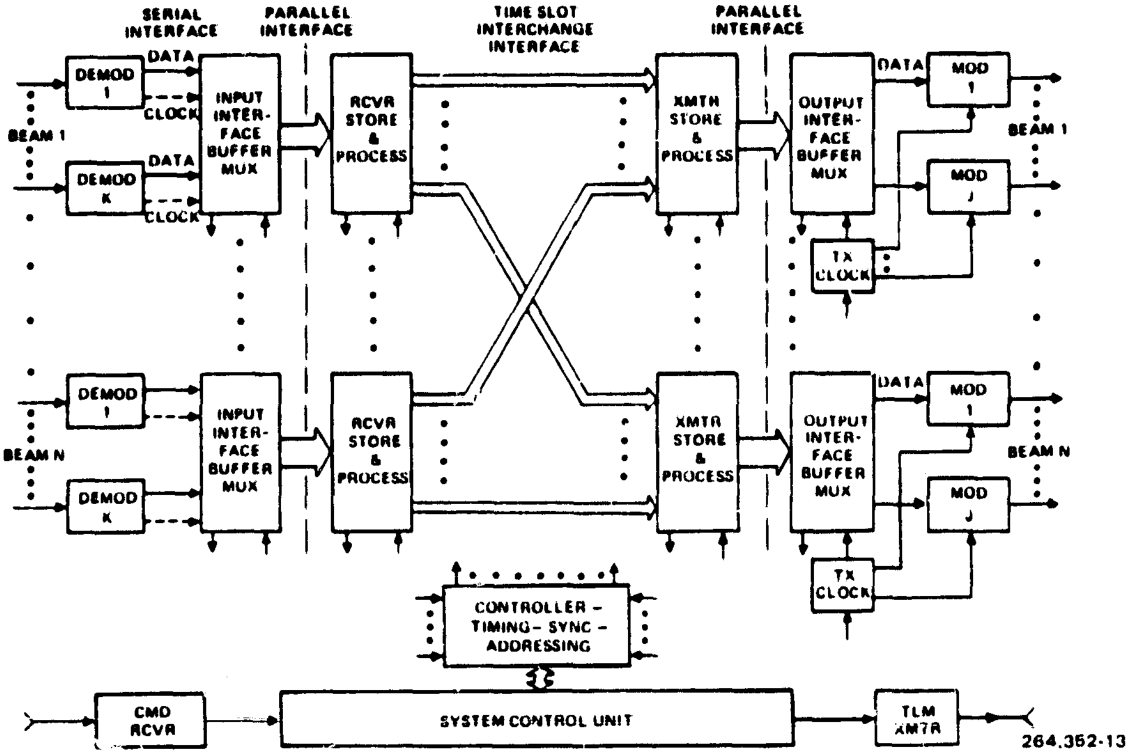


Figure 1-11. Baseline Concept for DTU, FDMA/TDMA Satellite Switched Multibeam Digital Processing Communications System

analog-to-digital conversion units. Data and messages flowing between payloads will be multiplexed onto data busses via microprocessors that determine destinations and select appropriate time slots. A central computer will control the peripheral processors and supervise the flow of data to and from the platform and between payloads. Figure 1-12 shows the approach to interconnection of the platform payloads in diagrammatic form.

The feasibility of large reflectors (greater than 10 meters) that can be deployed accurately to maintain surface shape for a decade of 200°C temperature variations encountered in space needs to be demonstrated. Large numbers of beams require complex feed systems with effective side lobe suppression characteristics and low loss distribution networks. Maintenance of low side lobe response (>30 dB) at all scan angles within the required field of view is especially important. A great deal of development work is needed to produce antennas with the kind of multiple beam performance needed to implement very high capacity communications payloads.

The use of multibeam antennas leads to a need for on-board switching (with or without processing) to provide the required connectivity between uplinks and downlinks. This need is especially critical for multimission geostationary platforms where in addition to intrapayload beam switching there is a requirement to interconnect payloads with related missions and functions. These needs

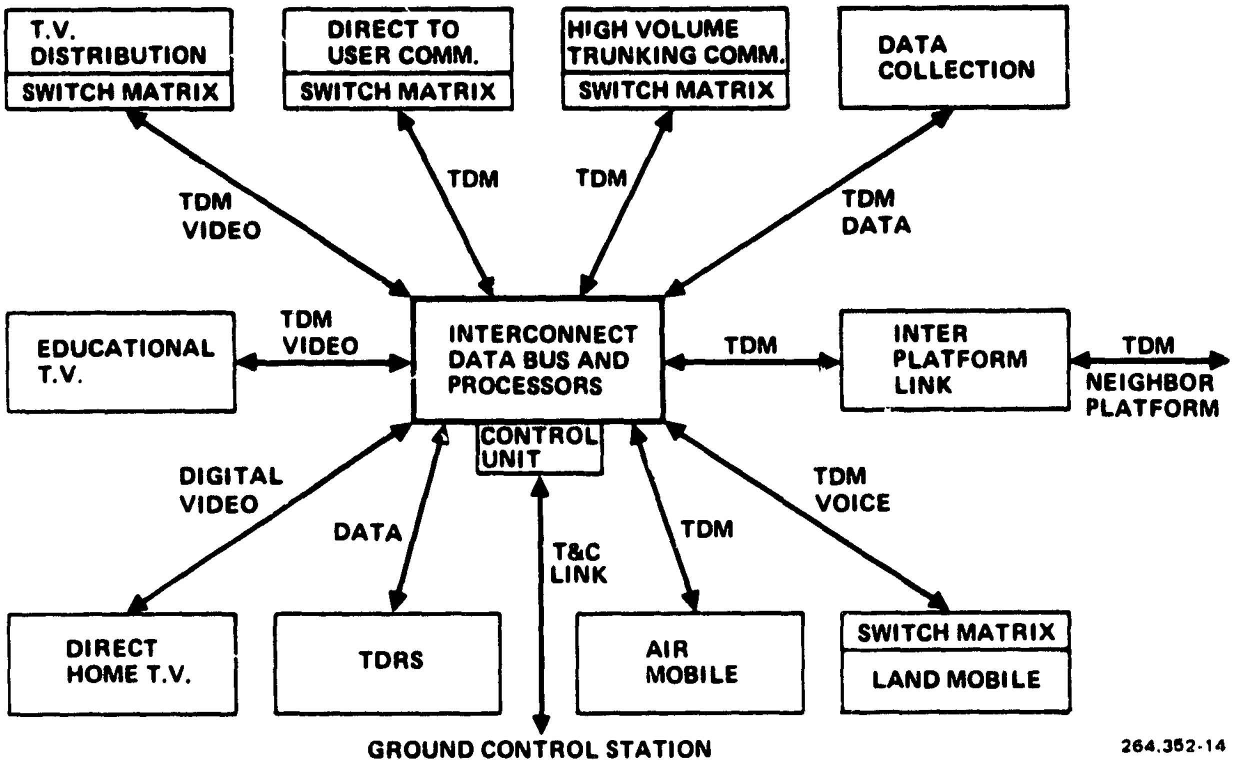


Figure 1-12. Platform Communications Payload Configuration

will be met by the development of multiport switch matrices. The basic crossbar and multistage switch matrix configurations are shown in Figure 1-13. The two classes of switching matrix are currently under development; RF/IF switching and base band switching. In RF switching, the incoming signal is converted to an IF of 4 to 12 GHz, passed through the switch matrix and reconverted for downlink transmission. The primary requirements for a microwave switch matrix are: better than 60 dB path isolation, less than 10 dB insertion loss, and nanosecond transfer times. A base band switch matrix with similar characteristics would be used in a regenerative transponder system where the incoming signals are demodulated before switching. The switch could also be part of a signal processor message routing, error correction, store and forwarding, etc.

Both RF and base band switches will be controlled by distribution control units (DCUs) designed to provide programmable cyclic sequences stored in memory, which operate the switch elements in the desired patterns. A remote command and telemetry link would supply control from the ground. Switching can also be accomplished directly in the time division mode where incoming data is stored in a large dynamic memory system and read out at the time appropriate for transmission to its destination, Figure 1-14. The major areas requiring attention in switch design are: integration and packaging of switches with large numbers of ports ($\geq 100 \times 100$) to keep weight and size within bounds; development of low power switching and control elements to limit power consumption; and design for reliable, long-life operation.

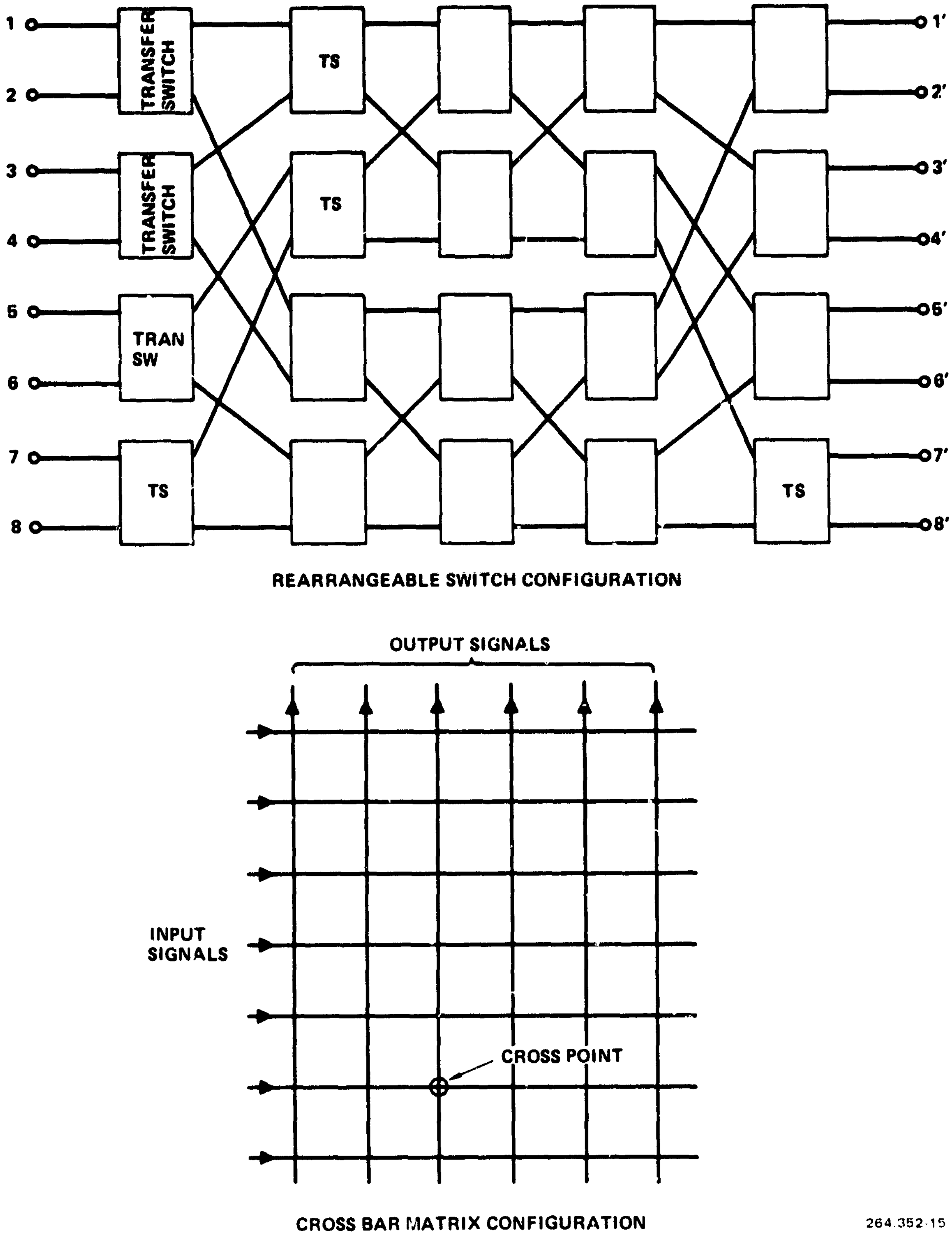


Figure 1-13. Matrix Switch Configurations

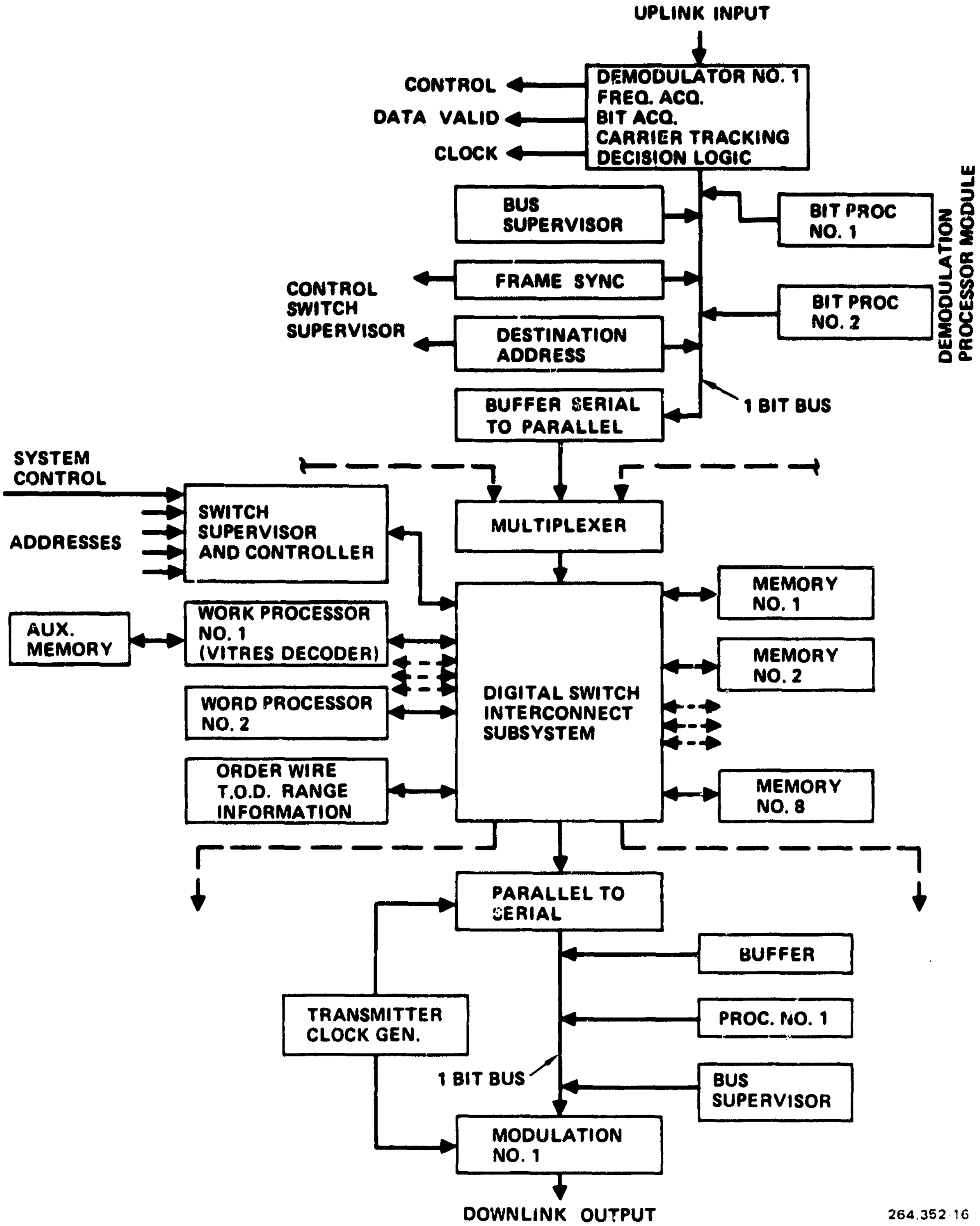


Figure 1-14. Baseband Processing Systems

A somewhat less critical but important technology is the development of interplatform links to carry traffic between platforms in neighboring and distant locations. An estimate of interplatform link traffic requirements, prepared by Future Systems Inc., is documented in Appendix C. These links can be implemented at microwave or optical frequencies. A microwave link has already been demonstrated between the LES 8 and 9 satellites. Very high capacity links may require the use of optical bandwidths.

Finally, the development of low cost highly reliable earth stations will play a substantial role in the spread of satellite communications. Ground equipment development and economics, including maintenance costs, will largely determine the feasibility of platform missions serving large numbers of earth stations. Bandwidth compression techniques will also be important in reducing operating costs and increasing system capacity.

1.4.5 PAYLOAD REQUIREMENTS. Each candidate payload must be defined in sufficient detail to permit reliable estimation of its primary physical and electrical characteristics. These data are basic to the design of the supporting platforms and define the character and level of support to be provided at the interfaces between payloads and platforms. The characteristics of the fixed point-to-point communications payloads are directly dependent on traffic demand and coverage requirements.

The architectures of the DTU and HVT payloads were discussed in detail in the previous section. Estimates of payload weight and power were made based on antenna size, number of beams, number of transponders, and the assumption that traffic demand would be equally shared between DTU and HVT services.

Table 1-18 lists the primary characteristics of the twelve operational communications payloads that include: quantity and size of antennas, pointing accuracy limits, operating frequencies, quantity, bandwidth and power of the payload transponders, and total payload weight and power requirements. Payloads 1, 2, and 10 are designed to meet the demands of the year 2000 nominal traffic model with some margin for forecasting error.

The remaining payloads are substantially less traffic-sensitive, and their characteristics are similar to those quoted in the COMSAT study. In some cases, adjustments have been made to compensate for increased area coverage requirements. Payload data are applicable to the Western Hemisphere (110°W) and Atlantic (15°W) locations. Note that the DTU and HVT payloads account for more than 50 percent of the total electrical and mechanical load requirements.

As was shown in Tables 1-16 and 1-17, the DTU and HVT architectures were upgraded to meet the substantially increased traffic demands of the year 2000 high traffic model. The multiple spot beamwidths were reduced from 0.35° to 0.1°. The numbers of beams were increased as needed to maintain contiguous coverage of populated areas. Where possible, rural areas requiring DTU services at low traffic levels were assumed to be served by a group of scanning beams. The effective capacity of the communications links was substantially increased

Table 1-18. Operational Communications Payload Data I[1]

Payload No.	Function	Antennas			Frequency		Transponders				Weight (kg)	Power (watts)	Comments
		No.	Size (meters)	Pointing Accuracy	Up (GHz)	Down (GHz)	No.	BW (MHz)	EIRP (dBW)	RF (watts)			
1	Direct to User Network	3	6.0	0.03°	14.0	12.0	400	40.0	51	2.0	1,240	6,500	Contiguous 0.35° Spot Beams
		3	4.0	0.03°	30.0	20.0	400	40.0	54	5.0	1,420	12,500	Baseband Switching
2 and 10	Domestic Regional and Transocean Trunking	1	15.0	0.03°	6.0	4.0	125	160.0	48	1.0	450	700	Dispersed 0.35 Spot Beams
		1	6.0	0.03°	30.0	20.0	100	200.0	57	10.0	380	3,200	Baseband Switching
3	TV Distribution	2	1.5	0.1°	17.0	12.0	75	40.0	53	10.0	400	4,000	Clusters of 1° Spot Beams
4	Tracking and Data Relay	2	5.0	–	22.0	2.1	2	5.0	30	26.0	330	680	TDRS Equivalent
		1	2.0	0.1°	15.0	13.0	1	225.0	58	30.0			
		1	Array	0.1°	2.2	2.1	1	5.0	50	–			
5	Educational TV	4	3.0	0.1°	14.0	2.5	16	17.5	36	3.0	480	400	Time Zone and Regional Spot Beams
		4	1.5	0.1°									
6	Direct to Home TV	1	1.5	0.1°	14.0	0.7	8	40.0	52	100.0	400	2,100	Regional Spot Beams
7	Air Mobile	1	Array	0.1°	1.6	1.5	5	5.0	38	20.0	200	1,200	Contiguous Regional Beams
		1	Horn		6.0	5.0	2	5.0	24	10.0			
8	Sea Mobile	1	Array	0.1°	1.6	1.5	2	5.0	30	60.0	400	600	Global and Regional Spot Beam Coverage
		1	20.0	0.1°	1.6	1.5	2	5.0	37	2.0			
		1	Horn	–	6.0	5.0	2	5.0	30	–			
9	Land Mobile	1	20.0	0.1°	0.9	0.8	30	20.0	45	30.0	530	4,000	Dispersed and Clustered Spot Beams
11	Interplatform	2	2.0	0.1°	62.0	55.0	2	1,000.0	60	65.0	100	300	East and West Looking Antennas
12	Data Collection	1	10.0	0.1°	0.4	0.4	4	0.03	14	1.0	100	100	Regional Spot Beams

[1] Compatible with year 2000 nominal traffic model.

by the use of more bandwidth efficient modulation techniques. Tables 1-19 and 1-20 show the parameters of the high traffic model communications payloads allocated to the Western Hemisphere and Atlantic locations.

The weight and power requirements of the DTU and HVT payloads at the Western Hemisphere location are substantially higher than those of the Atlantic location for the high traffic model. The differential arises from the unbalance in high traffic model forecasts. Note that the fixed point-to-point communications payload share of the total has risen to 75 percent for the Western Hemisphere location and 60 percent for the Atlantic location. This variation underlines payload sensitivity to differences in traffic demand. Changes in the characteristics of the other communications payloads reflect increased service demand and application of more advanced technology.

Payload data for the candidate secondary payloads are listed in Tables 1-21 through 1-24. Payloads in Table 1-21 support environmental observation and position location missions of considerable interest to the meteorological research community. The Department of Defense provided the data for the payloads listed in Table 1-22. The mission of these payloads is to demonstrate advanced space technology experiments and concepts with potential military applications. The payload data shown in Table 1-24 was supplied by the NASA Headquarters Office of Space Science. The primary purpose of these payloads is to support atmospheric and ionospheric scientific investigations. Each table contains those payload parameters considered to have primary effects on platform configuration and design. Most of the secondary payloads have relatively modest weight and power requirements. The priority task in platform design is to accommodate the large fixed point-to-point communications payload. Excess capability will be used to accommodate selected secondary payloads with flexible location and orientation requirement.

1.4.6 MISSION/PAYLOAD ALLOCATION. In view of the wide variety of missions and payloads that can be considered as suitable for installation on a geostationary platform, it is important to develop an order of priority. The mission categories to be considered include: communications, earth observation, military and scientific. These categories were evaluated for priority of candidacy in terms of social benefit, return on investment, importance to national security, and degree of public acceptance and support. When these criteria are applied, communications missions plainly take precedence over the others. Satellite communications already has a high degree of acceptance and public support; its social benefits are evident and the return on investment is such that a large number of commercial organizations have entered the field. The other mission categories also contribute important social benefits, but require taxpayer support, provide intangible returns, and are often short on public acceptance.

Taking account of the above considerations, the candidate missions and payloads were allocated in accordance with the flow chart shown in Figure 1-15. Allocation was based on mission category, orbital location, and type of traffic model. Earth observation, military, and scientific missions are secondary to the operational communications missions. The communications functions to be performed at the two orbital locations are essentially the same.

Table 1-19. Operational Communications Payload Data II[1] (Western Hemisphere Location)

Payload No.	Function	Antennas No.	Antennas Size (meters)	Antennas Pointing Accuracy	Frequency Up (GHz)	Frequency Down (GHz)	Transponders No.	Transponders BW (MHz)	Transponders EIRP (dBW)	Transponders RF (watts)	Weight (kg)	Power (watts)	Comments
1	Direct to User Network	2	20.0	0.01°	14.0	12.0	1,000	40.0	58	2	2,880	15,000	Fixed, Clustered and Scanning Beams
		2	10.0	0.01°	30.0	20.0	1,000	40.0	63	4	2,880	28,000	16 Level APSK Modulation
2	Domestic and Regional Trunking	1	60.0	0.01°	6.0	4.0	125	160.0	50	1	850	1,200	Fixed and Scanning Spot Beams
		1	10.0	0.01°	30.0	20.0	100	200.0	64	10	450	4,000	16 Level APSK Modulation
3	TV Distribution	2	1.5	0.1°	17.0	12.0	75	40.0	53	10	400	4,000	Clusters of 1° Spot Beams
4	Tracking and Data Relay	2	5.0	–	2.2	2.1	2	3.0	50	26	330	680	TDRS Equivalent
		1	2.0	0.1°	15.0	13.0	1	225.0	58	30			
		1	Array	0.1°	2.2	2.1	1	5.0	50	–			
5	Educational TV	4	3.0	0.1°	14.0	2.5	16	17.5	36	3	480	400	Time Zone and Regional Spot Beams
		4	1.5	0.1°									
6	Direct to Home TV	1	1.5	0.1°	14.0	0.7	8	40.0	52	100	400	2,100	Regional Spot Beams
		1	10.0										
7	Air Mobile	1	Array	0.1°	1.6	1.5	5	5.0	38	20	200	1,200	Contiguous Regional Beams
		1	Horn	-	6.0	5.0	2	5.0	24	10			
9	Land Mobile	1	60.0	0.1°	0.9	0.8	100	20.0	45	30	700	4,000	Dispersed and Clustered Spot Beams
11	Interplatform	2	2.0	0.1°	32.0	25.0	2	500.0	60	65	100	300	East and West Looking Antennas
12	Data Collection	1	10.0	0.1°	0.4	0.4	4	0.03	14	1	100	100	Regional Spot Beams

[1] Compatible with year 2000 high traffic model.

Table 1-20. Operational Communications Payload Data III[1] (Atlantic Location)

Payload No.	Function	Antennas No.	Antennas Size (meters)	Antennas Pointing Accuracy	Frequency Up (GHz)	Frequency Down (GHz)	Transponders No.	Transponders BW (MHz)	Transponders EIRP (dBW)	Transponders RF (watts)	Weight (kg)	Power (watts)	Comments
1	Direct to User Network	1	20.0	0.01°	14.0	12.0	500	40.0	58	2	1.440	7,500	Fixed, Clustered and Scanning Beams
		1	10.0	0.01°	30.0	20.0	500	40.0	63	5	1,440	14,000	16 Level APSK Modulation
2 and 10	Domestic Regional and Transocean Trunking	1	60.0	0.01°	6.0	4.0	125	160.0	50	1	850	1,200	Fixed and Scanning Spot Beams
		1	10.0	0.01°	30.0	20.0	100	200.0	64	10	450	4,000	16 Level APSK Modulation
3	TV Distribution	2	1.5	0.1°	17.0	12.0	75	40.0	53	10	400	4,000	Clusters of 1° Spot Beams
4	Tracking and Data Relay	2	5.0	–	2.2	2.1	2	5.0	30	26	330	680	TDRS Equivalent
		1	2.0	0.1°	15.0	13.0	1	225.0	58	30			
		1	Array	0.1°	2.2	2.1	1	5.0	50	–			
5	Educational TV	4	3.0	0.1°	14.0	2.5	16	17.5	36	3	480	400	Time Zone and Regional Spot Beams
		4	1.5	0.1°									
6	Direct to Home TV	1	1.5	0.1°	14.0	9.7	8	40.0	52	100	400	2,100	Regional Spot Beams
		1	10.0										
7	Air Mobile	1	Array	0.1°	1.6	1.5	5	5.0	38	20	200	1,200	Contiguous Regional Beams
		1	Horn	–	6.0	5.0	2	5.0	24	10			
8	Sea Mobile	1	Array	0.1°	1.6	1.5	2	5.0	30	60	400	600	Global and Regional Spot Beam Coverage
		1	20.0	0.1°	1.6	1.5	2	5.0	37	2			
		1	Horn	–	6.0	5.0	2	5.0	30	–			
9	Land Mobile	1	60.0	0.1°	0.9	0.8	100	20.0	45	10	700	4,000	Dispersed and Clustered Spot Beams
11	Interplatform	2	2.0	0.1°	32.0	25.0	2	500.0	60	10	100	300	East and West Looking Antennas
12	Data Collection	1	10.0	0.1°	0.4	0.4	4	0.03	14	1	100	100	Regional Spot Beams

[1] Compatible with year 2000 high traffic model.

Table 1-21. Environmental Observations and Position Location Payload Data

Payload No.	Function	Antennas No.	Antennas Size (meters)	Antennas Pointing Accuracy	Frequency Up (GHz)	Frequency Down (GHz)	Transponders No.	Transponders BW (MHz)	Transponders EIRP (dBW)	Transponders RF (watts)	Weight (kg)	Power (watts)	Comments
17	Lightning Mapper	1 7	1.0 Helices	$12° \times 10^{-3}$ ±0.5°	VIS 1.2	2	2	10	Platform Avionics Link		220	300	Optical Telescope 20 meter interferometer
18	Atmospheric Sounder	1	$0.7M^2$	±0.5°	V/IR	2	1	5			185	50	Uses modified VAS with built-in scanning and pointing
19	Visual and IR Radiometer	1	1.0	$\pm 3° \times 10^{-4}$	V/IR	2	2	10			500	100	Self-contained attitude control
20	Microwave Radiometer	1	4.5	±0.1°	EHF	2	1	2			136	150	X-Y Raster scan
27	RF Interferometer	7	–	±0.10°	1.2	2	-	–			112	215	Helix antennas mounted on 100 meter booms

Table 1-22. Candidate DoD Communications Payload Data I

Payload No.	Function	Orientation	Pointing Accuracy	Stability	Data Rate (bps)	Size (meter)	Weight (kg)	Power (W)	Comments
31	DMSP Data Relay Relay	Earth	0.3°	–	3M	–	150	100	Relay data from satellites in sun-synchronous orbit.
32	Line Scan Cloud Imager	Earth	0.01°	–	–	–	150	150	Will provide mosaic storage of cloud images.
33	Materials Exposure Unrecovered	Variable	–	–	–	–	10	25	Will monitor on-orbit failure of electronic devices and correlate with charged particle monitor.
34	ACOSS Demonstration	None	0.03°	Drift 0.2 μR Jitter 0.02 μR	–	–	–	–	Demonstration of active control of 4 meter diameter test structure.
38	Aerosol and Cloud Height Sensor	Earth	0.10°	–	–	0.75^3	50	100	Scanning telescope that senses heights of water vapor and gas layers.
39	Solar Flare Monitor	Sun	10.0	–	–	0.75^3	100	100	X-ray and gamma-ray imaging of solar surface.
40	Solar Flare Isotope Monitor	Sun	–	–	–	–	13	6	

Table 1-23. Candidate DoD Communications Payload Data II

Payload No.	Function	Orientation	Pointing Accuracy	Stability	Data Rate (bps)	Size (m)	Weight (kg)	Power (W)	Comments
41	Ion and Proton Sensor	Sun	–	–	–	–	8	6	
42	Global UV Radiance	Earth	0.1°	–	–	0.4^3	50	20	Imaging sensors scan earth's disc.
43	Magnetic Substorm Monitor	Variable	–	–	–	0.1^3	5	5	Measures in-orbit magnetic fluxes and fields.
44	Charged Particle Monitor	Sun	0.1°	–	–	0.1^3	5	10	Measures particles in range 1-100 eV. Need 2000 in^2 surface.
51	Cryogenic IR Radiator	None	–	–	–	10^2	120	–	Large low temperature passive cooler for IR sensors.
52	BOSS Evaluation	Earth	5 arc sec	1 arc sec	–	1^3	150	400	IR surveillance using 0.5 diameter telescope.
53	GEMINI Evaluation	Earth	5 arc sec	–	–	20^3	820	1800	IR surveillance using two 0.5 diameter telescopes.
54	EHF System	Earth	–	–	–	–	230	500	
55	Aircraft Laser Relay	Earth	–	–	–	–	320	550	
56	Fiber Optics Demonstration	None	–	–	–	–	12	30	

Table 1-24. Candidate NASA Science Payload

Payload No.	Function	Orientation	Pointing Accuracy	Stability	Data Rate (bps)	Size, (m)	Weight (kg)	Power (W)	Comments
71	Earth Optical Telescope	Earth		1 arc sec	50M	1.5 × 2	1100	2K	Study atmospheric structure.
73	Chemical Release Module Observation	Earth		0.01°	300K and Video	0.5 × 1.5	200	250	High altitude plasma investigations.
75	Spectrometric Observatory	Earth	0.1°	1 arc sec	2M	0.5 × 1.5 × 2.0	350	150	Atmospheric analysis.
76	Fabry-Perot Interferometer / Photometer	Earth	1 arc min	1 arc sec	50K	0.5 × 2.5	150	200	High resolution photometry and interferometry of atmospheric components.
77	IR Occultation Instrument	Earth	0.1°	1 arc min	4M	0.5 × 1.0 × 2.5	200	400	High resolution IR spectrometry.
78	Cryogenic Cooled Limb Scanner	Earth Limb	1 arc min	1 arc sec	1M	1 × 3	500	1500	Atmospheric temperature profiles.
79	Low Light Television	Earth	1 arc min	1 arc sec	300K and Video	1.0 × 2.5	300	1K	Auroral and air glow investigations.
81	Microwave Sounder	Earth and Sun	20 arc sec			0.5^3	50+	200	Centimeter and millimeter wave measurements.
82	Soft X-Ray Telescope	Earth	1 arc min	2 arc sec	500K	0.5 × 12	400	3K	Auroral X-ray emission measurements.
83	Hard X-Ray Telescope	Earth	1 arc min	2 arc sec	500K	0.5 × 12			
84	Bistatic Forward Scatter Radar	Earth	2°			0.75^3	700	100	Ionospheric measurements.

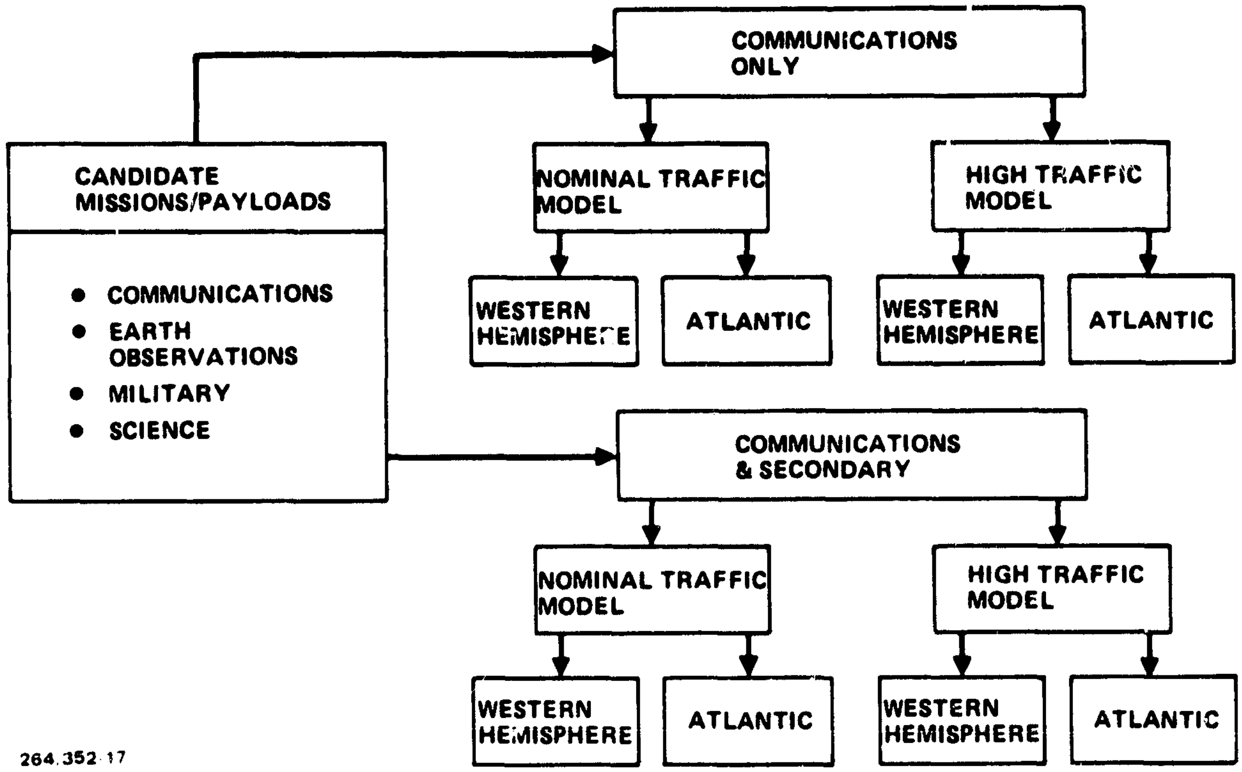


Figure 1-15. Mission/Payload Allocation Ground Rules

Table 1-25 shows the payload allocations for the Western Hemisphere location with analyses of the weight and power requirements for both the nominal and high traffic models. Similar data on the payload allocations to the Atlantic location are given in Table 1-26. Minor differences exist between the two allocation schemes, e.g., the sea mobile mission was not included in the Western Hemisphere list. However, a case could be made for providing a sea mobile payload at 110°W to serve shipping in the Eastern Pacific Ocean. Similarly, the direct-to-home TV mission was omitted from the Western Hemisphere payload allocation corresponding to the nominal traffic model. Recent developments in this area suggest that a demand for direct-to-home TV services may materialize more rapidly than was originally anticipated. Payload weight and power differentials derive from the contrasting demands of the nominal and high traffic models and some differences in payload versus technology such as the use of larger antennas and more complex feed systems.

The secondary payloads listed in Tables 1-21 through 1-24 were allocated to the Western Hemisphere and Atlantic locations to supplement the communications payloads and form multipurpose/multidisciplinary configurations. The communications plus secondary payload distributions for the two locations are shown in Tables 1-27 and 1-28. For convenience, the payloads have been partitioned into functional groups and the weight and power requirements pertaining to each group are listed in Tables 1-27 and 1-28. The number of each mission is also listed to facilitate identification. The advanced technology secondary

Table 1-25. Communications Payload Allocation, Western Hemisphere, 110°W

No.	Mission	Nominal Traffic Model Weight (kg)	Nominal Traffic Model Power (watts)	High Traffic Model Weight (kg)	High Traffic Model Power (watts)
1	Direct-to-User Network	2,660	18,000	5,760	43,000
2	Domestic and Regional Trunking	830	3,900	1,300	5,200
3	TV Distribution	400	4,000	400	4,000
4	Tracking and Data Relay	330	680	330	680
5	Educational TV	480	400	480	400
6	Direct to Home TV	—	—	440	2,100
7	Air Mobile	200	1,200	200	1,200
9	Land Mobile	530	4,000	700	4,000
11	Intersatellite	100	300	100	300
12	Data Collection	100	100	100	100
		5,630	32,580	9,770	60,980

Table 1-26. Communications Payload Allocation, Atlantic, 15°W

No.	Mission	Nominal Traffic Model Weight (kg)	Nominal Traffic Model Power (watts)	High Traffic Model Weight (kg)	High Traffic Model Power (watts)
1	Direct-to-User Network	2,660	18,000	2,880	21,500
2 & 10	Domestic and Regional and Transocean Trunking	830	3,900	1,300	5,200
3	TV Distribution	400	4,000	400	4,000
4	Tracking and Data Relay	330	680	330	680
5	Educational TV	480	400	480	400
6	Direct-to-Home TV	400	2,100	400	2,100
7	Air Mobile	200	1,200	200	1,200
8	Sea Mobile	400	600	400	600
9	Land Mobile	530	4,000	700	4,000
11	Intersatellite	100	300	100	300
12	Data Collection	100	100	100	100
		6,430	35,280	7,290	40,080

Table 1-27. Communications and Secondary Payload Allocations, Western Hemisphere, 110°W

Payload Grouping	Mission No.	Weight (kg)	Power (watts)
Nominal Traffic Model			
Point-to-Point Communications	1, 2	3,490	21,900
Broadcast and Relay	3, 4, 5, 11, 12	1,410	5,480
Mobile Communications	7, 9	730	5,200
Environmental/Observation	17, 18, 19, 20, 27	1,250	820
Military Communications	31, 54, 55	700	1,150
Earth Observation (DoD)	32, 38, 42, 52	400	670
Passive Exposure (DoD)	33, 43, 56	30	60
Space Science (NASA)	71	1,100	2,000
		9,110	37,280
High Traffic Model			
Point-to-Point Communications	1, 2	7,060	48,200
Broadcast and Relay	3, 4, 5, 6, 11, 12	1,810	7,580
Mobile Communications	7, 9	900	5,200
Environmental/Observation	17, 18, 19, 20, 27	1,250	820
Military Communications	31, 54, 55	700	1,150
Earth Observation (DoD)	32, 38, 42, 52	400	670
Passive Exposure (DoD)	33, 43, 56	30	60
Earth Observation (OSS)	71, 73, 75, 76, 77, 79, 81, 84	3,150	4,350
High Technology Space Science (OSS)	78, 82, 83	900	4,500
		16,200	72,530

Table 1-28. Communications and Secondary Payload Allocations, Atlantic, 15°W

Payload Grouping	Mission No.	Weight (kg)	Power (watts)
Nominal Traffic Model			
Point-to-Point Communications	1, 2, 10	3,490	21,900
Broadcast and Relay	3, 4, 5, 6, 11, 12	1,810	7,480
Mobile Communications	7, 8, 9	1,130	5,800
Environmental/Observation	17, 18, 27	620	570
Military Communications	31	150	100
Solar Observation (DoD)	39, 40, 41, 44	130	120
Space Science (OSS)	73, 75, 76, 77, 79, 81, 84	2,050	2,350
		9,380	38,320
High Traffic Model			
Point-to-Point Communications	1, 2, 10	4,180	26,700
Broadcast and Relay	3, 4, 5, 6, 11, 12	1,810	7,580
Mobile Communications	7, 8, 9	1,300	5,800
Environmental/Observation	17, 18, 27	620	570
Military Communications	31	150	100
Solar Observation (DoD)	39, 40, 41, 44	130	120
High Technology Surveillance (DoD)	34, 36, 51, 53	2,500	3,000
		10,690	43,870

payloads have in general been allocated to the set that serves the high traffic model. Inclusion of the secondary payload at either orbital location results in a substantial increase in overall weight and power requirements. Allocation of the secondary payloads was based on, 1) mission geographic and orientation requirements; 2) maintenance of rough equivalence in weight and power at the two locations; and 3) level of technology.

It should be noted that totalling the payload weight and power requirements is not meant to imply commitment to a single large platform at each location. The objective is to show the range of candidate payloads, their disciplinary groupings, and the potential impact on platform design. Discussions concerning the accommodation of these collections of payloads on one or more platforms are not appropriate to this task. Figure 1-16 presents a diagrammatic summary of the results of the payload allocation process.

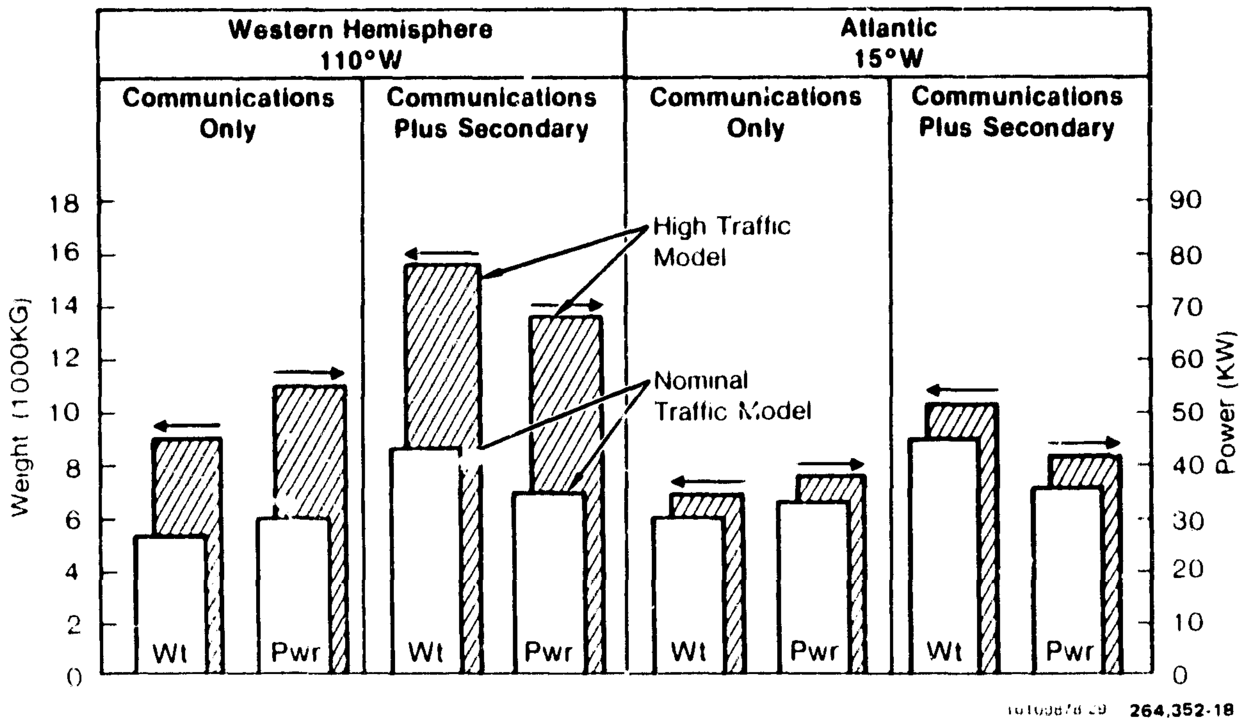


Figure 1-16. Payload Allocation Summary

The communication payloads listed in Tables 1-25 and 1-26 were sized to meet traffic models developed for the year 2000. Orbiting these payloads on a geostationary platform or a series of platforms to be launched in the 1990s would result in a large surplus of communications capacity. A more economical approach would be to orbit increments of the total payload at three year intervals with sufficient capacity to accommodate the growth in traffic during the ensuing period. Table 1-29 shows an approach modularizing the communications payloads into segments with approximately similar weight increments. In order to maintain

Table 1-29. Time Phasing of Payloads in Weight Increments

Payload	Year, Weight (kg)			
	1990	1993	1996	1999
Direct to User Network	(Ku band) 700	(Ku band) 700	(Ka band) 700	(Ka band) 700
Domestic and Regional Trunking	(C-band) 300	(C-band) 300	(Ka band) 300	(Ka band) 300
TV Distribution	400			
Tracking and Data Relay		400		
Educational TV			200	
Direct to Home TV				400
Air Mobile	200			
Land Mobile		300	300	
Interplatform	200	200	200	200
Data Collection				100
Total Payloads Weight, kg	1800	1900	1700	1700

full service area coverage and connectivity throughout the incrementation process, each module would require a full complement of antennas and inter-module communication links. The immediate effect of modularizing the communications payloads would be a probable increase in total weight and power requirements of 10 percent to 30 percent, depending on the number of modules needed to provide the required transmission capacity.

1.4.7 PLATFORM SUPPORT REQUIREMENTS. The platform must supply support functions to the payloads to ensure that they perform correctly and meet their mission objectives. The subsystems incorporated with the platform to provide payload support include:

a. Structure.

b. Power supply.

c. Thermal control.

d. Attitude control.

e. Command control and telemetry.

f. Propulsion.

Each of these subsystems will interface directly or indirectly with the payloads. The primary payload characteristics of volume, weight, and power directly affect platform design and structural configuration. Other parameters such as pointing accuracy, stationkeeping tolerance, and thermal constraints determine platform attitude control, thermal control, and propulsion subsystem design requirements. Payload susceptibility to EMI and chemical contamination must also be considered.

Figure 1-17 shows in diagrammatic form a summary of the platform support requirements for communication payloads at the Western Hemisphere location. For payloads sized to meet the nominal traffic model, the platform structure must accommodate a total of 30 antennas ranging in size from 1.5 to 15 meters. The power supply must support an average load of 31 kW. Twenty-seven kW of heat must be dissipated by thermal radiators to maintain payload temperature ranges between 0 and 40C. The command and telemetry equipment must control and monitor the status of almost 1400 transponders. Attitude and velocity control subsystems will be sized to meet basic platform orientation and station-keeping requirements (i.e., ±0.1°). Tighter pointing tolerances will require individual payload stabilization. The proportionately higher requirements of payloads sized to meet the high traffic model are indicated by the numbers inside the boxes. Similar platform support requirements data for communications payloads at the Atlantic location are shown in Figure 1-18. Figures 1-19 and 1-20 include the secondary payloads in the support requirements for the Western Hemisphere and the Atlantic locations. The main impact of the secondary payloads is a substantial increase in weight, power, and the number of small

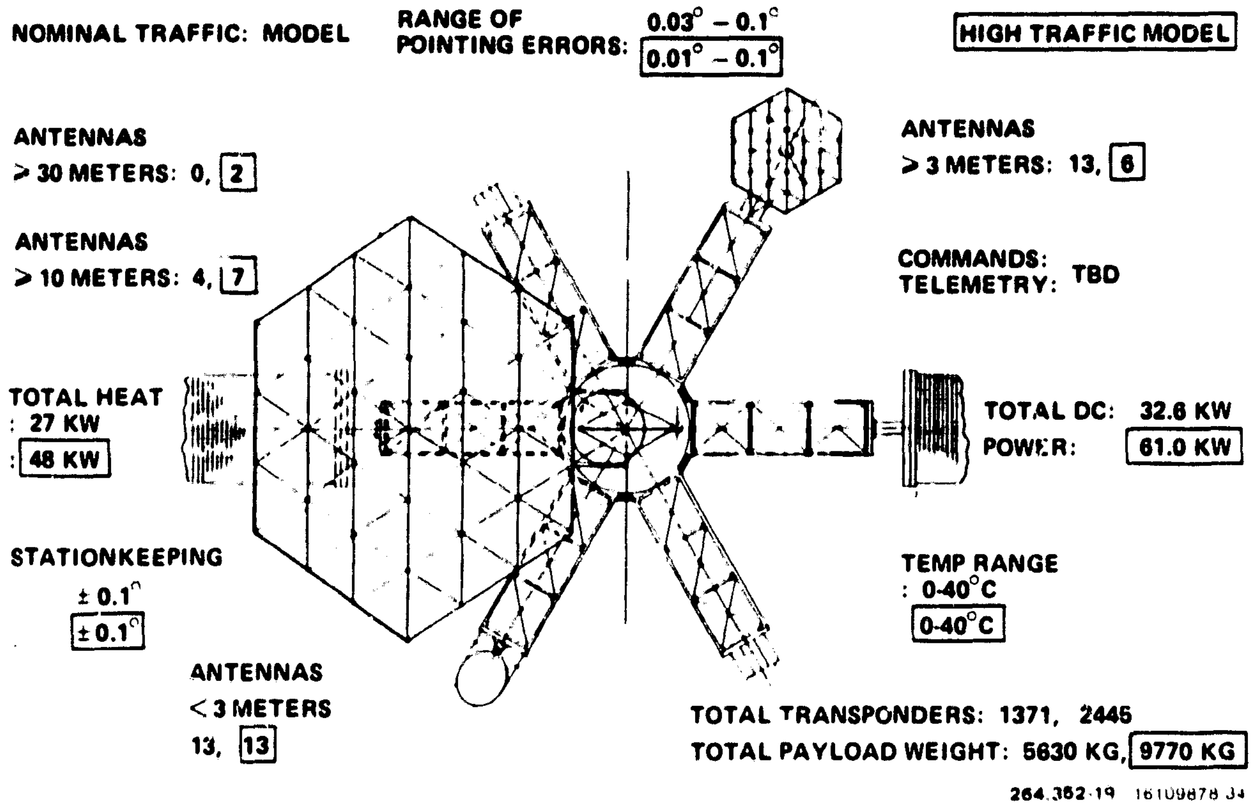


Figure 1-17. Platform Support Requirements, Western Hemisphere Location, Communications Payloads Only

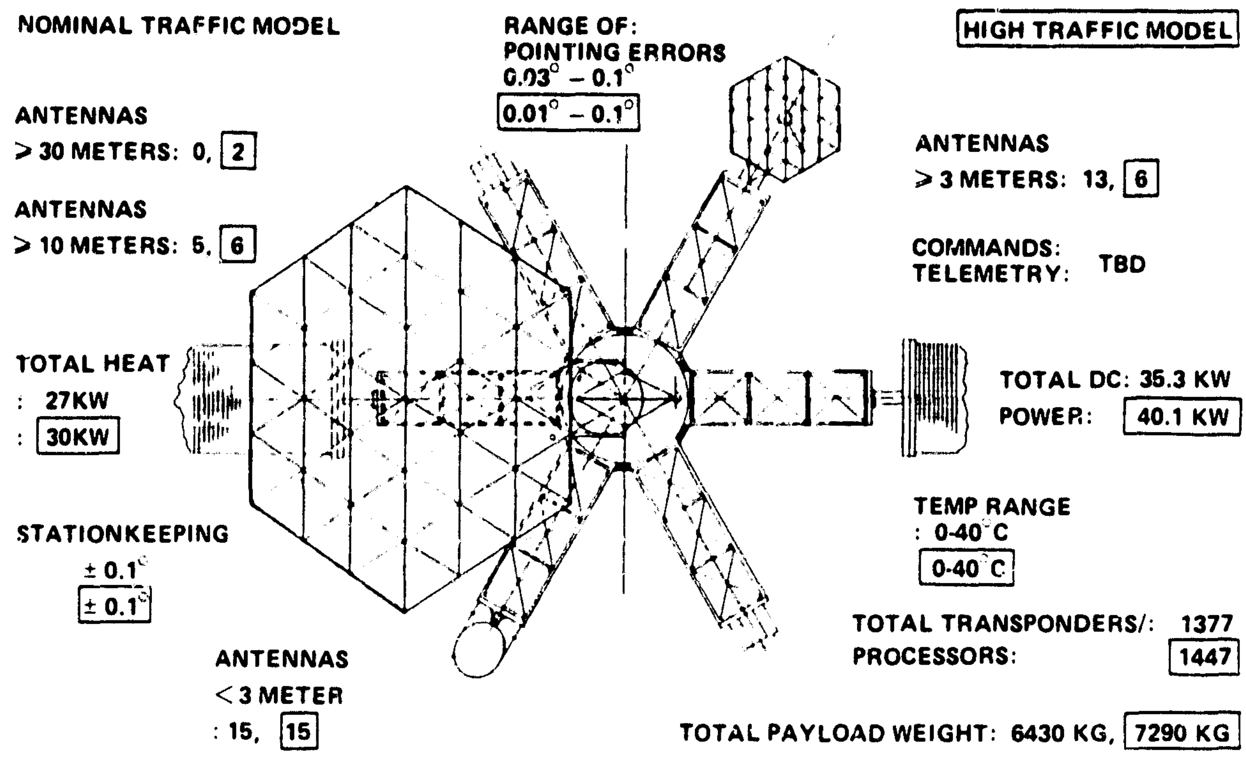


Figure 1-18. Platform Support Requirement, Atlantic Location, Communications Payloads Only

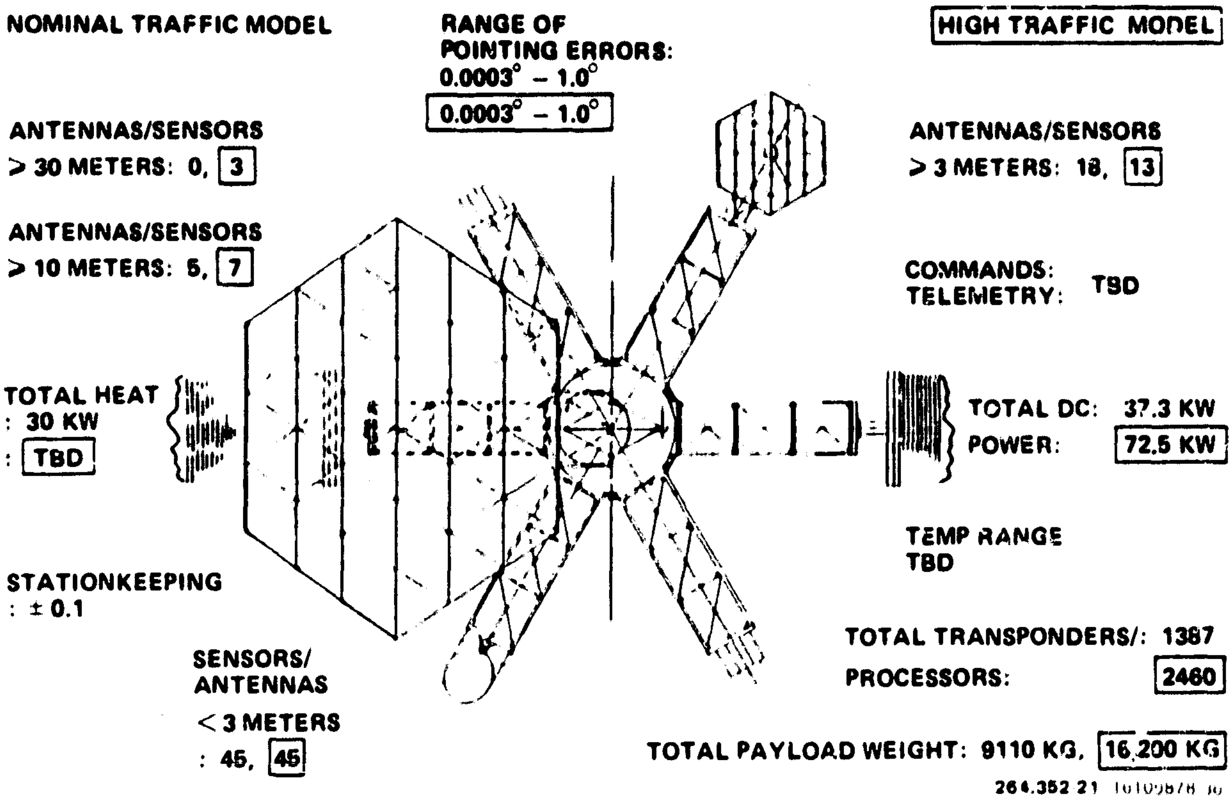


Figure 1-19. Platform Support Requirements, Western Hemisphere Location, Communications and Secondary Payloads

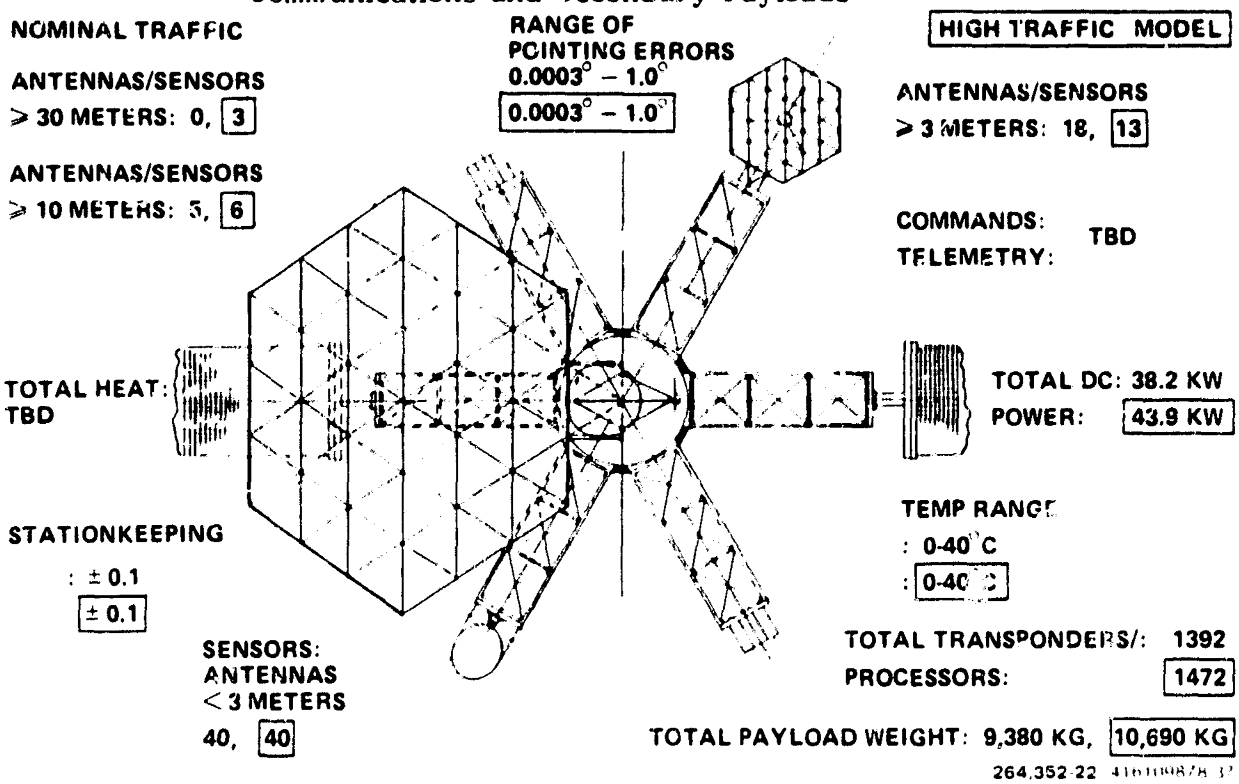


Figure 1-20. Platform Support Requirements, Atlantic Location, Communications and Secondary Payloads

antennas and sensors to be accommodated. A more detailed breakdown of platform support requirements for the communication payloads at the Western Hemisphere location is given in Table 1-30, which contains a listing of primary platform interface data for each of the communications payloads. The list is intended to be representative rather than exhaustive. In areas such as EMI and chemical contamination a more detailed definition of payload characteristics is needed to determine filtering, shielding, and isolation requirements. Although the major payload power, weight, and waste heat parameters have been summed for the respective locations, this is not meant to imply a requirement for a single large platform. The purpose is to show the magnitude of platform capability needed to support the payloads allocated to that location. Some of the major considerations affecting the sizing of individual platform capabilities include: whether the payloads are integrated into one configuration or split into several; how many platforms are in the cluster; time phasing of the payloads to meet progressive mission changes; and rate and level of platform funding.

1.5 REQUIREMENTS DOCUMENTATION

The purpose of requirements documentation is to tabulate all relevant payload data and organize it in a form that will facilitate accomplishment of subsequent study tasks. The primary repositories of payload information are the payload data sheets contained in Appendix E. Figure 1-21 and Table 1-31 are examples of data organization. Each communications payload is described by three data sheets that provide details of the antenna and transponder configurations, and antenna and transponder data (e.g., antenna size, quantity, and gain; transponder operating frequencies, bandwidth, RF power, noise, temperature, etc.). The data also include weight and power budgets, ground segment parameters, platform support requirements, supporting research and technology needs, and selected economic data. Similar three page data sheets were developed for the environmental observation and position location payloads.

The DoD and OSS space science payloads are each covered by a single data sheet with the format shown in Table 1-31. The payloads were not defined in sufficient detail for the three page data sheet format.

For convenience, the basic payload parameters were also tabulated as shown in Tables 1-18 through 1-24 in Section 1.4.5 of this report.

The nominal and high traffic models used to size the DTU and HVT payloads are supported by population statistics and economic growth analyses contained in Appendix A. These data provide the bases for traffic projections to the year 2000 and estimates of potential demand for video conferencing services. Estimates of intersatellite link capacity are also provided. The estimates are based on interconnection of clusters of small platforms or large, widely separated platforms.

C-2

Table 1-30. Platform Support Requirements, Communications Payloads, Nominal Traffic Model, Western Hemisphere Location

No.	Function	Orienta-tion	Pointing Accuracy (degrees)	Commands Telemetry	Size Meters (Dish)	Weight (kg)	Power (watts, DC)	Heat (watts)	Temp Range (°C)	Station Keeping (degrees)	RFI EMI	Contam-ination
1	Direct-to-User	Earth	0.03 0.03	TBD	6(3) 4(3)	1,240 1,420	6,500 11,500	6,000 10,000	0-40	±0.1 ±0.1	TBD	TBD
2	Domestic and Regional Tunking	Earth	0.03 0.03	TBD	15 6	450 380	700 2,200	650 1,290	0-40	±0.1 ±0.1		
3	TV Distribution	Earth	0.1	TBD	1.5(2)	400	4,000	3,000	0-40	±0.1		
4	Tracking and Data Relay	Earth	0.1	30/30	5(2)	330	680	600	0-40			
5	Educational TV	Earth	0.1	24/24	3(4) 1.5(4)	200	200	150	0-40	±0.1		
6	Direct-to-Home TV	Earth	0.1	30/30	1.5 10	400	2,100	1,300	0-40	±0.1		
7	Air Mobile	Earth	0.1	21/21	2(array)	200	900	750	0-40			
9	Land Mobile	Earth	0.1	TBD	20	530	4,000	3,000	0-40			
11	Interplatform	Cross Link	0.1	8/8	2(2)	70	120	100	0-40	±0.1		
12	Data Collection	Earth	0.1	10/10	10	100	100	90	0-40	±0.1		

Payload #11

Candidate Payload Data Summary - Sheet 1

Date: March 28, 1980

Code No: COM 11

Name: Inter-Satellite Links

Category: Communications

Orbital Location(s): 15°W & 110°W

Description: Provides direct platform to platform links.

See also attachment #1

A. Antenna/Sensor Configuration

B. Transponder/Processor Configuration

C. Antenna/Sensor Data

1. No. 2 per link
2. Type: Center fed reflectors
3. Size: 3 meters
4. Coverage/FOV:
5. No. of Beams/Feeds: 2
6. Pattern/Beamwidth: 0.3
7. Max. Pointing Error: ±0.03°
8. Sensitivity (G/T): 33 dB/K
9. Peak/EOC Gain: 60 dB EOC
10. Other:

D. Transponder/Processor Data

1. No. 2
2. Type: Processing
3. Transmit Frequency: 55 GHz
4. Receive Frequency: 62 GHz
5. Bandwidth(s)/Data Rate(s): 1 GHz
6. Transmit Power(s)/EIRP: 65 watts
7. Noise Figure/Temperature:
8. Type of Access/Modulation:
9. On-Board Switching: (M×N)
10. Other:

264.352-23-1

Figure 1-21. Typical Payload Data Requirements Documentation (Sheet 1 of 3)

Payload #11

Candidate Payload Data Summary - Sheet 2

Date: March 28, 1980

E.	Weight/Power Estimates	Weight (Kg)	Power (W)
1.	Antennas/Sensors	40	
2.	Receivers:	10	10
3.	Transmitters:	40	250
4.	Processors:		
5.	Switch Matrix:		
6.	Power Converters:	5	20
7.	Cabling, Harness etc.	5	20
8.	Totals:	100	300
9.	Notes:		

F. Support Requirements

1. Sunlight/Eclipse Power: 300 watts
2. Sunlight/Eclipse, Heat Loss: 230 watts
3. Platform Attitude Control: ±0.1°
4. Stationkeeping: ±0.1°
5. Thermal Control: 0 to 40°C
6. Payload Volume: TBD
7. T, T&C, Avionics: ✓ Yes No
8. Mission Duration: 8 yrs
9. Mission Duty Cycle: 100%
10. Interconnect Switch: (M×N) TBD
11. Other:

G. Ground Segment Not applicable

1. No. of Stations/Users:
2. Antenna Size(s):
3. Beamwidth(s):
4. Peak Gain(s):
5. Noise Temperature:
6. Receive Frequencies:
7. Transmit Frequencies:
8. Modulation/Access:
9. Transmit Power:
10. Other:

H. Economic Data

1. Traffic Capacity:
2. Space Segment Cost:
3. Ground Segment Cost:
4. Estimated Revenue/Yr:
5. User Communities: Platform Payloads
6. Technology Availability Date: 1985
7. Market Need Date: 1990
8. Other:

264.352-23-2

Figure 1-21. Typical Payload Data Requirements Documentation (Sheet 2 of 3)

Payload #11

Candidate Payload Data Summary - Sheet 3

Date: March 28, 1980

I. Payload Development Schedule

Item	Calendar Year
1. Design	
2. Development	
3. Fabrication	
4. Integration	
5. Test	

J. Supporting Research & Technology Needs

High power 55 GHz transmitters.

K. Special Requirements/Constraints

1. To avoid confusion with the tracking and data relay (TDR) mission (which has links between low-earth orbit satellites and a geostationary platform), the term inter-platform link (IPL) has been coined for traffic between platforms.

2. This link may be used to control remotely located platforms from the U.S.

3. The lowest presently allocated frequency is 55 GHz. As an alternative an optical link may be used.

A 25.25- to 26.25-GHz band has been porposed to the SWARC for this service. For a given antenna aperture, the beamwidth (and pointing accuracy requirements) doubles.

264.352 23-3

Figure 1-21. Typical Payload Data Requirements Documentation (Sheet 3 of 3)

Table 1-31. DoD Candidate Payloads for the Geostationary Platform, Payload 31

Mission Name: Defense Meterological Satellite Program Data Relay

Mission Description: This payload is designed to relay 2-3 Mbps from 3 satellites in 450 nm sun synchronous orbits (98.7° inclination). The payload will operate in the 1-3 GHz frequency band. Maximum of 30 minutes delay in data reception. Desired IOC of 1985.

Platform Interface Requirements:

Weight: 150 kg
Power: 100 watts
Pointing Accuracy: ±0.3°

Experimenter: Capt Ed Merz
Organization: SAMSO
Telephone No.: (213) 643-0708

Sizing of the DTU and HVT payloads also required detailed analyses of the ground-to-satellite and satellite-to-ground communication links to ensure adequate operating margins under adverse propagation and cochannel interference conditions. The 6/4 GHz, 14/12 GHz, and 30/20 GHz link budgets with supporting assumptions concerning required rain margin, link availability, and carrier to interference ratios are contained in Appendix D.

1.6 RESULTS AND CONCLUSIONS

The purpose of this task has been to develop a comprehensive set of mission and payload requirements and document them in a form that would facilitate the accomplishment of subsequent tasks. All missions considered to be potential candidates for platform installation were identified and grouped according to function, sponsor, orientation, and pointing requirements. Missions found unsuitable for the geostationary orbital location were eliminated from the list.

Traffic models developed for the regions surrounding the Atlantic Ocean indicate a demand for up to 3000 equivalent 40 MHz transponders by the year 2000 to meet basic voice, data, and video transmission requirements. The increasing cost of travel may also stimulate a demand for video conferencing services. Replacement of only 5 percent to 10 percent of business air travel by video conferences could result in a need for more than 8000 additional transponders to serve the same area by the year 2000.

The greatest impact of this burgeoning demand will be on the fixed point-to-point communication services. Direct to user networks and high volume trunking services will require high capacity payloads employing multiple beam antennas and on-board switching to achieve the necessary expansion of usable bandwidth. The size, weight, and power requirements of these payloads are enough to preempt the major portion of platform payload capability.

The selected platform locations of 15°W and 110°W recognize community of interest, the need for equipment commonality, and the advantages of integrating local, regional, and transoceanic communications. Allocation of payloads to these locations is based on equitable division of traffic, functional characteristics, and rough equalization of overall weight and power requirements. Not all payloads need to be placed in orbit at the same time. Communications payload requirements are a function of the development of markets for new services and growth in demand for existing services. This situation supports a modular approach to platform implementation in which sections of platform are scheduled for launch on an as-required basis. Once in orbit, modules may be linked physically or electromagnetically depending on the type and complexity of interconnection required.

Platform support requirements needed to service payloads are similar in character to those provided by conventional satellites. Support requirements are the main source of economies in scale due to the reduction in subsystem replication. In principle, the larger the platform, the greater the economy. However, these gains can be offset by the increases in transportation cost when more then one shuttle flight is needed to complete the platform. Optimum platform size and configuration is an area requiring careful study to balance operational benefits against program cost. Considerations of unattended platform lifetime versus on-orbit servicing costs must also be weighed.

Communications payload architecture has considerable impact on platform design due to the substantial weight and power requirements generated to meet projected traffic demand. Large antennas (10 meters or greater) are needed to produce multiple (100+) narrow spot beams. At frequencies above 10 GHz, provisions for adequate rain margins increase downlink transmitter parameters.

Development of high capacity communication payloads is very dependent on progress in multibeam antenna technology and the development of multiport high speed switching devices. High capacity crosslinks are also needed to maintain connectivity between platform modules, whether physically linked or in a cluster configuration.

One may conclude from this discussion that:

a. The primary mission for a geostationary platform is satellite communications.

b. Considerable growth in demand can be anticipated for the future.

c. A geostationary platform can contribute substantially to the relief of spectrum saturation and equatorial orbit congestion.

d. Demand for communications services can best be met by payloads combining multifrequency operation with extensive space diversity provided by multiple beam antennas and on-board switching.

e. The optimum platform configuration may be modular in both space and time to accommodate time phased mission requirements and budgetary constraints.

SECTION 2

TASK 2: CONCEPT SELECTION

Government and industry studies during the late 1970s indicated that large geostationary platforms combining many communications services could not only alleviate the growing problems of orbital arc and frequency spectrum saturation, but could also provide new services and lower user costs (References 2.1, 2.2, 2.3, 2.4, 2.5, 2.7, and 2.8).

Advanced development work by NASA, COMSAT, and the Aerospace Corporation have developed a variety of platform concepts made feasible by the capability of the Space Transportation System (STS). These concepts vary widely in their payloads, platform size and mass, and in OTV requirements. The studies have clearly established the technical and economic feasibility of the large platform approach, but have not attempted to define optimum solutions for minimum cost and for system design parameters such as platform size, lifetime, geosynchronous transfer vehicles, and construction and servicing approaches. These require further analysis and selection in order to proceed with system design, and are the subject of this section of the report.

2.1 TASK OBJECTIVES

The objective of Task 2 is to conceptually define candidate platform system concepts that span a range of design and operational approaches and through system level tradeoff studies, select one or several concepts for further definition in Task 3.

2.2 INPUT DATA

Sources of data used for Task 2 were the following:

a. Payloads. These definitions were taken from the payload data sheets, Appendix E, that were outputs from Task 1, Mission/Payload Definition.

b. Assumptions and Guidelines. These were per the revised study plan (Reference 2.12).

c. Space transportation system capabilities and description. Shuttle and OTV performance, configurations, and costs were obtained from NASA/MSFC (Reference 2.9).

d. Teleoperator maneuvering system (TMS). Descriptive data for the TMS was obtained from References 2.10 and 2.11. (Former nomenclature for the TMS was remote teleoperator system.)

e. Platform configuration and subsystems. Information from prior studies (References 2.2, 2.3, 2.13, and 2.14) was used to develop parametric platform design data and scaling laws.

2.3 METHODOLOGY

System level trade studies were carried out to parametrically define and evaluate alternative platform design, transportation, and operational approaches, and to select the most promising concepts for further definition in Task 3. The quantitative evaluation criterion employed for evaluation of alternative concepts was comparative program cost for acquisition and operations.

To be certain that the full range of mission requirements was covered, trade studies were done for both the smallest and the largest mission sets, i.e., Set N - nominal traffic model, Western Hemisphere location; and Set V - high traffic model, Atlantic and Western Hemisphere locations (Reference Table 2-1). The payloads comprising each mission set are listed in Table 2-2. Later, a third system model was constructed for Mission Set P - nominal traffic model, Atlantic and Western Hemisphere locations.

Table 2-1. Mission Sets

Code	Traffic Model	Location(s)
N	Nominal	WH
M	Nominal	ATL
P	Nominal	Both
S	High	WH
T	High	ATL
V	High	Both

Table 2-2. Payloads

*KEY	
	W = WEST HEM.
	A = ATLANTIC
	E = EITHER
	B = BOTH

NOMINAL TRAFFIC MODEL, WH ONLY			
P/L NO.	MISSION	WEIGHT KG	POWER W
1, 2	PT-PT COMMUNICATIONS	3,480	20,800
3	TV DISTRIBUTION	400	4,000
4	TRACKING & DATA R LAY	330	680
5	EDUCATIONAL TV	200	200
6	DIRECT TV	400	2,100
7	AIR MOBILE	200	900
9	LAND MOBILE	530	4,000
11	INTERPLATFORM LINKS	70	120
12	DATA COLLECTION	100	100
17	LIGHTNING MAPPER	320	300
18	ATMOSPHERIC SOUNDER	190	50
19,20	RADIOMETERS	650	250
27	RF INTERFEROMETER	120	220
31	DMSP DATA RELAY	150	100
54	DOD EHF EXP.	230	600
55	DOD LASER COMM. EXP.	320	550
32	ADV. OLS CLOUD IMAGER	150	150
38	AEROSOL & CLOUD HT SENSOR	50	100
42	GLOBAL UV RADIANCE	50	20
52	BOSS EVALUATION	150	400
33	MATERIALS EXPOSURE	10	25
43	MAGNETIC SUBSTORM MONITOR	10	5
56	FIBER OPTICS DEMONSTRATION	10	30
71	EARTH OPTICAL TELESCOPE	1,100	2,000
	TOTAL (PAYLOADS ONLY)	9,230	37,7[illegible]

HIGH TRAFFIC MODEL BOTH HEMISPHERES				
P/L NO.	MISSION	*	WEIGHT KG	POWER W
1, 2	PT-PT COMMUNICATIONS (WH)	W	6,910	46,200
1,2,10	PT-PT COMMUNICATIONS (ATL)	A	4,030	24,700
3	TV DISTRIBUTION	B	400	4,300
4	TRACKING & DATA RELAY	B	330	680
5	EDUCATIONAL TV	B	200	200
6	DIRECT TV	B	400	2,100
7	AIR MOBILE	B	200	900
8	SEA MOBILE	A	400	600
9	LAND MOBILE	B	700	4,000
11	INTERPLATFORM LINKS	B	70	120
12	DATA COLLECTION	B	100	100
17	LIGHTNING MAPPER	B	350	300
18	ATMOSPHERIC SOUNDER	B	200	50
19,20	RADIOMETERS	E	650	250
27	RF INTERFEROMETER	B	150	250
31	DMSP DATA RELAY	B	150	100
54,55	DOD COMM. EXP (EHF, LASER)	E	550	1,050
32,38,42	EARTH OBSER.	E	250	270
39,40,41,44	DOD SOLAR GROUP	E	150	150
33,43,56	DOD EXPOSURE GROUP	E	30	70
34	ACOSS/HALO	E	1,100	600
52,36	BOSS/AOSP	E	500	1,100
51,78	CRYO LIMB SCANNER	E	670	6,000
71	EARTH OPTICAL TELESCOPE	E	1,100	2,000
53	GEMINI EVALUATION	E	820	1,800
73,75,76,77	OSS GROUP I	E	900	1,100
79	LLL TV	E	300	1,000
81,82,83,84	OSS GROUP II	E	1,250	3,350
	TOTAL (PAYLOADS ONLY)		33,622	114,640

The trade study philosophy employed was to develop a family of platform concepts that would accommodate each of the mission sets using various construction, delivery, and operational modes and to determine program costs that are sensitive to platform system concept definitions. Figure 2-1 is a flow diagram that illustrates the methodology followed for the major system trade study that evaluated economy of scale, transfer vehicle launch mode and delivery capabilities, and platform operational mode. Table 2-3 presents an overview of the procedures followed. All of the platform system concepts were designed to the common set of ground rules listed in Table 2-4.

The study plan identified nine candidate system trade study areas. These are listed in the left column of Table 2-5. As the studies developed it became apparent that there was a great deal of interdependence between many of these trade study areas, coupled together by the candidate platform system design options. This coupling is indicated by the X's entered under the four option columns in Table 2-5. As the array of candidate system options and suboptions

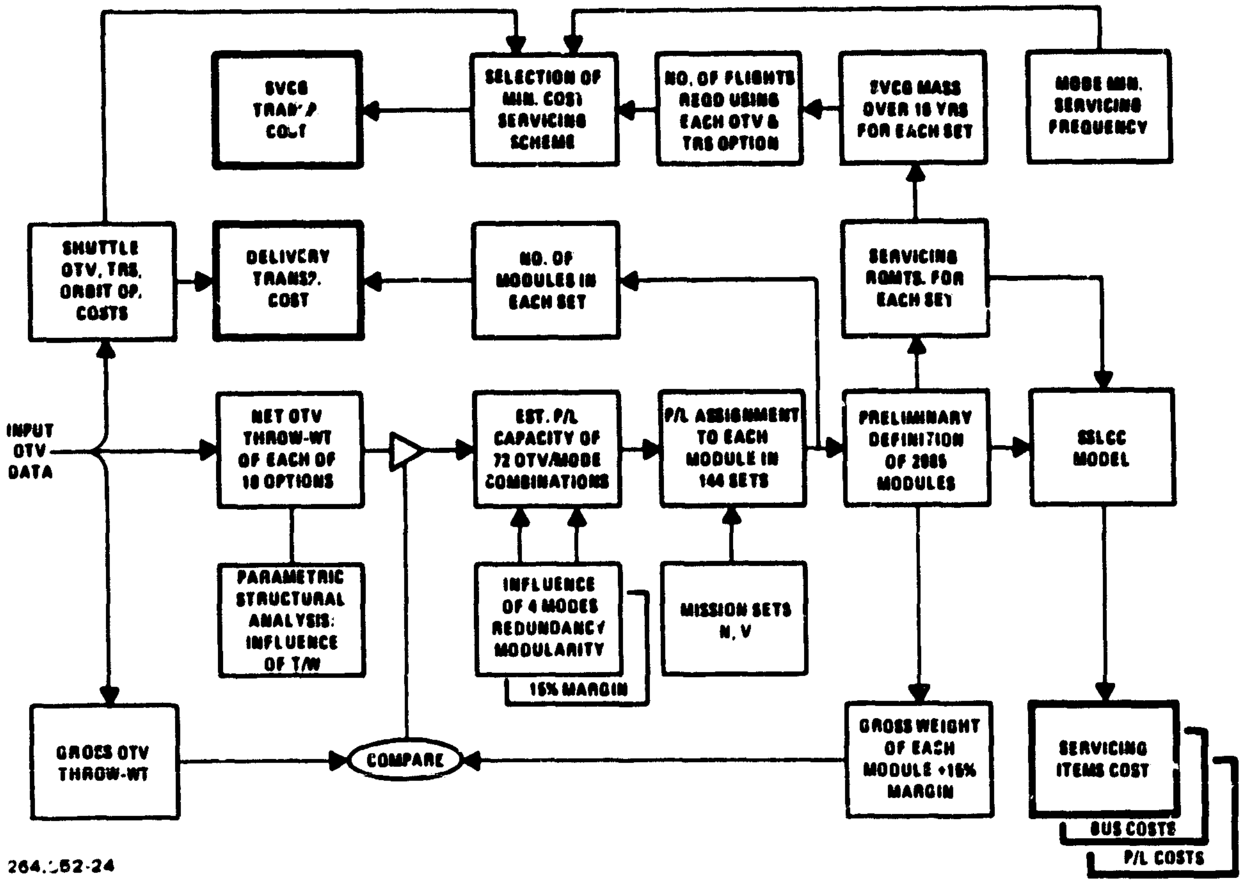


Figure 2-1. Basic System Trades Methodology

Table 2-3. Task 2 Trades Methodology

Identify options.
Investigate couplings.
Reduce number of variables to be dealt with simultaneously as much as possible.
Launch mode, transfer vehicle, and operating mode intimately coupled. Must be considered simultaneously, resulting in 72 options.
Mission set size and evolutionary buildup mode uncoupled from the above.
Seventy-two options investigated first for mission set N and then for V.
Only the best options used to investigate influence of evolutionary buildup mode.
Best options and best alternative mode options subjected to funding spread and net present value analysis.

Table 2-4. Ground Rules

System IOC Date: 1992
Common Platform Elements for Western Hemisphere and Atlantic Missions – A Design Goal
Lifetime: Nominal 16 Years – A Design Goal
– Baseline: Unmanned Servicing at GEO
– Alternate: Long Life, Nonserviced System
Minimum Development and Operations Cost – A Design Goal
Maximum Use of Existing and Projected (1990s) Technology
STS
– 65,000 lb Shuttle
– Existing and Improved Upper Stages
– New OTV Family

Table 2-5. Scope and Interrelationship of System Trade Studies

Trade Study Areas	Platform System Options			
	Transfer Vehicles	Launch Mode	Operational Modes	Evolutionary Buildup
Servicing versus Nonservicing			X	
Single versus Multiple Platforms (Economy of Scale)	X	X		X
Evolution Buildup Options (Time Phasing)				X
Construction Location Options (LEO versus GEO)		X		X
Transportation Options (OTV Capabilities)	X	X		
Structural Options				
Deployment/Assembly Options	X		X	X
Construction Base Options		X		X
Logistic Support Options	X		X	X

became better defined, it became obvious that the dimensions of the tradeoff matrix would be unmanageable if all were to be included in the trades. Therefore, screening of the candidates eliminated the least promising concepts and enabled us to concentrate on the remainder.

Transfer Vehicle Options. By far the widest range of options was the potential choice of orbit transfer vehicles. The data base provided by MSFC (Reference 2.9) included the inertial upper stage (IUS), Centaur, a single and dual stage orbit transfer vehicle (OTV) and an interim OTV (IOTV). Some of these included different launch modes (ground or space-mated) and low or standard thrust engines. Expendable, reusable, and round trip operational modes were also included. These various combinations resulted in 30 discrete vehicle/operating mode combinations to be considered. Screening of these candidates was based upon parameters such as performance capability, dollars per kilogram delivered to GEO, thrust-to-weight ratio and attendant structural weight penalty, and payload length availability. This screening operation enabled us to reduce the number of platform delivery vehicle candidates from 30 down to the 19 that were used in the trade studies. The selected delivery vehicle options and their pertinent characteristics are shown in Table 2-6.

Launch Mode Options. The launch modes that were considered covered the entire range of STS capabilities, from multiple payloads of conventional geosynchronous satellites using SSUS-A and -D in a single Shuttle launch, to multiple Shuttle launches per platform. Table 2-7 defines the four basic launch mode options (Cases I, II, III, and IV) and the suboptions for Cases I' and III'. These launch modes are summarized in Figure 2-2.

Operational Mode Options. The top-level choice of operational modes was between platforms that are serviced or are not serviced. Suboptions included the choice of individual platform life for the nonserviced platform approach and the servicing frequency for the serviced platform approach. The nine operational mode options described in Table 2-8 were defined and parametric platform design scaling laws were developed for each mode.

Initially, several sets of platform concepts were defined to investigate the interaction of economy of scale and operating mode. Each group of platforms collectively accommodate a preliminary set of communications and secondary payloads for the Western Hemisphere location. The total payload mass and power requirements were 7000 kg and 33 kW, respectively. To examine the effects of economy of scale, the payload complement was divided in fractions as follows: 1/2, 1/3, 1/4, 1/5, 1/6, 1/8, 1/12, and 1/20. Payload weight and power requirements were arithmetically divided per the above fractions and, after adjustment for operating mode weight penalties, were accommodated on platforms designed for operating modes A, B, C, and D. The resultant platform (bus plus payload) mass was then compared to the delivery vehicle capabilities, and compatible vehicles were identified. Operating modes E and F were then added to the analysis to

Table 2-6. Transfer Vehicle Options

Code	2-Stage IUS	4-Stage IUS	Centaur	IOTV	1-Stage OTV	2-Stage OTV	Low Thrust Engine	Reusable	Expendable	Ground Mated	Space Mated	Gross Capacity to GEO (kg)	T/W Ratio	Structural Weight Penalty (kg)	Cargo Bay Length Available (ft)	Cost/Flight ($M)	$/Gram	Used in Trade: Yes	Used in Trade: No
a					X		LT	R		X		2,608	0.13		26	37	14	X	
b			X				LT		E	X		4,763	0.19		26	62*	13	X	
c				X			LT		E	X		5,670	0.08		26	59	10	X	
d					X		LT		E	X		6,895	0.07		26	57	10	X	
e					X				E	X		7,802	0.64	492	26	67	9	X	
f				X					E	X		6,895	0.69	448	26	59	9	X	
g				X			LT		E		X	9,190	0.06		60	100	11	X	
h					X		LT		E		X	11,340	0.05		60	108	10	X	
j						X	LT	R			X	16,878	0.035		60	124	7	X	
k						X	LT		E		X	25,600	0.024		60	184	7	X	
l						X		R			X	19,505	0.31	780	60	124	6	X	
m						X			E		X	27,851	0.22		60	184	7	X	
n					X				E		X	13,018	0.43	716	60	108	8	X	
o				X					E		X	10,206	0.51	612	60	100	10	X	
p					X			R			X	5,897	0.78	413	60	78	13	X	
q					X			R		X		3,493	1.08	147	26	37	11	X	
r			X						E	X		5,443	1 76	400	26	62*	11	X	
s	X								E	X		2,313	2.	N/A	33	46	20	X**	
v		X	(2L, 2L)						E		X	9,072	1.85	857	60	134	15	X	
t			X (DUAL)						E		X	9,526	1.15		26	133	14		X
u		X	(2L, 2S)						E		X	5,216	1.25		45	92	18		X
i					X		LT	R			X	4,296	0.10		60	78	18		X

*Updated Centaur costs.

**Type S used only for Case I.

Table 2-7. Launch Mode Cases

Case I	Individual dedicated satellites Conventional design, variety of upper stages
Case I'	Individual large satellites Standard TDRSS type bus, 2-stage IUS, 1990 technology
Case II	Small platforms Optimized to transfer vehicle/shuttle capability Ground mated to upper stage Single shuttle
Case III	Medium platforms Optimized to transfer vehicle/shuttle capability Space mated to upper stage at LEO Multiple shuttles One shuttle for platform One or more shuttles for transfer vehicle stages
Case III'	Large platforms Optimized to full capacity of 2-stage transfer vehicle Beyond volume limit of shuttle cargo bay Two platform segments mated to LEO, then space mated to transfer vehicle Multiple shuttles Two shuttles for platform Two shuttles for transfer vehicle stages
Case IV	Single very large platform Beyond STS capability as defined

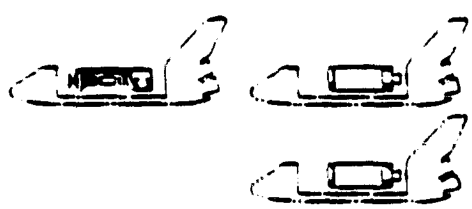
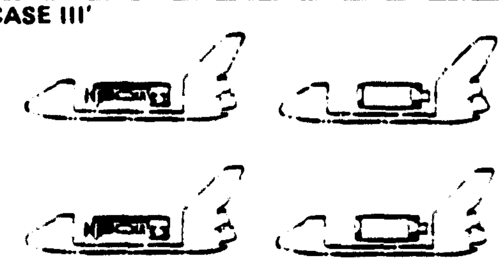
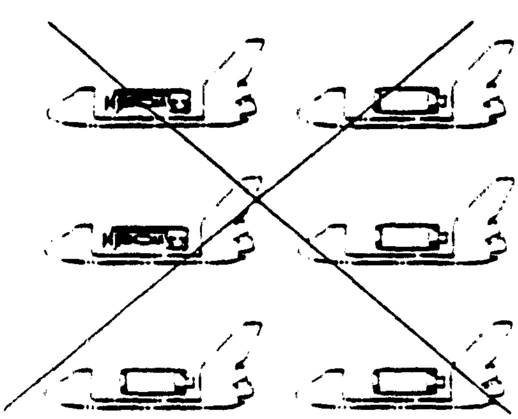
CASE I		INDIVIDUAL SATELLITES WITH A WIDE VARIETY OF UNIQUE DESIGNS ARE EMPLOYED TO ACCOMMODATE THE MISSION MODEL. TRANSPORTATION IS PROVIDED BY THE SHUTTLE, SSYS, AND IUS AS REQUIRED.
CASE I'		A STANDARD BUS DESIGN (BASED ON THE TDRS, BUT WITH 1990 TECHNOLOGY INCORPORATED) IS EMPLOYED TO ACCOMMODATE THE MISSION MODEL. TRANSPORTATION IS PROVIDED BY THE SHUTTLE AND 2-STAGE IUS.
CASE II		A SMALL PLATFORM AND ITS OTV ARE LAUNCHED TO LEO BY ONE SHUTTLE FLIGHT. OTV TRANSFERS PLATFORM TO GEO.
CASE III		A MEDIUM SIZE PLATFORM (OR PLATFORM MODULE) DELIVERED TO LEO IN ONE SHUTTLE FLIGHT. ONE OR TWO ADDITIONAL SHUTTLE FLIGHTS DELIVER AN OTV TO LEO WHERE IT IS MATED WITH THE PLATFORM PRIOR TO TRANSFER TO GEO.
CASE III'		HALVES OF A LARGE PLATFORM MODULE DELIVERED IN TWO SHUTTLE FLIGHTS TO LEO WHERE THEY ARE MATED. TWO SHUTTLE FLIGHTS DELIVER OTV STAGES TO LEO WHERE THEY ARE MATED TO EACH OTHER AND TO THE PLATFORM.
CASE IV		SINGLE VERY LARGE PLATFORM REQUIRES MORE THAN 4 DELIVERY FLIGHTS FOR PLATFORM ELEMENTS AND OTV'S. NOT FEASIBLE WITH STS AS DEFINED.

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Figure 2-2. Launch Mode Options

Table 2-8. Operational Mode Options

Mode	Description	Nominal Service Interval, Years
A	Serviced, 16 Year Life, 5 Year Consumables Capacity	2
B†	Nonserviced, 8 Year Life, Replaced	N/A
C†	Nonserviced, 16 Year Life, Highly Redundant	N/A
C'†	Serviced As Required, 16 Year Life, 8 Year Consumables	≤ 8
D	Serviced, 16 Year Life, 5 Year Consumables Capacity	2
E	Serviced, 16 Year Life, 2 Year Consumables Capacity	2
F	Serviced, 16 Year Life, 2 Year Consumables Capacity	2
G	Serviced, 16 Year Life, 3 Year Consumables Capacity	1/2
H*	Serviced, 16 Year Life, 3 Year Consumables Capacity	1/2

† Selected for system level trade studies.

* Used for evolutionary buildup trades.

determine the sensitivity of servicing interval on overall platform design and beginning-of-life (BOL) mass. The influence of operating mode was evaluated at this point by comparing total mass delivered to orbit for each system concept; platform costs were not developed.

At this point, operating Mode A (similar to Mode D but a 50 percent RF power penalty imposed for servicing accessibility) was determined to be unrealistic and was dropped from further consideration.

Several more iterations were performed using updated mission payload sets with increased mass and power requirements, with updated OTV types, capabilities and costs, and with platform bus and payload costs included in the analyses. Each of these iterations helped to further refine our trade study methodology and assisted in screening out unnecessary variables from the system trade studies. Based on these findings, operational modes B, C, C', and E were selected for the system trade studies. Figure 2-3 illustrates the features of each of these four operational modes.

MODE B: NON-SERVICED, 8-YEAR LIFE, REPLACED
MODE C: NON-SERVICED, 16-YEAR LIFE (HIGHLY REDUNDANT)
MODE E: SERVICED EACH 2 YEARS, 3-YEAR CONSUMABLES CAPACITY
MODE C': HYBIRD MODE

- HIGHLY REDUNDANT, 16 YEAR SUBSYSTEMS LIFE
- SERVICEABLE AS NECESSARY
- 8-YEAR CONSUMABLES CAPACITY
- PAYLOAD UPDATE MAINLY THROUGH MODULAR GROWTH

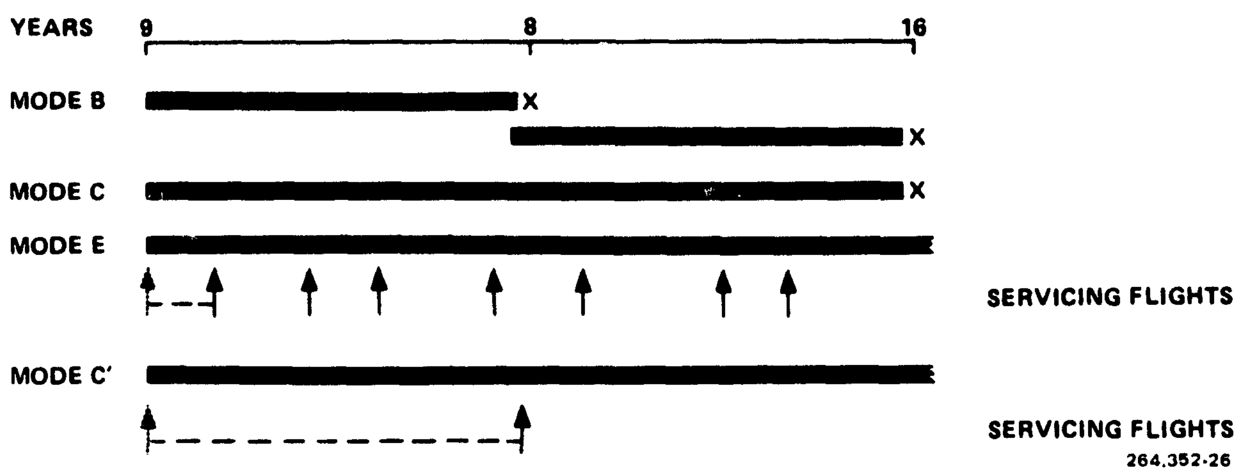

Figure 2-3. Operational Modes for System Trade Studies

Evolutionary Buildup Options. The final major system design option considered was the choice of evolutionary buildup mode. The four options are described in Table 2-9 and are shown in Figure 2-4. Evolutionary buildup permits the time-phased delivery of payloads to GEO commensurate with user needs for communications traffic demands or for accommodating experimental payloads in a timely manner. Evolutinary buildup also permits development, production, and module delivery costs to be spread over a long time base and thus reduces peak annual funding requirements.

Table 2-9. Evolutionary Buildup Options

MODE H – Payload addition.

- Single very large platform put in GEO.
- Small initial payload complement.
- Payloads added by servicing flights (2 per year).

MODE J – Docked dependent modules.

- Modules may be Case II, III, or III'.
- Subsystems shared between modules.
- Docking at GEO.

MODE K – Cluster.

- Independent modules flying in formation at GEO.
- Connectivity by microwave link.

MODE L – Docked independent modules.

- No subsystem sharing.
- Hardwire connectivity.

Summary of Options. The spectrum of system design options is summarized in Table 2-10. The basic system trade study evaluated economy of scale, transfer vehicle launch mode and delivery capabilities, and platform operational mode. The study was conducted using the following options:

a. Launch mode - II, III, and III'.

b. Transfer vehicle - a through v (except S).

c. Operating mode - B, C, C', and E.

d. Buildup mode - K.

e. Mission sets - N and V.

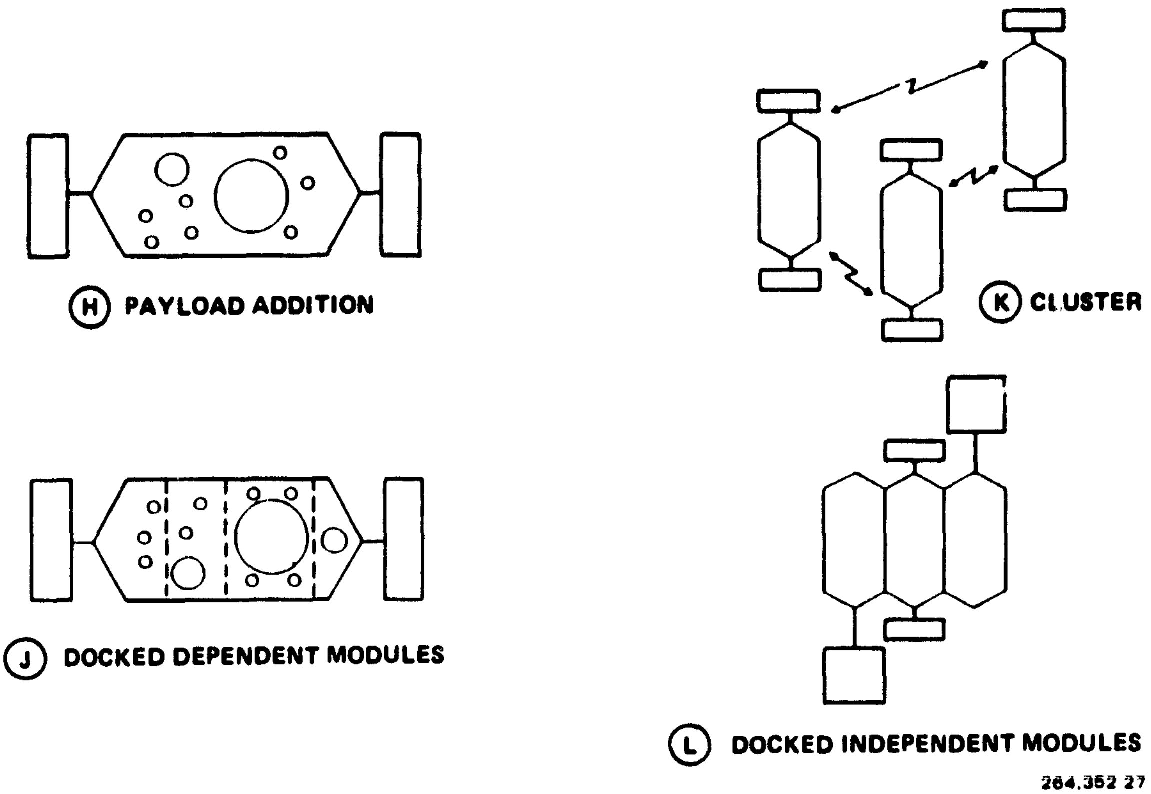

Figure 2-4. Evolutionary Buildup Options

The combinations of launch mode and transfer vehicles determine the maximum size and/or mass and payload accommodation capability of each platform. The resultant payload accommodation capability and the selected mission set determine the number of platforms required for each concept. This combination yields a 72 cell matrix (18 OTVs with 4 operating modes) for each of the two mission sets, or a total of 144 concepts that were analyzed for buildup mode K.

Cost estimates for an additional set of 72 options were later developed for mission set P to provide a data base for selection of preferred system concepts. These three mode K options are identified in the upper section of Table 2-11.

After obtaining the results for buildup mode K, several of the most promising concepts (i.e., payload set, number of platforms, OTV selected) were selected to explore other modes of evolutionary buildup. This resulted in the development of four additional concepts for buildup mode H (evolutionary payload buildup), three additional concepts for mode J (docked dependent modules), and two additional concepts for mode L (docked independent modules).

For comparative purposes, concepts and system costs were also developed for accommodating the same payloads (mission set N, V, and P) on a variety of small, conventional satellites (Launch Case I) and also on larger IUS-launched individual

Table 2-10. Summary of System Design Options

LAUNCH MODE

	I	INDIVIDUAL SATELLITE (CONVENTIONAL)
	I'	INDIVIDUAL SATELLITE (STANDARD TDRSS BUS)
*	II	SMALL MODULE + TV, SINGLE SHUTTLE
*	III	MEDIUM MODULE IN SHUTTLE, SPACE MATING
*	III'	LARGE MODULE IN 2 SHUTTLES, SPACE MATING
	IV	SINGLE VERY LARGE PLATFORM

TRANSFER VEHICLE

*	a	OTV	LT	R	II	2,608 KG	$ 37 M
*	b	CENTAUR	LT	E	II	4,763	62
*	b'	CENTAUR					50
*	c	IOTV	LT	E	II	5,670	59
*	d	OTV	LT	E	II	6,895	67
*	e	OTV		E	II	7,802	67
*	f	IOTV		E	II	6,895	59
*	g	IOTV	LT	E	III	9,190	100
*	h	OTV	LT	E	III	11,340	108
*	j	2-OTV	LT	R	III	16,878	124
*	k	2 OTV	LT	E	III	25,600	184
*	l	2-OTV		R	III	19,505	124
*	m	2-OTV		E	III	27,851	184
*	n	OTV		E	III	13,018	163
*	o	IOTV		E	III	10,206	100
*	p	OTV		R	III	5,897	78
*	q	OTV		R	II	3,493	37
*	r	CENTAUR		E	II	5,443	62
*	r'	CENTAUR					50
	s	2-IUS		E	I	2,313	46
*	v	4-IUS		E	III	9,072	134

OPERATING MODE

*	B	THROWAWAY, UNSERVICED, REPLACED AFTER 8 YEARS
*	C	HIGHLY REDUNDANT, UNSERVICED, 16 YEAR LIFE
*	E	FREQUENTLY SERVICED, PERMANENT FACILITY, SERVICED EVERY 2 YEARS (AVERAGE)
*	C'	HYBRID, HIGHLY REDUNDANT, SERVICEABLE, PERMANENT FACILITY, SERVICED EVERY 8 YEARS (AVG), P/L UPDATE BY NEW MODULES

BUILDUP MODE

	H	PAYLOAD ADDITION
	J	DOCKED DEPENDENT MODULES, SHARED SUBSYSTEMS
*	K	CLUSTER, MICROWAVE LINKS
	L	DOCKED INDEPENDENT MODULES, NO SUBSYSTEM SHARING

MISSION SET

*	N	NOMINAL, WESTERN HEMISPHERE
*	V	HIGH, BOTH LOCATIONS

*Options selected for basic system trade studies.

Table 2-11. Summary of System Concepts Developed in Trade Studies

Buildup Mode	Mission Set	Traffic Model	Locations	No. of Concepts	Item Nos.	Launch Case	Operational Mode	OTV Type
K	N	Nominal	W. Hemisphere	72	1-72	II,III,III'	B,C,C',E	a-v[1]
K	V	High	W. Hemisphere and Atlantic	72	73-144	II,III,III'	B,C,C',E	a-v[1]
K	P	Nominal	W. Hemisphere and Atlantic	72	501-572	II,III,III'	B,C,C',E	a-v[1]
H	N	Nominal	W. Hemisphere	2	464,472	III	E	j,m
H	V	High	W. Hemisphere and Atlantic	2	448,484	III'	E	j,m
J	N	Nominal	W. Hemisphere	1	234	II	C'	d
L	V	High	W. Hemisphere and Atlantic	1	276	II	C'	d
J	V	High	W. Hemisphere and Atlantic	1	276[1]	II	C'	d
L	V	High	W. Hemisphere and Atlantic	1	337	III	C'	j
J	V	High	W. Hemisphere and Atlantic	1	337[1]	III	C'	j
K	N	Nominal	W. Hemisphere	2	146,147	I	B,C	x[2]
K	N	Nominal	W. Hemisphere	2	145,150	I'	B,C	s
K	V	High	W. Hemisphere and Atlantic	2	148,149	I'	B,C	s
K	P	Nominal	W. Hemisphere and Atlantic	1	573	I'	B	s
K	P	Nominal	W. Hemisphere and Atlantic	1	574	I'	B	x[2]
K	P	Nominal	W. Hemisphere	1	401	II	C'	j
J	P	Nominal	W. Hemisphere	1	402	II	C'	d
K	V	High	W. Hemisphere and Atlantic	1	403	III	E	j
J	V	High	W. Hemisphere and Atlantic	1	404	III	C'	l

[1] Except s

[2] x = SSUS-A, -D and IUS-2

satellites (launch case I'). The individual satellites are not truly equivalent to the larger platforms because they do not provide the same level of communications interconnectivity. Additionally, some large payloads had to be split into smaller segments and accommodated on multiple spacecraft; this could raise questions such as: "Can one 1200 kg telescope be replaced by three 400 kg telescopes that collectively can perform the same mission?"

The Case I program costs were based on the extrapolation of the MSFC economic analysis (Reference 2.3) to mission set N based on payload mass. Case I' costs were developed for mission sets N, V, and P, using a common TDRS-derived bus, specific payload assignments, and with transportation provided by the Shuttle and the two-stage IUS.

The lower section of Table 2-11 identifies the four platform system concepts that were jointly selected by NASA and Convair for further definition in Task 3. These encompass a range of buildup modes, launch cases, operational modes, OTV types, and both nominal and high traffic models.

2.4 ANALYSIS AND RESULTS

A preliminary set of trade studies was begun while Task 1 efforts were underway to define mission models and payload descriptions. These preliminary trades helped to better define the design options and to identify coupling effects.

The preliminary trade studies were run with some simplifying assumptions, for example, with preliminary payload descriptions and with payload mass and power arithmetically divided to determine the number of platforms required to accommodate the mission set. Detailed results of these preliminary trade studies are not included in this report. The prelininary studies did show, however, that economy of scale was present and, also, that transportation costs were a significant factor. The preliminary trades also developed design data for a range of platforms defined in the system trade studies.

2.4.1 PLATFORM DESIGN PHILOSOPHY. The primary system design consideration is to provide user support with a high availability. Current 8 year life satellite systems have achieved system availability of A - 0.9999 utilizing dual redundancy of critical components plus on-orbit spare satellites. Platform systems must achieve a similar availability factor, but with a longer lifetime (nominal 16 years) and without the luxury of on-orbit spare platforms. The main design issues that must be addressed to achieve high availability are: 1) random failures, 2) wear-out, and 3) consumables. The design approaches to solving these problems are summarized in Table 2-12. In addition, the table identifies approaches to installing and servicing payload equipment for each of the selected operating modes.

As a result of the preliminary trade studies, we found that some combinations of servicing schedule and design are infeasible, and some are wasteful and uneconomical compared to others. At the same time, the range of servicing frequencies

Table 2-12. Platform System Design Philosophy

Issue	Design Approach			
	Nonserviced, 8-Year Life and Replaced (Mode B)	Nonserviced, 16-Year Life (Mode C)	Serviced As Required 16-Year Life (Mode C')	Serviced 16-Year Life (Mode E)
Random Failures	Redundant Elements	Redundant Elements	Redundant Elements	Redundant Elements, Replace
Wearout	Redundant Elements	Redundant Elements	Redundant Elements	Replace Before Wearout
Consumables	Size for 8 Years	Size for 16 Years	Size for 8 Years and Replenish	Size for 2 to 5 Years and Replenish
Payload Equipment	Install Updated Equipment on Second Platform (8-Year Interval)	Addition/ Replacement Not Possible	Optional Installation and Exchange During Servicing Mission	Install and Exchange Modules During Servicing Mission

considered needed to be expanded. If payload addition and update could be handled by the modular growth scheme, the servicing philosophy trade could be broadened to include variations not only in frequency, but in extent.

From this preliminary analysis and screening, four distinctly different classes of modes emerged. The best mode within each class was selected for the final trade matrix. They are:

Mode B: 8 year life unserviced, the mode now employed with all communications satellites. Very low development risk. Very little growth capability toward permanent facilities.

Mode C: 16 year life unserviced, using highly redundant subsystems and primary payload systems. Looks more obtainable all the time. Recent tests show nickel-hydrogen batteries can be expected to have at least 12 year lifetimes, and 16 is not unreasonable for 1990. A very economical approach to a 16 year mission, but no progress toward permanent facilities. If a servicing scheme can be devised that is economically competitive with this one, so that the less tangible benefits of servicing can be obtained for little or no cost, such a mode would be preferred over this one.

Mode E: The best of the conventional servicing schemes, it employs a servicing schedule that can vary in frequency from a few months to nearly three years (the capacity of the consumables tanks), but which averages two years. Thus, seven servicing flights would be flown in the 16 year mission life. These would be full-range servicing missions, capable of replenishing consumables, updating or adding payloads, and replacing failed or degraded modules.

Mode C': A hybrid scheme where redundancy is used to provide basic platform subsystems with as much reliability as is practical (16 year design life), but where servicing is used to replenish consumables and selected subsystems subject to wearout after the first 8 years. For purposes of this analysis, the entire energy storage subsystem (batteries) is replaced. In practice, any set of subsystems could be included. The final decision would be made during full-scale development based on life-test data then available, and could include payloads or payload subsystems. This mode allows for the evolutionary development of a full servicing capability for later modules as the technology develops and transportation costs decrease.

The physical effect of implementing these design philosophies is reflected in payload and subsystem component quantities and level of modularity. The impact of designing the platforms for high reliability, long life and servicing was assessed and the results are shown in Table 2-13. Weight penalties were established and applied to the payloads and parametric platform designs reflecting additions or deletions of redundant elements, and modular design of space replaceable units (SRUs) employed for unmanned servicing.

Table 2-13. Reliability and Servicing Design Impact (Payload and Subsystems)

Requirements	Implementation	Design Impact (Penalties)	
1. Design for 8-year life, unserviced	Dual redundancy of critical elements	Baseline	
2. Design for 16-year life, unserviced	Triple redundancy of critical elements	+29% weight penalty	
3. Design for 2- to 5-year operating period between servicing	Minor reduction in redundancy	-10% wt	+12.5% weight penalty
4. Design for remote servicing capability	Modular packaging of communication equipment and subsystems	+25% wt	

Dual redundancy of critical active elements was established as a baseline for 8 year life without servicing, analogous to current satellite design. It was assumed that, employing 1990 technology, adequate reliability for 16 years without servicing can be achieved by employing triple redundancy. The weight penalty assessed for triple redundancy is 29 percent. This value was derived by analyzing current satellite subsystem and payload designs and determining the relative mass of redundant critical elements. The result of this analysis is plotted in Figure 2-5. During the preliminary trade studies, quad-redundancy was also evaluated to test the sensitivity of results to redundancy level.

For operational modes employing on-orbit unmanned servicing, it was assumed that a minor reduction in redundancy would be permissible and a 20 percent reduction in weight was allowed. However, since the equipment would not have to be remotely exchanged by an on-orbit servicer, a weight penalty was assessed for modular packaging, guides, quick-disconnects, etc. Prior studies of on-orbit servicing (Reference 2.13) estimated that a weight penalty of 20 percent to 30 percent would be imposed; therefore, a penalty of 25 percent was assessed for operational modes employing servicing. These opposing design impacts resulted in a combined weight penalty of $k = 0.9 \times 1.25 = 1.125$ or a 12.5 percent weight penalty for serviced operational modes.

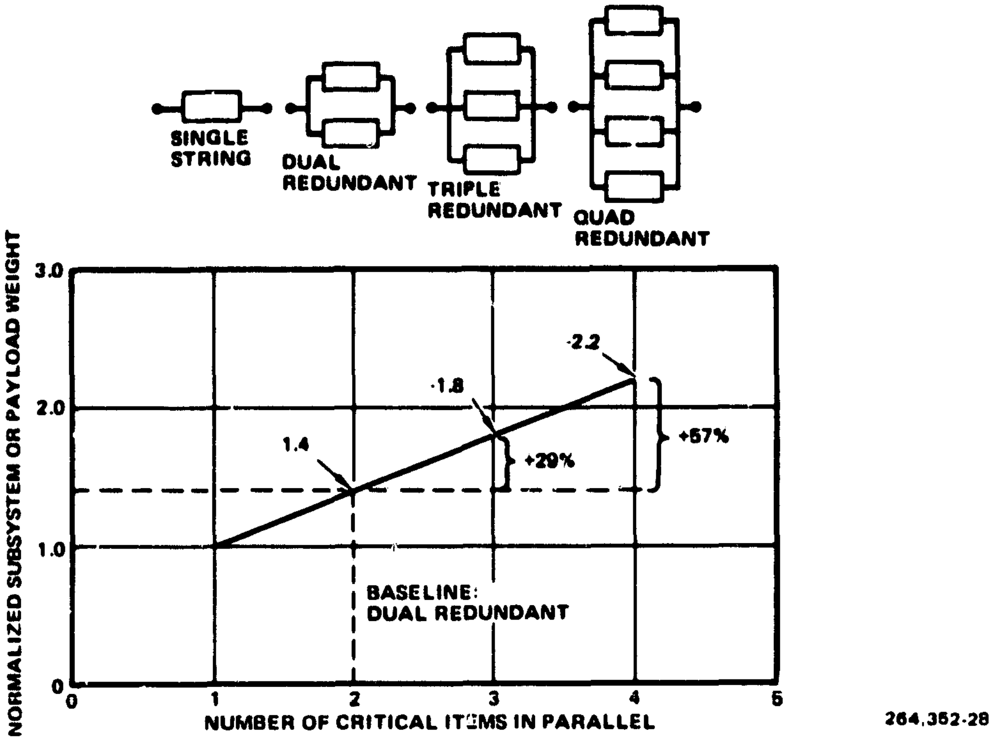

Figure 2-5. Increase in Mass Versus Redundancy

The weight penalties that were assessed for each of the four operational modes are summarized in Table 2-14. These were applied uniformly throughout all of the system trade studies.

Table 2-14. Weight Penalty Assessments

Operational Mode	Subsystem and Payload Weight Penalty Factor (k)	Rationale
B	k = 1.0	Baseline - 8 year life, nonserviced
C	k = 1.29	16-year life, nonserviced
E	k = 1.125	16-year life, serviced
C'	k = 1.29	Subsystems and payloads - 16-year life, nonserviced
	k = 1.125	Batteries - changed at 8 years

2.4.2 BASIC SYSTEM TRADE STUDIES. As outlined in Section 2.3, the basic system trade studies were conducted for 144 system concepts employing launch modes II, III and III', and buildup mode K. The results are discussed in this section. A comparison of platform options versus individual satellites (launch modes I and I') is given in Section 2.4.3. The methodology flow diagram shown in Figure 2-1 applies to this discussion.

2.4.2.1 OTV Selection. The family of OTV candidates defined by NASA (Reference 2.9) is listed in Table 2-15.

Each vehicle candidate was considered in both expendable and reusable modes, both high and low thrust versions, and in both premated (Case II) and mated at LEO (Cases III and III') modes of operation.

A few combinations dropped out early because they had less payload capability than a less expensive vehicle. For example, the dual-stage Centaur had less capability in both weight and volume than the IOTV, yet it cost more and involved more complexity, so was eliminated from further consideration. The one-stage reusable low-thrust OTV, when used in Case III, had less capability than its expendable version used in Case II, yet cost more. Some of the IUS versions were similarly discarded. Two versions of IUS, while appearing similarly uneconomical, were retained because of their relatively advanced state of development.

The final OTV candidates thus became:

Case II Low Thrust (T/W<1)

a	OTV	LT	R
b	Centaur	LT	E
c	IOTV	LT	E
d	OTV	LT	E
e	OTV		E
f	IOTV		E

Case II High Thrust (1<T/W<2)

q	OTV	R
r	Centaur	E

Case I (T/W>2)

s	2-Stage IUS	E

Case III Low Thrust

g	IOTV	LT	E
h	OTV	LT	E
j	2-Stage OTV	LT	R
k	2-Stage OTV	LT	E
l	2-Stage OTV		R
m	2-Stage OTV		E
n	OTV		E
o	IOTV		E
p	OTV		R

Case III High Thrust (1<T/W<2)

v	4-Stage IUS (2L + 2L + P/L)

Table 2-15. STS Upper Stage Options (Cost in Millions of 1980 Dollars)

Upper Stage Option	Geostationary Performance lb	Geostationary Performance kg	No. of STS Flights	No. of Upper Stages	Maximum Thrust to Weight Ratio	Maximum Payload Length, ft	Orbital Assembly Required	Transportation Cost Stages + Shuttle = Total $M	Specific Cost, $/kg	ASE Weight (OTV), kg	Code
IUS											
2 Stage (L,S)	5,100	2,313	1	2	2.35	33	No	14 + 32 = 46	19,888	1,849	s
4 Stage (2L,2L)	20,000	9,072	3	4	1.93	60	Yes (2)	20 + 114 = 134	14,771	1,849	v
Centaur											
Expendable	12,000	5,443	1	1	1.76	26	No	80 + 32 = 62	11,391	4,400	r
LT Expendable	10,500	4,763	1	1	0.19	26	No	30 + 32 = 62	13,017	4,400	b
IOTV											
Expendable	15,200	6,895	1	1	0.69	26	No	27 + 32 = 59	8,557	2,566	f
LT Expendable	12,500	5,670	1	1	0.08	26	No	27 + 32 = 59	10,406	2,566	c
Stage Meets Payload On-Orbit	22,500	10,206	2	1	0.51	60	Yes	27 + 73 = 100	9,791	2,566	o
LT	20,260	9,190	2	1	0.06	60	Yes	27 + 73 = 100	10,882	2,566	g
OTV (Single STS Launch)											
Expendable	17,200	7,802	1	1	0.64	26	No	35 + 32 = 67	8,588	2,566	e
LT Expendable	15,200	6,895	1	1	0.07	26	No	35 + 32 = 67	9,717	2,566	d
Reusable	7,700	3,493	1	1	1.08	26	No	5 + 32 = 37	10,593	2,566	q
LT Reusable	5,750	2,608	1	1	0.13	26	No	5 + 32 = 37	14,187	2,566	a
Retrieve	5,200	2,359	1	1	1.32	26	No	5 + 32 = 37	15,685	2,566	N/A
Round Trip	3,100	1,406	1	1	1.62	26	No	5 + 32 = 37	26,316	2,566	N/A
OTV (Stage Meets Payload On-Orbit)											
Expendable	28,700	13,018	2	1	0.43	60	Yes	35 + 73 = 108	8,296	2,566	n
LT Expendable	25,000	11,340	2	1	0.05	60	Yes	35 + 73 = 108	9,524	2,566	h
Reusable	13,000	5,897	2	1	0.78	60	Yes	5 + 73 = 78	13,227	2,566	p
Round Trip	3,700	1,678	2	1	1.52	60	Yes	5 + 73 = 78	46,484	2,566	N/A
OTV (2 Stages Meet Payload On-Orbit)											
Expendable	61,400	27,851	3	2	0.22	60	Yes (2)	70 + 114 = 184	6,607	2,566	m
LT Expendable	56,440	25,600	3	2	0.024	60	Yes (2)	70 + 114 = 184	7,187	2,566	k
Reusable	43,000	19,505	3	2	0.31	60	Yes (2)	10 + 114 = 124	6,357	2,566	l
LT Reusable	37,210	16,878	3	2	0.035	60	Yes (2)	10 + 114 = 124	7,347	2,566	j
Retrieve	16,000	7,258	2	2	0.68	60	Yes	10 + 73 = 83	11,436	2,566	N/A
Round Trip	11,800	5,352	3	2	0.83	60	Yes (2)	10 + 114 = 124	23,169	2,566	N/A

The 2 stage IUS (Code S) was retained only for launch cases I and I' because of its high thrust to weight ratio, which makes it practical only for satellites that are deployed at GEO.

Based upon the OTV delivery mass capability to GEO, estimates were made of the payload mass and power requirements that could be accommodated on platforms delivered by these OTVs. These estimates are listed in Table 2-16. The estimates take into account the payload and subsystem weight penalties associated with each operational mode, but do not reflect a penalty proportional to the thrust-to-weight ratio. These estimates are based on parametric platform design data developed during the preliminary trade studies. These relationships were as follows:

$$M_{PL} = \frac{M_{PL} - b_1}{m_1} \div k$$

$$P_{PY} = \frac{M_{PL} - b_2}{m_2} \div k$$

where:

M_{PY} = payload mass, kg

P_{PY} = payload power, watts

M_{PL} = platform mass, kg (i.e., OTV capability)

and the coefficients were:

Mode	b_1	m_1	k	b_2	m_2
B	500	2.575	1	600	0.5543
C	700	3.620	1.29	1000	0.9833
C'	700	2.475	1.29	1000	0.6700
D	900	2.325	1.125	1000	0.5833
E	900	2.196	1.125	1000	0.5375
F	900	2.135	1.125	1000	0.5133

A series of parametric analyses were performed to arrive at an estimate of the effect of thrust to weight greater than 0.3 upon the structural weight of the platform. Approximate structural weight penalties were assigned and used in estimating the weight of payloads, which could be accommodated by each vehicle in each of the operational modes (B, C, C', and E).

Table 2-16. Payload Mass and Power Limits

Upper Stage Options	Stage Perf. to GEO, kg	Maximum Payload Mass, kg/Power, W											
		Mode B (2) Non-Serviced 8 Year Consum.		Mode C (3) Non-Serviced 16 Year Consum.		Mode C' (3) Serviced 8 Year Consum.		Mode D (4) Serviced 5 Year Consum.		Mode E (4) Serviced 3 Year Consum.		Mode F (4) Serviced 2 Year Consum.	
		Mass	Power	Mass	Power	Mass	Power	Mass	Power	Mass	Power	Mass	Power
IUS													
2 Stage (L,S)	2,313	704	3,955	345	2,184	505	3,303	540	3,608	572	3,952	588	4,073
3 Stage (3L)	4,082	1,391	7,060	724	3,930	1,059	5,943	1,217	6,493	1,288	7,111	1,325	7,329
4 Stage (2L,2S)	5,216	1,831	9,050	967	5,049	1,414	7,636	1,650	8,342	1,747	9,129	1,797	9,417
4 Stage (3L,1L)	6,124	2,184	10,644	1,162	5,945	1,699	8,991	1,997	9,822	2,115	10,757	2,175	11,088
4 Stage (2L,2L)	8,392	3,065	14,625	1,647	8,183	2,409	12,376	2,864	13,520	3,033	14,807	3,120	15,262
4 Stage (2L,2L)	9,072	3,330	15,819	1,793	8,854	2,622	13,391	3,124	14,629	3,308	16,021	3,403	16,514
Centaur													
Expendable	5,443	1,920	9,449	1,016	5,273	1,486	7,975	1,737	8,712	1,839	9,541	1,892	9,834
LT Expendable	4,763	1,656	8,255	870	4,602	1,273	6,960	1,477	7,603	1,564	8,327	1,609	8,583
Dual Stages	9,526	3,505	16,616	1,890	9,302	2,764	14,069	3,298	15,369	3,492	16,832	3,592	17,350
IOTV													
Expendable	6,895	2,483	11,998	1,327	6,706	1,940	10,142	2,292	11,079	2,427	12,134	2,496	12,507
LT Expendable	5,670	2,008	9,847	1,064	5,497	1,557	8,313	1,824	9,082	1,931	9,946	1,986	10,252
Stage Meets Payload On-Orbit	10,206	3,769	17,809	2,036	9,973	2,977	15,084	3,558	16,478	3,767	18,046	3,875	18,601
LT Meets Payload On-Orbit	9,190	3,375	16,026	1,818	8,971	2,659	13,567	3,169	14,821	3,356	16,232	3,452	16,731
OTV (Single STS Launch)													
Expendable	7,802	2,836	13,590	1,521	7,601	2,224	11,496	2,639	12,558	2,794	13,754	2,874	14,176
LT Expendable	6,895	2,483	11,998	1,327	6,706	1,940	10,142	2,292	11,079	2,427	12,134	2,496	12,507
Reusable	3,493	1,162	6,026	598	3,348	875	5,064	991	5,532	1,050	6,059	1,080	6,245
LT Reusable	2,608	819	4,473	409	2,475	598	3,743	653	4,089	691	4,479	711	4,616
Retrieve	(1)												
Round Trip	(1)												
OTV (Stage Meets Payload On-Orbit)													
Expendable	13,018	4,861	22,745	2,638	12,748	3,858	19,281	4,633	21,063	4,906	23,068	5,046	23,777
LT Expendable	11,340	4,210	19,800	2,278	11,092	3,333	16,776	3,991	18,327	4,226	20,071	4,347	20,688
Reusable	5,897	2,096	10,246	1,113	5,721	1,628	8,652	1,910	9,452	2,023	10,352	2,081	10,670
LT Reusable	4,296	1,474	7,435	770	4,141	1,126	6,263	1,298	6,842	1,375	7,493	1,414	7,723
Round Trip	(1)												

Table 2-16. Payload Mass and Power Limits, Contd

Upper Stage Options	Stage Perf. to GEO, kg	Maximum Payload Mass, kg/Power, W											
		Mode B (2) Non-Serviced 8 Year Consum.		Mode C (3) Non-Serviced 16 Year Consum.		Mode C' (3) Serviced 8 Year Consum.		Mode D (4) Serviced 5 Year Consum.		Mode E (4) Serviced 3 Year Consum.		Mode F (4) Serviced 2 Year Consum.	
		Mass	Power	Mass	Power	Mass	Power	Mass	Power	Mass	Power	Mass	Power
OTV (2 Stages Meet Payload On-Orbit)													
Expendable	27,851	10,622	48,782	5,814	27,387	8,504	41,419	10,304	45,249	10,911	49,555	11,223	51,079
LT Expendable	25,600	9,748	44,831	5,332	25,165	7,799	38,060	9,443	41,578	8,785	45,536	10,286	46,935
Reusable	19,505	7,381	34,132	4,027	19,150	5,890	28,963	7,113	31,640	7,532	34,652	7,747	35,717
LT Reusable	16,878	6,360	29,521	3,464	16,558	5,067	25,042	6,109	27,357	6,468	29,961	6,654	30,882
Retrieve	(1)												
Round Trip	(1)												

(1) N/A for delivery.

(2) If payload power exceeds limit, decrease payload mass at the rate of 55 kg/kW of excess power.

(3) If payload power exceeds limit, decrease payload mass at the rate of 71 kg/kW of excess power.

(4) If payload power exceeds limit, decrease payload mass at the rate of 62 kg/kW of excess power.

These adjusted estimated payload capabilities for each of the 72 combinations (18 vehicles with 4 modes) are as follows:

	kg				
aC	409	bE	1564	oB	3157
qC	451	pE	1610	lC	3247
aC'	598	bB	1656	hC'	3333
rC	616	pB	1683	gE	3356
aE	691	eC'	1732	gB	3375
pC	700	vC'	1765	jC	3464
qC'	728	gC	1818	nB	4145
aB	819	nC	1922	nE	4190
bC	870	cE	1931	hB	4210
fC	879	dC'	1940	hE	4226
qE	903	fE	1979	jC'	5067
vC	936	cB	2008	lC'	5110
qB	1015	fB	2035	kC	5332
eC	1029	hC	2278	mC	5814
cC	1064	eE	2302	jB	6360
rC'	1086	eB	2344	jE	6468
pC'	1215	oC'	2365	lB	6701
bC'	1273	dE	2427	lE	6752
dC	1327	vE	2451	kC'	7799
oC	1424	vB	2473	mC'	8504
rE	1439	dB	2483	kB	9748
fC'	1492	gC'	2659	kE	9999
rB	1520	nC'	3142	mB	10622
cC'	1557	cE	3155	mE	10911

These figures have been adjusted downward in cases C and C' to allow for the added redundancy required in the payloads in those modes. Thus, the basic payload weights can be used when allocating payloads to a platform up to these limits. Similarly, the estimated payload capabilities for Mode E have been adjusted slightly to allow for the necessary modularization of the payloads.

A 15 percent margin was applied to reflect uncertainties in the payload weights. The resulting estimated margined payload capacities per platform varied from 248 kg for aC to 9250 kg for mB and mE.

2.4.2.2 Payload Assignments. Specific payloads were assigned to platform modules in each set until the entire mission model was accommodated. This payload allocation process determined the number of platforms required for each delivery vehicle/operational mode combination. These results are shown in Tables 2-17 and 2-18 for mission sets N and V, respectively. The specific payloads assigned to each platform in each of the sets are identified in Appendix F.

In all, 628 platforms were defined for the Western Hemisphere nominal traffic model. The number required varied from 67 for aC to 1 for mB and mE. For the high traffic model (both locations), 2357 platforms were defined. The number required varies from 225 for aC to 3 for mB and mE.

There are some large payloads that are not divisible. In particular, No. 34, ACOSS/HALO, in the high traffic model and No. 71, earth optical telescope, in both traffic models. These payloads are estimated to weigh 1100 kg each. Because they are relatively low in power requirements, they can be accommodated on combinations whose estimated payload capacity was a little less than that. But they cannot go in one piece on combinations above options rC' on Table 2-17 and 2-18. Thus, those OTV/mode options are not really capable of supporting the entire mission model. Because these large payloads are not absolute requirements, rather than discard the smaller platform combinations, these payloads were arbitrarily divided and an equivalent number of platforms included in the appropriate sets. As the platforms get smaller, the same thing must be done to other payloads as well.

Thus, while all the options theoretically provide the same total mission set to the same reliability, for those above combinatin rC in Tables 2-17 and 2-18, the practicality of doing so is suspect.

2.4.2.3 Platform Synthesis. Parametric platform design concepts were developed for each of 72 sets for mission sets N and V. For each set, a standard platform bus was parametrically designed to accommodate the maximum weight and maximum power requirements of each payload group. Based upon payload weight and power requirements, the platform structure and supporting subsystems were sized, taking into account redundancy and modularity appropriate for each operational mode. The structural weight estimates included the impact of high thrust to weight ratios. The total platform weight, including payloads, was calculated and a 15 percent contingency factor included. In some cases, this total was found to exceed the assigned OTV capability so another iteration was performed. A new, lower estimated margined payload weight was determined and the payload allocation process repeated. This increased the number of platforms for that set.

For the smaller platforms, where large payloads had to be subdivided, the attendant duplication of antennas, etc., caused the number of platforms to go up sharply. The parametric platform designs were developed using scaling factors and weight estimating relationships developed from the preliminary trade studies for each of the operational modes.

Platform mass and power estimating data sheets for the 144 mode K system concepts are included in Appendix G. One example of these data sheets is shown in Figure 2-6. This example shows a platform concept designed to accommodate a payload complement with a mass of 2103 kg, drawing power of 8120 watts.

Table 2-17. Number of Platforms Required Versus OTV and Mode (Mission Set N)

(P/L Mass Margin - 15%)

Item No.	Platform Set No.	OTV	Mode	Gross Payload Weight, kg*	Margined Weight, kg	No. of Platforms
1	51	a	C	409	248	67
2	31	q	C	451	340	39
3	52	a	C'	598	411	31
4	32	r	C	616	500	26
5	33	a	E	691	580	19
6	33	p	C	700	580	19
7	33	q	C'	728	580	19
8	34	a	B	819	690	16
9	34	b	C	870	690	16
10	34	f	C	879	690	16
11	55	q	E	903	780	15
12	55	v	C	930	780	15
13	35	q	B	1,015	860	14
14	35	e	C	1,029	860	14
15	53	c	C	1,064	876	13
16	36	r	C'	1,086	900	12
17	37	p	C'	1,215	1,100	9
18	54	b	C'	1,273	1,060	10
19	37	d	C	1,327	1,100	9
20	38	o	C	1,424	1,210	9
21	38	r	E	1,439	1,210	9
22	38	f	C'	1,492	1,210	9
23	38	r	B	1,520	1,210	9

*Reduced for T/W penalty where applicable.

Table 2-17. Number of Platforms Required Versus OTV and Mode (Mission Set N), Contd

(P/L Mass Margin - 15%)

Item No.	Platform Set No.	OTV	Mode	Gross Payload Weight, kg*	Margined Weight, kg	No. of Platforms
24	39	c	C'	1,557	1,320	8
25	39	b	E	1,564	1,320	8
26	39	p	E	1,610	1,320	8
27	56	b	B	1,656	1,400	7
28	56	p	B	1,683	1,400	7
29	56	e	C'	1,732	1,400	7
30	56	v	C'	1,765	1,400	7
31	56	g	C	1,818	1,400	7
32	40	n	C	1,922	1,630	6
33	40	c	E	1,931	1,630	6
34	40	d	C'	1,940	1,630	6
35	40	f	E	1,979	1,630	6
36	40	c	B	2,008	1,630	6
37	40	f	B	2,035	1,630	6
38	41	h	C	2,278	1,970	5
39	41	e	E	2,302	1,970	5
40	41	e	B	2,344	1,970	5
41	41	o	C'	2,365	1,970	5
42	41	d	E	2,427	1,970	5
43	41	v	E	2,451	1,970	5
44	41	v	B	2,473	1,970	5
45	41	d	B	2,483	1,970	5
46	42	g	C'	2,659	2,250	5

*Reduced for T/W penalty where applicable.

Table 2-17. Number of Platforms Required Versus OTV and Mode (Mission Set N), Contd

(P/L Mass Margin - 15%)

Item No.	Platform Set No.	OTV	Mode	Gross Payload Weight, kg*	Margined Weight, kg	No of Platforms
47	43	n	C'	3,142	2,650	4
48	43	o	E	3,155	2,650	4
49	43	o	B	3,157	2,650	4
50	43	l	C	3,247	2,650	4
51	43	h	C'	3,333	2,650	4
52	43	g	E	3,356	2,650	4
53	43	g	B	3,375	2,650	4
54	43	j	C	3,464	2,650	4
55	44	n	B	4,145	3,500	3
56	44	n	E	4,190	3,500	3
57	44	h	B	4,210	3,500	3
58	44	h	E	4,226	3,500	3
59	45	j	C'	5,067	4,300	3
60	45	l	C'	5,110	4,300	3
61	45	k	C	5,332	4,300	3
62	46	m	C	5,814	4,900	2
63	47	j	B	6,360	5,400	2
64	47	j	E	6,468	5,400	2
65	47	l	B	6,701	5,400	2
66	47	l	E	6,752	5,400	2
67	48	k	C'	7,799	6,600	2
68	48	m	C'	8,504	6,600	2
69	49	k	B	9,748	8,200	2
70	49	k	E	9,999	8,200	2
71	50	m	B	10,622	9,250	1
72	50	m	E	10,911	9,260	1

*Reduced for T/W penalty where applicable.

Table 2-18. Number of Platforms Required Versus OTV and Mode (Mission Set V)

(P/L Mass Margin - 15%)

Item No.	Platform Set No.	OTV	Mode	Gross Payload Weight, kg*	Margined Weight, kg	No. of Platforms
85	72	a	C	409	248	225
86	73	q	C	451	340	163
87	74	a	C'	598	411	145
88	75	r	C	616	500	121
89	76	a	E	691	580	95
90	77	p	C	700	591	90
91	78	q	C'	728	615	87
92	79	a	B	819	690	79
93	80	b	C	870	730	70
94	80	f	C	879	735	70
95	81	q	E	903	780	62
96	82	v	C	936	788	58
97	83	q	B	1,015	860	52
98	84	e	C	1,029	868	51
99	85	c	C	1,064	876	50
100	86	r	C'	1,086	900	47
101	61	p	C'	1,215	1,100	33
73	60	b	C'	1,273	1,060	34
74	61	d	C	1,327	1,100	33
102	87	o	C	1,424	1,210	30
103	87	r	E	1,439	1,210	30
104	88	f	C'	1,492	1,240	29
105	89	r	B	1,520	1,250	27
75	62	c	C'	1,557	1,320	26
106	62	b	E	1,564	1,320	26

*Reduced for T/W penalty where applicable.

Table 2-18. Number of Platforms Required
Versus OTV and Mode (Mission Set V), Contd

(P/L Mass Margin - 15%)

Item No.	Platform Set No.	OTV	Mode	Gross Payload Weight, kg*	Margined Weight, kg	No. of Platforms
107	90	p	E	1,610	1,360	25
108	90	b	B	1,656	1,400	25
109	91	p	B	1,683	1,420	24
110	91	e	C'	1,732	1,440	24
111	92	v	C'	1,765	1,470	23
112	93	g	C	1,818	1,515	22
113	63	n	C	1,922	1,630	20
114	63	c	E	1,931	1,630	20
76	63	d	C'	1,940	1,630	20
115	63	f	E	1,979	1,630	20
116	63	c	B	2,008	1,630	20
117	101	f	B	2,035	1,760	20
118	94	h	C	2,278	1,970	17
119	94	e	E	2,302	1,970	17
120	94	e	B	2,344	1,970	17
121	94	o	C'	2,365	1,970	17
122	95	d	E	2,427	2,050	16
123	95	v	E	2,451	2,050	16
124	95	v	B	2,473	2,050	16
125	95	d	B	2,483	2,050	16
77	64	g	C'	2,659	2,250	14
126	65	n	C'	3,142	2,650	12
127	65	o	E	3,155	2,650	12
128	65	o	B	3,157	2,650	12
78	65	l	C	3,247	2,650	12

*Reduced for T/W penalty where applicable.

Table 2-18. Number of Platforms Required Versus OTV and Mode (Mission Set V), Contd

(P/L Mass Margin - 15%)

Item No.	Platform Set No.	OTV	Mode	Gross Payload Weight, kg*	Margined Weight, kg	No. of Platforms
129	96	h	C'	3,333	2,800	12
130	96	g	E	3,356	2,800	12
131	96	g	B	3,375	2,800	12
132	97	j	C	3,464	2,930	11
133	98	n	B	4,145	3,500	9
134	98	n	E	4,190	3,500	9
135	98	h	B	4,210	3,500	9
136	98	h	E	4,226	3,580	9
137	66	j	C'	5,067	4,300	7
79	66	l	C'	5,110	4,300	7
138	66	k	C	5,332	4,300	7
80	67	m	C	5,814	4,900	6
139	68	j	B	6,360	5,400	6
140	68	j	[illegible]	6,478	5,400	6
81	68	l	B	6,701	5,400	6
141	68	l	E	6,752	5,400	6
142	99	k	C'	7,799	6,600	5
82	69	m	C'	8,504	7,395	4
143	100	k	B	9,748	8,200	4
144	100	k	E	9,785	8,200	4
83	70	m	B	10,622	9,250	3
84	70	m	E	10,911	9,250	3

*Reduced for T/W penalty where applicable.

PLATFORM MASS & POWER ESTIMATES

PLATFORM NO. 606C'

OTV: Centaur, L. T. Expendable

OPER. MODE: C' – Non-serviced, 16 yr life, consumables replenished at 8 yrs

Platform Elements		Estimating Basis	Power, watts	Mass, kg
1. Payload Equipment		Item: 73 Case: II ($M_{PY} < 3000$)	6,000	1,367
2. Structure - Basic		$M_S = 0.31\ (M_{PY}) + 50 = 474$ kg	0	521
- Secondary		10% of $M_S = 47$ kg		
- T/W Penalty		T/W = 0.19; Penalty = 0 kg		
3. EPS		$M_E = 0.0609\ (P_o) + 200 = 704$ kg		704
		$P_E = 0.067\ (P_o) + 100 = 654$ W	654	
4. ACS		$M_A = 0.0294\ (M_{PL}) + 64 = 204$ kg		204
		$P_A = 0.011\ (M_{PL}) + 30 = 82$ W	82	
5. RCS	$M_P = 0.166\ (M_{PL})$	$M_R = 1.2\ (M_P) = 1.2 \times (791) = 949$ kg		949
	$M_R = M_P + 0.2\ M_P$	$P_R = 0.008\ (M_{PY}) + 20 = 31$ W ($M_{PY} < 4400$)	31	
6. TCC		$M_T = 0.0319\ (M_{PY}) + 52 = 96$ kg		96
		$P_T = 0.0195\ (M_{PY}) + 40 = 67$ W	67	
7. TCS		$M_H = 0.0175\ (M_{PY}) + 52 = 76$ kg		76
		$P_H = 0.0438\ (M_{PY}) + 100 = 160$ W	160	
8. Rendezvous & Docking		$M_{RD} = 0.0193\ (M_{PY}) + 200 = 226$ kg		226
		$P_{RD} = 200$ W	200	
		Sub Tot:	7,194	4,143
9. Contingency & Integration		15% of the above power and mass	1,079	621
			P_o	M_{PL}
NO. OF PLATFORMS: 34		TOTALS:	8,273	4,765

264 352 29

Figure 2-6. Mass and Power Estimating Data Sheet

The structure and each of the supporting subsystems are sized and contingencies of 15 percent are applied. The total mass is 6646 kg. The delivery capability of the single stage OTV used in the low thrust expendable mode with a single Shuttle launch (launch case II) was given as 6895 kg, leaving a margin of 250 kg. For this concept, six platforms accommodate the nominal traffic model payloads at the Western Hemisphere location (mission set N). The delivery of the platform to this location would be time-phased over about a six year period.

When the OTV/platform assembly is delivered to the parking orbit by a Shuttle, the assembly is rotated out of the cargo bay and positioned relative to the Orbiter while the platform elements are deployed and checked out by the crew. Subsystems and payloads are preattached and prewired to the maximum extent consistent with Orbiter volume constraints. Certain intallation tasks may be accomplished by planned EVA where this mode yields an advantage in reducing platform complexity or cost and/or in increasing reliability. However, most deployment will be accomplished automatically. Unplanned EVA is also available as a backup operating mode to correct anomalies.

When the platform and OTV checkout are satisfactorily completed, the assembly is released from the Orbiter and the OTV begins the LEO-GEO transfer phase. The OTV transfers the platform to a designated aim point near its assigned orbital slot using a multiple perigee burn, single apogee burn trajectory.

When the earth station command and control link is established and the platform attitude control subsystem is activated and acquires its references, the OTV releases the platform, backs away to a safe distance, and then lofts itself to a super-synchronous disposal orbit where it cannot interfere with geostationary platforms or satellites.

For this concept, the orbital slot will be shared by six platforms arranged in a rotating circular constellation that will maintain them well within a ±0.1 degree area as viewed from the earth, yet will maintain minimum separation distances and minimize orbit adjustment propellant usage. This is accomplished by placing each of the modules in orbits that deviate slightly from geostationary orbit (slightly inclined and slightly elliptical) with the proper nodal point phasing.

The platform on-board propulsion system is used to control the placement of each platform module into its desired orbit and then maintain its relative position. Values of orbit eccentricity of $e = 0.00011$ and inclination of $i = 0.0125$ degrees will result in a circular constellation with a diameter on the order of 18 km.

This concept is designed to require a minimum of servicing while assuring high system availability. Platform subsystems are designed for 16 years of life and employ triple redundancy of critical elements. The reaction control system (RCS) which provides both attitude control and stationkeeping propulsion is sized to carry an 8 year supply of propellant and will be replenished at intervals ≤ 8

years. Batteries are packaged in modules that can be replaced in orbit by an unmanned servicing vehicle. Battery usable life is currently prcjected to be about 10 years; therefore, as few as one servicing flight could suffice for a 16 year platform mission. Payload equipment can either be designed for long life through high redundancy or for repair or replacement via logistics flights; this choice is a user option.

The 2103 kg weight shown for the payload complement already includes a k factor of 1.29 for triple redundancy, as do the mass estimates for the EPS, ACS, RCS (dry), TTC, and TCS subsystems.

2.4.2.4 Packaging Analysis. Packaging of the platforms for ascent from earth to LEO is an important design parameter that determines the number of shuttle launches required and thus transportation costs. Since detailed designs were not possible for all of the candidate platform options, the packaging analysis was parametrically performed based on previous GDC large space structures studies. For launch case II (Reference Tables 2-19 and 2-20) where the mated platform and OTV together occupy the Orbiter cargo bay, the packaging density criterion used was 984 kg per meter of length. All but one concept met this criterion. The one exception was Item 119, which had a packaging density of 994 kg per meter.

For launch cases III and III', where the packaged platform can occupy the full 18.3 m length of the cargo bay, the packaging criterion used was 1300 kg per meter of length. This is equivalent to a packaging efficiency factor of about 80 percent. For cases III and III', an additional mass allowance was added for the ASE required to support the platform. This allowance was +20 percent; therefore, the gross platform weight used was 1.2 times the net weight. The gross weight was then used in computing the packaging densities.

It was determined that three concepts for mission set N (Reference Table 2-19) and eight concepts for mission set V (Reference Table 2-20) would not meet the criterion for a single Shuttle launch to LEO, but would require one extra flight for each platform. These results were then input to the transportaion cost analysis.

2.4.2.5 Servicing Requirements. Platform servicing requirements were determined from the detailed subsystem and payload definitions in accordance with the servicing philosophy of the particular option being investigated. Each subsystem was considered individually. In the power system, for example, it is assumed that solar arrays are never replaced, 100 percent of the batteries are replaced, and 52 percent of the power control avionics is replaced during the 16 year mission life (mode E). From such figures and rate of use of consumables, the total mass that must be delivered to each platform by servicing flights during the mission life was calculated.

Table 2-19. Platform Packaging - Mission Set N

Item No.	Bus Type	No. of Platforms	Launch Case II	Launch Case III	Launch Case III'	Net Platform Mass kg	Cargo Bag Length m	Net Platform Packaging Density kg/m	Case II Is Net D ≤ 984 kg/m Yes	Case II Is Net D ≤ 984 kg/m No	Case III Gross* Platform Mass kg	Case III Gross* Packaging Density kg/m	Case III Is Gross D ≤ 1300 kg/m Yes	Case III Is Gross D ≤ 1300 kg/m No	Case III' No. of Extra Flights to LEO
1	51aC	67	X			2,482	7.9	314	X	–	–	–	–	–	–
2	31qC	39	X			3,328	7.9	421	X	–	–	–	–	–	–
3	52aC'	31	X			2,646	7.9	335	X	–	–	–	–	–	–
4	32rC	26	X			5,014	7.9	635	X	–	–	–	–	–	–
5	33aE	19	X			2,626	7.9	332	X	–	–	–	–	–	–
6	33pC	19		X		5,309	18.3	290	–	–	6,371	568	X	–	–
7	33qC'	19	X			4,360	7.9	552	X	–	–	–	–	–	–
8	34aB	16	X			2,640	7.9	334	X	–	–	–	–	–	–
9	34bC	16	X			4,780	7.9	605	X	–	–	–	–	–	–
10	34fC	16	X			5,795	7.9	734	X	–	–	–	–	–	–
11	55qE	15	X			3,167	7.9	401	X	–	–	–	–	–	–
12	55vC	15		X		7,056	18.3	386	–	–	8,437	463	–	–	–
13	35qB	14	X			3,333	7.9	422	X	–	–	–	–	–	–
14	35eC	14	X			6,730	7.9	852	X	–	–	–	–	–	–
15	53cC	13	X			5,572	7.9	705	X	–	–	–	–	–	–
16	36rC'	12	X			4,956	7.9	627	X	–	–	–	–	–	–
17	37pC'	9		X		5,548	18.3	303	–	–	6,658	364	–	–	–
18	54bC'	10	X			4,756	7.9	602	X	–	–	–	–	–	–
19	37dC	9	X			6,857	7.9	868	X	–	–	–	–	–	–
20	38oC	9		X		8,657	18.3	473	–	–	10,388	568	X	–	–
21	38rE	9	X			4,728	7.9	598	X	–	–	–	–	–	–
22	38fC'	9	X			5,893	7.9	746	X	–	–	–	–	–	–
23	38rB	9	X			4,645	7.9	588	X	–	–	–	–	–	–
24	39cC'	8	X			5,689	7.9	720	X	–	–	–	–	–	–
25	39bE	8	X			4,635	7.9	587	X	–	–	–	–	–	–
26	39pE	8		X		5,173	18.3	283	–	–	6,208	339	X	–	–
27	56bB	7	X			4,612	7.9	584	X	–	–	–	–	–	–

Table 2-19. Platform Packaging - Mission Set N, Contd

Item No.	Bus Type	No. of Platforms	Launch Case II	Launch Case III	Launch Case III'	Net Platform Mass kg	Cargo Bag Length m	Net Platform Packaging Density kg/m	Case II Is Net D ≤ 984 kg/m Yes	Case II Is Net D ≤ 984 kg/m No	Case III Gross* Platform Mass kg	Case III Gross* Packaging Density kg/m	Case III Is Gross D ≤ 1300 kg/m Yes	Case III Is Gross D ≤ 1300 kg/m No	Case III' No. of Extra Flights to LEO
28	56pB	7		X		5,251	18.3	287	–	–	6,301	344	X	–	–
29	56eC'	7	X			6,667	7.9	844	X	–	–	–	–	–	–
30	56vC'	7		X		7,237	18.3	395	–	–	8,684	474	X	–	–
31	56gC	7		X		8,327	18.3	455	–	–	9,992	546	X	–	–
32	40nC	6		X		11,566	18.3	632	–	–	13,879	758	X	–	–
33	40cE	6	X			5,676	7.9	718	X	–	–	–	–	–	–
34	40dC'	6	X			6,645	7.9	841	X	–	–	–	–	–	–
35	40fE	6	X			6,259	7.9	792	X	–	–	–	–	–	–
36	40cB	6	X			5,218	7.9	661	X	–	–	–	–	–	–
37	40fB	6	X			5,910	7.9	748	X	–	–	–	–	–	
38	41hC	5		X		10,902	18.3	596	–	–	13,082	715	X	–	–
39	41eE	5	X			6,825	7.9	864	X	–	–	–	–	–	–
40	41eB	5	X			6,816	7.9	863	X	–	–	–	–	–	–
41	41oC'	5		X		8,629	18.3	472	–	–	10,355	566	X	–	–
42	41dE	5	X			6,205	7.9	785	X	–	–	–	–	–	–
43	41vE	5		X		7,321	18.3	400	–	–	8,785	480	X	–	–
44	41vB	5		X		7,380	18.3	403	–	–	8,856	484	X	–	–
45	41dB	5	X			6,055	7.9	766	X	–	–	–	–	–	–
46	42gC'	5		X		7,673	18.3	419	–	–	9,208	503	X	–	–
47	43nC'	4		X		10,942	18.3	598	–	–	13,130	717	X	–	–
48	43oE	4		X		8,717	18.3	476	–	–	10,460	571	X	–	–
49	43oB	4		X		8,764	18.3	479	–	–	10,517	575	X	–	–
50	43lC	4		X		15,829	18.3	865	–	–	18,995	1,038	X	–	–
51	43hC'	4		X		9,799	18.3	535	–	–	11,759	643	X	–	–
52	43gE	4		X		7,919	18.3	433	–	–	9,503	519	X	–	–
53	43gB	4		X		7,817	18.3	427	–	–	9,380	513	X	–	–
54	43jC	4		X		14,059	18.3	768	–	–	16,871	922	X	–	–

Table 2-19. Platform Packaging - Mission Set N, Contd

Item No.	Bus Type	No. of Platforms	Launch Case II	Launch Case III	Launch Case III'	Net Platform Mass kg	Cargo Bag Length m	Net Platform Packaging Density kg/m	Case II Is Net D ≤ 984 kg/m Yes	Case II Is Net D ≤ 984 kg/m No	Case III Gross* Platform Mass kg	Case III Gross* Packaging Density kg/m	Case III Is Gross D ≤ 1300 kg/m Yes	Case III Is Gross D ≤ 1300 kg/m No	Case III' No. of Extra Flights to LEO
55	44nB	3		X		11,163	18.3	610	–	–	13,395	732	X	–	–
56	44nE	3		X		10,980	18.3	600	–	–	13,176	720	X	–	–
57	44hB	3		X		10,056	18.3	550	–	–	12,067	659	X	–	–
58	44hE	3		X		10,047	18.3	549	–	–	12,056	659	X	–	–
59	47jC'	2		X		16,872	18.3	922	–	–	20,246	1,106	X	–	–
60	47lC'	2		X		18,090	18.3	989	–	–	21,708	1,186	X	–	–
61	45kC	3		X		18,134	18.3	991	–	–	21,761	1,189	X	–	–
62	46mC	2			X	24,442	18.3	1,336	–	–	29,330	1,603	–	X	1
63	47jB	2		X		13,545	18.3	740	–	–	16,254	888	X	–	–
64	47jE	2		X		13,361	18.3	730	–	–	16,033	876	X	-	–
65	47lB	2		X		14,751	18.3	806	–	–	17,701	967	X	–	–
66	47lE	2		X		14,377	18.3	786	–	–	17,252	943	X	–	–
67	48kC'	2		X		16,872	18.3	922	–	–	20,246	1,106	X	–	–
68	48mC'	2		X		16,872	18.3	922	–	–	20,246	1,106	X	–	–
69	49kB	2		X		13,545	18.3	740	–	–	16,254	888	X	–	–
70	49kE	2		X		13,361	18.3	730	–	–	16,033	876	X	–	–
71	50nB	1			X	24,621	18.3	1,345	–	–	29,545	1,614	–	X	1
72	50mE	1			X	23,893	18.3	1,306	–	–	38,672	1,567	–	X	1

*G = 1.2 × N

Table 2-20. Platform Packaging - Mission Set V

Item No.	Bus Type	No. of Platforms	Launch Case II	Launch Case III	Launch Case III'	Net Platform Mass kg	Cargo Bag Length m	Net Platform Packaging Density kg/m	Case II Is Net D ≤ 984 kg/m Yes	Case II Is Net D ≤ 984 kg/m No	Case III Gross* Platform Mass kg	Case III Gross* Packaging Density kg/m	Case III Is Gross D ≤ 1300 kg/m Yes	Case III Is Gross D ≤ 1300 kg/m No	Case III' No. of Extra Flights to LEO
85	72aC	60	X			2,487	7.9	315	X	–	–	–	–	–	–
86	73qC	163	X			3,321	7.9	420	X	–	–	–	–	–	–
87	74aC'	145	X			2,690	7.9	341	X	–	–	–	–	–	–
88	75rC	121	X			4,841	7.9	613	X	–	–	–	–	–	–
89	76aE	95	X			3,212	7.9	407	X	–	–	–	–	–	–
90	77pC	90		X		5,275	18.3	288	–	–	6,330	346	X	–	–
91	78qC'	87	X			3,512	7.9	445	X	–	–	–	–	–	–
92	79aB	79 (×2)	X			2,639	7.9	334	X	–	–	–	–	–	–
93	80bC	70	X			4,952	7.9	627	X	–	–	–	–	–	–
94	80fC	70	X			6,008	7.9	761	X	–	–	–	–	–	–
95	81qE	62	X			3,891	7.9	493	X	–	–	–	–	–	–
96	82vC	58		X		7,150	18.3	391	–	–	8,580	469	X	–	–
97	83qB	52 (×2)	X			3,311	7.9	419	X	–	–	–	–	–	–
98	84eC	51	X			6,730	7.9	852	X	–	–	–	–	–	–
99	85cC	50	X			5,655	7.9	716	X	–	–	–	–	–	–
100	86rC'	47	X			4,812	7.9	609	X	–	–	–	–	–	–
101	61pC'	33		X		5,637	18.3	308	–	–	6,764	370	X	–	–
(73)	60bC'	34	X			4,765	7.9	603	X	–	–	–	–	–	–
(74)	61dC	33	X			6,815	7.9	863	X	–	–	–	–	–	–
102	87oC	30		X		8,734	18.3	477	–	–	10,481	573	X	–	–
103	87rE	30	X			5,413	7.9	685	X	–	–	–	–	–	–
104	88fC'	29	X			6,036	7.9	764	X	–	–	–	–	–	–
105	89rB	27 (×2)	X			4,871	7.9	617	X	–	–	–	–	–	–
(75)	62cC'	26	X			5,590	7.9	708	X	–	–	–	–	–	–
106	62bE	26	X			4,527	7.9	573	X	–	–	–	–	–	–
107	90pE	25		X		5,831	18.3	319	–	–	6,997	382	X	–	–
108	90bB	25 (×2)	X			4,568	7.9	578	X	–	–	–	–	–	–

Table 2-20. Platform Packaging - Mission Set V, Contd

Item No.	Bus Type	No. of Platforms	Launch Case II	Launch Case III	Launch Case III'	Net Platform Mass kg	Cargo Bag Length m	Net Platform Packaging Density kg/m	Case II Is Net D ≤ 984 kg/m Yes	Case II Is Net D ≤ 984 kg/m No	Case III Gross* Platform Mass kg	Case III Gross* Packaging Density kg/m	Case III Is Gross D ≤ 1300 kg/m Yes	Case III Is Gross D ≤ 1300 kg/m No	Case III' No. of Extra Flights to LEO
109	91pB	24 (×2)		X		5,285	18.3	289	–	–	6,342	347	X	–	–
110	91eC'	24	X			6,771	7.9	857	X	–	–	–	–	–	–
111	92vC'	23		X		7,463	18.3	408	–	–	8,956	489	X	–	–
112	93gC	22		X		8,895	18.3	486	–	–	10,674	583	X	–	–
113	63nC	20		X		11,251	18.3	615	–	–	13,501	738	X	–	–
114	63cE	20	X			5,393	7.9	683	X	–	–	–	–	–	–
(76)	63dC'	20	X			6,574	7.9	832	X	–	–	–	–	–	–
115	63fE	20	X			6,621	7.9	838	X	–	–	–	–	–	–
116	63cB	20 (×2)	X			5,236	7.9	663	X	–	–	–	–	–	–
117	101fB	20 (×2)	X			6,327	7.9	801	X	–	–	–	–	–	–
118	94hC	17		X		11,621	18.3	635	–	–	13,945	762	X	–	–
119	94eE	17	X			7,849	7.9	994	–	X	–	–	–	–	–
120	94eB	17 (×2)	X			7,193	7.9	911	X	–	–	–	–	–	–
121	94oC'	17		X		9,051	18.3	495	–	–	10,861	594	X	–	–
122	95dE	16	X			7,441	7.9	942	X	–	–	–	–	–	–
123	95vE	16		X		8,556	18.3	468	–	–	10,267	561	X	–	–
124	95vB	16 (×2)		X		7,995	18.3	437	–	–	9,594	524	X	–	–
125	95dB	16	X			6,670	7.9	844	X	–	–	–	–	–	–
(77)	64gC'	14		X		9,010	18.3	492	–	–	10,812	590	X	–	–
126	65nC'	12		X		11,605	18.3	634	–	–	13,926	761	X	–	–
127	65oE	12		X		9,279	16.3	507	–	–	11,135	608	X	–	–
128	65oB	12 (×2)		X		9,358	18.3	511	–	–	11,230	613	X	–	–
(78)	65lC	12		X		16,955	18.3	927	–	–	20,346	1,112	X	–	–
129	96hC'	12		X		10,886	18.3	595	–	–	13,063	714	X	–	–
130	96gE	12		X		8,977	18.3	491	–	–	10,772	589	X	–	–
131	96gB	12 (×2)		X		8,730	18.3	477	–	–	10,476	572	X	–	–
132	97jC	11		X		16,558	18.3	905	–	–	19,870	1,086	X	–	–

Table 2-20. Platform Packaging - Mission Set V, Contd

Item No.	Bus Type	No. of Platforms	Launch Case II	Launch Case III	Launch Case III'	Net Platform Mass kg	Cargo Bag Length m	Net Platform Packaging Density kg/m	Case II Is Net D ≤ 984 kg/m Yes	Case II Is Net D ≤ 984 kg/m No	Case III Gross* Platform Mass kg	Case III Gross* Packaging Density kg/m	Case III Is Gross D ≤ 1300 kg/m Yes	Case III Is Gross D ≤ 1300 kg/m No	Case III' No. of Extra Flights to LEO
133	98nB	9 (×2)		X		11,788	18.3	644	-	-	14,146	773	X	-	-
134	98nE	9		X		11,573	18.3	632	-	-	13,888	759	X	-	-
135	98hB	9 (×2)		X		10,681	18.3	564	-	-	12,817	700	X	-	-
136	98hE	9		X		10,641	18.3	581	-	-	12,769	698	X	-	-
137	66jC'	7		X		14,807	18.3	809	-	-	17,768	971	X	-	-
(79)	66lC'	7		X		16,025	18.3	876	-	-	19,230	1,351	X	-	-
138	66kC	7			X	21,638	18.3	1,182	-	-	25,966	1,419	-	X	1
(80)	67mC	6			X	25,676	18.3	1,403	-	-	30,811	1,684	-	X	1
139	68jB	6 (×2)		X		15,838	18.3	865	-	-	19,006	1,039	X	-	-
140	68jE	6		X		15,539	18.3	849	-	-	18,647	1,019	X	-	-
(81)	68lB	6 (×2)		X		16,936	18.3	925	-	-	20,323	1,111	X	-	-
141	68lE	6		X		16,193	18.3	885	-	-	19,431	1,062	X	-	-
142	99kC'	5			X	23,918	18.3	1,307	-	-	28,702	1,568	-	X	1
(82)	69mC'	4			X	26,430	18.3	1,444	-	-	31,716	1,733	-	X	1
143	100kB	4 (×2)			X	23,785	18.3	1,300	-	-	28,542	1,560	-	X	1
144	100kE	4			X	23,093	18.3	1,262	-	-	27,712	1,514	-	X	1
(83)	70mB	3 (×2)			X	26,666	18.3	1,457	-	-	31,999	1,749	-	X	1
(84)	70mE	3			X	25,832	18.3	1,412	-	-	30,998	1,694	-	X	1

*G = 1.2 × N

Both reusable and expendable servicing vehicle modes were evaluated and the lowest cost solution was chosen. The cost of servicing items was also estimated and was added to platform bus and payload costs.

Basic servicing requirements for operational modes C^1 and E were developed based upon the following guidelines:

Mode C^1

a. One servicing flight during 16 year mission.

b. Replenish propellants (8 year supply).

c. Replace batteries (one set).

d. No other servicing, updating, etc., of subsystems and payloads. These use triple redundancy and are designed for 16 year life.

Mode E

a. Servicing flights are flown at approximately two year intervals, i.e., seven flights during 16 year mission.

b. Propellant storage capacity is sized for a three year supply, and must be replenished at intervals no longer than three years.

c. Subsystems and payloads use dual redundancy and are designed for on-orbit replacement of modules.

d. Complete payload modules can also be exchanged.

e. Replacement rates are as follows:

1. Payloads - one set (mass equivalent plus 15 percent margin) replaced over 16 year mission; charge production cost only.

2. Subsystems - add 15 percent weight margin; charge production costs.

(a)	Structure	- None.
(b)	EPS	- One set of batteries. - No changeout of solar arrays. - 40 percent of distribution system.
(c)	ACS	- 52 percent of total weight.
(d)	RCS	- 40 percent of dry weight. - 100 percent of propellant.
(e)	TTC	- 52 percent of total weight.
(f)	TCS	- 25 percent of total weight.
(g)	R&D	- 25 percent of avionics weight.

The mass transfer requirements for a 16 year mission period for mission sets N and V are given in Tables 2-21 and 2-22, respectively.

Servicing was accomplished using a remotely controlled Teleoperator Maneuvering System (TMS) at GEO. The baseline TMS description is given in Table 2-23; details are discussed in Section 5.3 of this volume. This description was derived from References 2.10 and 2.11. The cost of using the TMS was given as $2M per flight in the reusable mode and $32M per flight in the expendable mode. Additional costs for the Shuttle and OTV were also added as appropriate for the specific OTV and use mode (i.e., expendable or reusable).

The mass of servicing payload transportable per flight by each candidate servicing OTV is determined by subtracting from its gross lifting capability the estimated weight of the TMS itself and an allowance for packaging and stowage racks. It is assumed that the OTV has the capability to rendezvous with the platform and fly formation with it during the servicing operation. Final approach and docking equipment as well as the propellant required to Shuttle between the OTV and the platform has been allocated to the TMS mass.

Three servicing modes were evaluated using 11 different OTV/Servicing mode combinations whose characteristics are given in Table 2-24. All possible combinations of OTVs (11), servicing modes (3), platform operational modes (2), and traffic models (2) were evaluated for 36 sets of platforms and the lowest cost method was found for each set. These results are included in Appendix H, and are summarized in Tables 2-25 and 2-26. The costs applicable to the lowest cost OTV/servicing mode combination for each platform concept was then used in determining total program costs.

The cost of servicing items delivered to GEO and installed by the TMS were also estimated. For mode E, one set of payloads was replaced over the 16 year mission. These were included under payload costs in the program cost estimates. Subsystem servicing items were evaluated per the servicing guidelines and are included under platform bus costs in the program cost estimates.

2.4.2.6 Transportation Requirements. Transportation requirements are of two categories: platform delivery missions, and servicing missions. The costs of servicing missions were developed in Section 2.4.2.5.

Delivery costs include the cost of the Shuttles and OTVs required to put the entire set into geostationary orbits; these are one of the most widely varying cost elements. For the nominal traffic model, it ranges from $225M for mE to $2.479B for aC. For the high traffic model, it ranges from a low of $675M for mE to $8.325B for aC. The launch and servicing costs for each of the mode K platform system concepts are summarized in Tables 2-27 and 2-28 for mission sets N and V, respectively. For those OTV/launch case combinations where space mating of OTV-to-platform, stage-to-stage, or platform module-to-platform module is required, such costs are included. The rate established by NASA for this was $9m per operation (Reference Table 2-15).

Table 2-21. Servicing Requirements for 16 Year Mission - Mission Set N

Mode C'					Mode E				
Item	Set No.	No. of Platforms	Mass per Platform, kg	Mass per Set, kg	Item	Set No.	No. of Platforms	Mass per Platform, kg	Mass per Set, kg
3	52aC'	31	653	20,243	5	33aE	19	2,066	39,263
7	33qC'	19	808	15,357	11	551E	15	2,472	37,073
16	36rC'	12	1,114	13,373	21	38rE	9	3,696	33,261
17	37pC'	9	1,269	11,422	25	39bE	8	3,912	31,298
18	54bC'	10	1,119	11,185	26	39pE	8	4,088	32,707
22	38fC'	9	1,336	12,023	33	40cE	6	4,870	29,219
24	39cC'	8	1,339	10,710	35	40fE	6	5,062	30,370
29	56eC'	7	1,525	10,675	3[illegible]	41eE	5	5,562	27,808
30	56vC'	7	1,634	11,440	42	41dE	5	5,360	26,801
34	40dC'	6	1,543	9,256	43	41vE	5	5,728	28,641
41	41oC'	5	1,942	9,710	48	43oE	4	7,257	29,026
46	42gC'	5	1,759	8,796	52	43qE	4	6,985	27,940
47	43nC'	4	2,468	9,870	56	44nE	3	9,392	28,176
51	43hC'	4	2,228	8,912	58	44hE	3	9,062	27,186
59	47jC'	2	3,893	7,778	64	47jE	2	12,354	24,707
60	47lC'	2	4,125	8,251	66	47lE	2	12,689	25,378
67	48kC'	2	3,893	7,786	70	49kE	2	12,354	24,707
68	48mC'	2	3,893	7,786	72	50mE	1	22,726	22,726

Notes:
1. Mode C': Each platform serviced once at 8 years to replenish propellant and replace batteries.
2. Mode E: Each platform serviced at intervals of $t \leq 3$ years to replenish propellant, replace failed/degraded redundant modules, and update/changeout payloads.
3. Mass values are net and do not include tare weights for packaging, teleoperator, etc.

Table 2-22. Servicing Requirements for 16 Year Mission - Mission Set V

Mode C'					Mode E				
Item	Set No.	No. of Platforms	Mass per Platform, kg	Mass per Set, kg	Item	Set No.	No. of Platforms	Mass per Platform, kg	Mass per Set, kg
73	60bC'	34	1,120	38,068	84	70mE	3	24,568	73,703
75	62cC'	26	1,298	33,753	106	62bE	26	3,815	99,197
76	63dC'	20	1,550	30,996	114	63cE	20	4,620	92,400
77	64gC'	14	2,161	30,260	144	100kE	4	21,876	87,502
79	66lC'	7	3,879	27,154	141	68lE	6	14,608	87,649
82	69mC'	4	6,537	26,149	89	76aE	95	2,228	211,700
101	61pC'	33	1,307	43,144	95	81qE	62	2,727	169,087
126	65nC'	12	2,760	33,117	103	87rE	30	3,953	118,599
87	74aC'	145	661	95,852	107	90pE	25	4,309	107,736
91	78qC'	87	817	71,118	115	63fE	20	5,030	100,606
100	86rC'	47	1,087	51,082	119	94eE	17	6,165	104,809
104	88fC'	29	1,383	40,116	122	95dE	16	6,129	98,069
110	91eC'	24	1,545	37,070	123	95vE	16	6,498	103.957
111	92vC'	23	1,677	38,568	127	65oE	12	7,781	93,370
121	94oC'	17	2,127	36,167	130	96gE	12	7,879	94,550
129	96hC'	12	2,624	31,489	134	98nE	9	9,956	89,603
137	66jC'	7	3,646	25,520	136	98hE	9	9,647	86,822
142	99kC'	5	5,911	29,553	140	68jE	6	14,455	86,732

Table 2-23. Baseline TMS Description

Dedicated servicer configuration

Launched and retrieved by reusable OTV

Controlled at GEO from ground station (RF relay through geostationary platforms)

Mass estimate:	Mass, kg
TMS core (dry)	636
Stowage rack/docking probe kit	60
Servicer mechanism kit	52
TV and navigation kit	68
Propellant and pressurant	57
Launch weight	873 kg
Retrieval weight (10% reserves)	822 kg

Table 2-24. Servicing Options Capabilities and Costs

Servicing Mode	Servicing Mode Description	OTV Type	Net Mass Transfer to GEO, kg	Cost per Flight, $M *
S-1	Reusable OTV and TMS	q	1,169	39
		p	2,474	80
		l	13,686	126
S-2	Expendable OTV and TMS	r	3,663	94
		f	4,873	91
		e	5,629	99
		n	9,975	140
		m	22,336	216
S-3	Reusable OTV and Expendable TMS	q	2,038	69
		p	4,041	110
		l	15,381	156

*Cost includes transportation and TMS use; excludes cost of servicing items and packaging.

Table 2-25. Servicing Transportation Costs Summary – Mission Set N

MODE C'						MODE E					
Item No.	Set No.	No. of Platforms	Transportation Costs			Item No.	Set No.	No. of Platforms	Transportation Costs*		
			S-1	S-2	S-3				S-1	S-2	S-3
			$M OTV	$M OTV	$M OTV				$M OTV	$M OTV	$M OTV
3	52aC'	31	252 l	(216) m	312 l	5	33nE	19	882 l	(693) e	1092 l
7	33qC'	19	252 l	216 m	(156) l	11	55qE	15	882 l	(693) e	1092 l
16	36rC'	12	(126) l	215 m	156 l	21	38rE	9	882 l	(637) f	990 p
17	37pC'	9	(126) l	198 e	156 l	25	39bE	8	882 l	(637) f	880 p
18	54bC'	10	(126) l	198 e	156 l	26	39pE	8	882 l	(637) f	880 p
22	38fC'	9	(126) l	216 m	156 l	33	40cE	6	882 l	(637) f	880 p
24	39cC'	8	(126) l	198 e	156 l	35	40fE	6	882 l	(637) f	880 p
29	56eC'	7	(126) l	198 e	156 l	39	41eE	5	882 l	(637) f	770 p
30	56vC'	7	(126) l	198 e	156 l	42	41dE	5	880 p	(637) f	770 p
34	40dC'	6	(126) l	140 n	156 l	43	41vE	5	882 l	(637) f	770 p
41	41oC'	5	(126) l	140 n	156 l	48	43oE	4	882 l	(637) f	770 p
46	42gC'	5	(126) l	140 n	156 l	52	43qE	4	882 l	(637) f	770 p
47	43nC'	4	(126) l	140 n	156 l	56	44nE	3	882 l	(637) f	770 p
51	43hC'	4	(126) l	140 n	156 l	58	44hE	3	880 p	(637) f	770 p
59	45jC'	3	(126) l	140 n	156 l	64	47jE	2	800 p	(574) r'	770 p
60	45lC'	3	(126) l	140 n	156 l	66	47lE	2	880 p	(574) r'	770 p
67	48kC'	2	(126) l	140 n	156 l	70	47kE	2	800 p	(574) r'	770 p
68	48mC'	2	(126) l	140 n	156 l	72	50mE	1	780 q	(574) r'	770 p

Servicing Modes:

S-1 = Reusable OTV & TMS
S-2 = Expendable OTV & TMS
S-3 = Reusable OTV; Expendable TMS
*Minimum of 7 flights required.
( ) = Lowest cost.

Table 2-26. Servicing Transportation Costs Summary – Mission Set V

MODE C'						MODE E					
Item No.	Set No.	No. of Platforms	Transportation Costs			Item No.	Set No.	No. of Platforms	Transportation Costs*		
			S-1	S-2	S-3				S-1	S-2	S-3
			$M OTV	$M OTV	$M OTV				$M OTV	$M OTV	$M OTV
73	60bC'	34	(378) l	432 m	468 l	84	70mE	3	(882) l	1120 n	1092 l
75	62cC'	26	(378) l	432 m	468 l	106	62bE	26	(1008) l	1400 n	1092 l
76	63dC'	20	378 l	432 m	(312) l	114	63cE	20	(882) l	1400 n	1092 l
77	64gC'	14	378 l	420 n	(312) l	144	100kE	4	(882) l	1120 n	936 l
79	66lC'	7	(252) l	420 n	312 l	141	68lE	6	(882) l	1260 n	1092 l
82	69mC'	4	(252) l	420 n	312 l	89	76aE	95	(2016) l	2160 m	2184 l
101	61pC'	33	504 l	(432) m	468 l	95	81qE	62	(1638) l	1728 m	1716 l
126	65nC'	12	(378) l	432 m	468 l	103	87rE	30	(1134) l	1512 m	1248 l
87	74nC'	145	(882) l	1080 m	1092 l	107	90pE	25	(1008) l	1512 m	1092 l
91	78qC'	87	(756) l	864 m	780 l	115	63fE	20	(1008) l	1400 n	1092 l
100	86rC'	47	(504) l	648 m	624 l	119	94eE	17	(1008) l	1512 m	1092 l
104	88fC'	29	(378) l	432 m	468 l	122	95dE	16	(1008) l	1400 n	1092 l
110	91eC'	24	(378) l	432 m	468 l	123	95vE	16	(1008) l	1512 m	1092 l
111	92vC'	23	(378) l	432 m	468 l	127	65oE	12	(882) l	1400 n	1092 l
121	94oC'	17	(378) l	432 m	468 l	130	96gE	12	(882) l	1400 n	1092 l
129	96hC'	12	378 l	432 m	(312) l	134	98nE	9	(882) l	1260 n	1092 l
137	66jC'	7	(252) l	420 n	312 l	136	98hE	9	(882) l	1260 n	1092 l
142	99kC'	5	378 l	420 n	(312) l	140	68jE	6	(882) l	1260 n	1092 l

Servicing Modes:
S-1 = Reusable OTV and RTS
S-2 = Expendable OTV and RTS
S-3 = Reusable OVT; Expendable RTS
*Minimum of 7 flights required
(0 = Lowest cost.

Table 2-27. Transportation Cost Summary - Mission Set N

Item No.	Bus Type	No. of Platforms n	Case II	Case III	Case III'	Launch Costs Per Platform: Basic Launch Cost $M	Launch Costs Per Platform: No. of Extra Flights to LEO	Launch Costs Per Platform: Extra Flight Cost $M	Launch Costs Per Platform: Launch Cost Per Platform $M	Launch Cost for n Platforms $M	Servicing Flight Costs: OTV Type	Servicing Flight Costs: No. of Flights	Servicing Flight Costs: Cost Per Flight $M	Servicing Flight Costs: Service Flight Costs $M	Total Transportation Costs $M
1	51aC	67	X			37	0	0	37	2479	–	–	–	–	2479
2	31qC	39	X			37	0	0	37	1443	–	–	–	–	1443
3	52aC'	31	X			37	0	0	37	1147	m	1	216	216	1363
4	32rC	26	X			62	0	0	62	1612	–	–	–	–	1612
5	33aE	19	X			37	0	0	37	703	e	7	99	693	1396
6	33pC	19		X		78	0	0	78	1482	–	–	–	–	1482
7	33qC'	19	X			37	0	0	37	703	m	1	216	216	919
8	34aB	16 (×2)	X			37	0	0	37	1184	–	–	–	–	1184
9	34bC	16	X			62	0	0	62	992	–	–	–	–	992
10	34fC	16	X			59	0	0	59	944	–	–	–	–	944
11	55qE	15	X			37	0	0	37	555	e	7	99	693	1248
12	55vC	15		X		134	0	0	134	2010	–	–	–	–	2010
13	35qB	14 (×2)	X			37	0	0	37	1036	–	–	–	–	1036
14	35eC	14	X			67	0	0	67	938	–	–	–	–	938
15	53cC	13	X			59	0	0	59	767	–	–	–	–	767
16	36rC'	12	X			62	0	0	62	744	l	1	126	126	870
17	37pC'	9		X		78	0	0	18	702	l	1	126	126	828
18	54bC'	10	X			62	0	0	62	620	l	1	126	126	746
19	37dC	9	X			67	0	0	67	603	–	–	–	–	603
20	38oC	9		X		100	0	0	100	900	–	–	–	–	900
21	38rE	9	X			62	0	0	62	558	f	7	91	637	1195
22	38fC'	9	X			59	0	0	59	531	l	1	126	126	657
23	38rB	9 (×2)	X			62	0	0	62	1116	–	–	–	–	1116
24	39cC'	8	X			59	0	0	59	472	l	1	126	126	598
25	39bE	8	X			62	0	0	62	496	f	7	91	637	1133
26	39pE	8		X		78	0	0	78	624	f	7	91	637	1261
27	56bB	7 (×2)	X			62	0	0	62	868	–	–	–	–	868
28	56pB	7 (×2)		X		78	0	0	78	1092	–	–	–	–	1092

Table 2-27. Transportation Cost Summary - Mission Set N, Contd

Item No.	Bus Type	No. of Platforms n	Case II	Case III	Case III'	Launch Costs Per Platform: Basic Launch Cost $M	Launch Costs Per Platform: No. of Extra Flights to LEO	Launch Costs Per Platform: Extra Flight Cost $M	Launch Costs Per Platform: Launch Cost Per Platform $M	Launch Cost for n Platforms $M	Servicing Flight Costs: OTV Type	Servicing Flight Costs: No. of Flights	Servicing Flight Costs: Cost Per Flight $M	Servicing Flight Costs: Service Flight Costs $M	Total Transportation Costs $M
29	56eC'	7	X			67	0	0	67	469	l	1	126	126	595
30	56vC'	7		X		134	0	0	134	938	l	1	126	126	1064
31	56gC	7		X		100	0	0	100	700	–	–	–	–	700
32	40nC	6		X		108	0	0	108	648	–	–	–	–	648
33	40cE	6	X			59	0	0	59	354	f	7	91	637	991
34	40dC'	6	X			67	0	0	67	402	l	1	126	126	528
35	40fE	6	X			59	0	0	59	354	f	7	91	637	991
36	40cB	6 (×2)	X			59	0	0	59	708	–	–	–	–	708
37	40fB	6 (×2)	X			59	0	0	59	708	–	–	–	–	738
38	41hC	5		X		108	0	0	108	540	–	–	–	–	540
39	41eE	5	X			67	0	0	67	335	f	7	91	637	972
40	41eB	5 (×2)	X			67	0	0	67	670	–	–	–	–	670
41	41oC'	5		X		100	0	0	100	500	l	1	126	126	626
42	41dE	5	X			67	0	0	67	335	f	7	91	637	972
43	41vE	5		X		134	0	0	134	670	f	7	91	637	1307
44	41vB	5 (×2)		X		134	0	0	134	1340	–	–	–	–	1340
45	41dB	5 (×2)	X			67	0	0	67	670	–	–	–	–	670
46	42gC'	5		X		100	0	0	100	500	l	1	126	126	626
47	43nC'	4		X		108	0	0	108	432	l	1	126	126	558
48	43oE	4		X		100	0	0	100	400	f	7	91	637	1037
49	43oB	4 (×2)		X		100	0	0	100	800	–	–	–	–	800
50	43lC	4		X		124	0	0	124	496	–	–	–	–	496
51	43hC'	4		X		108	0	0	108	432	l	1	126	126	558
52	43gE	4		X		100	0	0	100	400	f	7	91	637	1037
53	43gB	4 (×2)		X		100	0	0	100	800	–	–	–	–	800
54	43jC	4		X		124	0	0	124	496	–	–	–	–	496
55	44nB	3 (×2)		X		108	0	0	108	648	–	–	–	–	648
56	44nE	3		X		108	0	0	108	324	f	7	91	637	961

Table 2-27. Transportation Cost Summary - Mission Set N, Contd

Item No.	Bus Type	No. of Platforms n	Case II	Case III	Case III'	Launch Costs Per Platform: Basic Launch Cost \$M	Launch Costs Per Platform: No. of Extra Flights to LEO	Launch Costs Per Platform: Extra Flight Cost \$M	Launch Costs Per Platform: Launch Cost Per Platform \$M	Launch Cost for n Platforms \$M	Servicing Flight Costs: OTV Type	Servicing Flight Costs: No. of Flights	Servicing Flight Costs: Cost Per Flight \$M	Servicing Flight Costs: Service Flight Costs \$M	Total Transportation Costs \$M
57	44hB	3 (×2)		X		108	0	0	108	648	–	–	–	–	648
58	44hE	3		X		108	0	0	108	324	f	7	91	637	961
59	47jC'	2		X		124	0	0	124	248	1	1	126	126	374
60	47lC'	2		X		124	0	0	124	248	1	1	126	126	374
61	45kC	3		X		184	0	0	184	552	–	–	–	–	552
62	46mC	2			X	184	1	41	225	450	–	–	–	–	450
63	47jB	2 (×2)		X		124	0	0	124	496	–	–	–	–	496
64	47jE	2		X		124	0	0	124	248	r'	7	82	574	822
65	47lB	2 (×2)		X		124	0	0	124	496	–	–	–	–	496
66	47lE	2		X		124	0	0	124	248	r'	7	82	574	822
67	48kC'	2		X		184	0	0	184	368	1	1	126	126	494
68	48mC'	2		X		184	0	0	184	368	1	1	126	126	494
69	49kB	2 (×2)		X		184	0	0	184	736	–	–	–	–	736
70	49kE	2		X		184	0	0	184	368	r'	7	82	574	942
71	50mB	1 (×2)			X	184	1	41	225	450	–	–	–	–	450
72	50mE	1			X	184	1	41	225	225	r'	7	82	574	799

Table 2-28. Transportation Cost Summary - Mission Set V

Item No.	Bus Type	No. of Platforms n	Case II	Case III	Case III'	Launch Costs Per Platform: Basic Launch Cost \$M	No. of Extra Flights to LEO	Extra Flight Cost \$M	Launch Cost Per Platform \$M	Launch Cost for n Platforms \$M	Servicing Flight Costs: OTV Type	No. of Flights	Cost Per Flight \$M	Service Flight Costs \$M	Total Transportation Costs \$M
85	72aC	225	X			37	0	0	37	8325	–	–	–	–	8325
86	73qC	163	X			37	0	0	37	6031	–	–	–	–	6031
87	74aC'	145	X			37	0	0	37	5365	1	7	126	882	6247
88	75rC	121	X			62	0	0	62	7502	–	–	–	–	7502
89	76aE	95	X			37	0	0	37	3515	1	16	126	2016	5531
90	77pC	90		X		78	0	0	78	7020	–	–	–	–	7020
91	78qC'	87	X			37	0	0	37	3219	1	6	126	756	3975
92	79aB	79 (×2)	X			37	0	0	37	5846	–	–	–	–	5846
93	80bC	70	X			62	0	0	62	4340	–	–	–	–	4349
94	80fC	70	X			59	0	0	59	4130	–	–	–	–	4130
95	81qE	62	X			37	0	0	37	2294	1	13	126	1638	3932
96	82vC	58		X		134	0	0	134	7772	–	–	–	–	7772
97	83qB	52 (×2)	X			37	0	0	37	3848	–	–	–	–	3849
98	84eC	51	X			67	0	0	67	3417	–	–	–	–	3417
99	85cC	50	X			59	0	0	59	2950	–	–	–	–	2950
100	86rC'	47	X			62	0	0	62	2914	1	4	126	504	3418
101	61pC'	33		X		78	0	0	78	2574	m	2	216	432	3006
(73)	60bC'	34	X			62	0	0	62	2108	1	3	126	378	2486
(74)	61dC	33	X			67	0	0	67	2211	–	–	–	–	2211
102	87oC	30		X		100	0	0	100	3000	–	–	–	–	3000
103	87rE	30	X			62	0	0	62	1860	1	9	126	1134	2994
104	88fC'	29	X			59	0	0	59	1711	1	3	126	378	2089
105	89rB	27 (×2)	X			62	0	0	62	3348	–	–	–	–	3349
(75)	62cC'	26	X			59	0	0	59	1534	1	3	126	378	1912
106	62hE	26	X			62	0	0	62	1612	1	8	126	1008	2620
107	90pE	25		X		78	0	0	78	1950	1	8	126	1008	2958
108	90bB	25 (×2)	X			62	0	0	62	3100	–	–	–	–	3100
109	91pB	24 (×2)		X		78	0	0	78	3744	–	–	–	–	3744
110	92eC'	23	X			67	0	0	67	1608	1	3	126	378	1986
111	92vC'	23		X		134	0	0	134	3082	1	3	126	378	3460

Table 2-28. Transportation Cost Summary - Mission Set V, Contd

Item No.	Bus Type	No. of Platforms n	Case II	Case III	Case III'	Launch Costs Per Platform: Basic Launch Cost $M	Launch Costs Per Platform: No. of Extra Flights to LEO	Launch Costs Per Platform: Extra Flight Cost $M	Launch Costs Per Platform: Launch Cost Per Platform $M	Launch Cost for n Platforms $M	Servicing Flight Costs: OTV Type	Servicing Flight Costs: No. of Flights	Servicing Flight Costs: Cost Per Flight $M	Servicing Flight Costs: Service Flight Costs $M	Total Transportation Costs $M
112	93gC	22		X		100	0	0	100	2200	–	–	–	–	2200
113	63nC	20		X		108	0	0	108	2160	–	–	–	–	2160
114	63cE	20	X			59	0	0	59	1180	1	7	126	882	2062
(76)	63dC'	20	X			67	0	0	67	1340	1	2	156	312	1652
115	63fE	20	X			59	0	0	59	1180	1	8	126	1008	2188
116	63cB	20 (×2)	X			59	0	0	59	2360	–	–	–	–	2360
117	101fB	20 (×2)	X			59	0	0	59	2360	–	–	–	–	2360
118	94hC	17		X		108	0	0	108	1836	–	–	–	–	1836
119	94eE	17	X			67	0	0	67	1139	1	8	126	1008	2147
120	94eB	17 (×2)	X			67	0	0	67	2278	–	–	–	–	2278
121	94oC'	17		X		100	0	0	100	1700	1	3	126	378	2078
122	95dE	16	X			67	0	0	67	1072	1	8	126	1008	2080
123	95vE	16		X		134	0	0	134	2144	1	8	126	1008	3152
124	95vB	16 (×2)		X		134	0	0	134	4288	–	–	–	–	4288
125	95dB	16 (×2)	X			67	0	0	67	2144	–	–	–	–	2144
(77)	64gC'	14		X		100	0	0	100	1400	1	2	156	312	1712
126	65nC'	12		X		108	0	0	108	1296	1	3	126	378	1674
127	65oE	12		X		100	0	0	100	1200	1	7	126	882	2082
128	65oB	12 (×2)		X		100	0	0	100	2400	–	–	–	–	2400
(78)	65lC	12		X		124	0	0	124	1488	–	–	–	–	1488
129	96hC'	12		X		108	0	0	108	1296	1	2	156	312	1608
130	96gE	12		X		100	0	0	100	1200	1	7	126	882	2082
131	96gB	12 (×2)		X		100	0	0	100	2400	–	–	–	–	2400
132	97jC	11		X		124	0	0	124	1364	–	–	–	–	1364
133	98nB	9 (×2)		X		108	0	0	108	1944	–	–	–	–	1944
134	98nE	9		X		108	0	0	108	972	1	7	126	882	1854
135	98hB	9 (×2)		X		108	0	0	108	1944	–	–	–	–	1944
136	98hE	9		X		108	0	0	108	972	1	7	126	882	1854
137	66jC'	7		X		124	0	0	124	868	1	2	126	252	1120

Table 2-28. Transportation Cost Summary - Mission Set V, Contd

Item No.	Bus Type	No. of Platforms n	Case II	Case III	Case III'	Launch Costs Per Platform: Basic Launch Cost $M	Launch Costs Per Platform: No. of Extra Flights to LEO	Launch Costs Per Platform: Extra Flight Cost $M	Launch Costs Per Platform: Launch Cost Per Platform $M	Launch Cost for n Platforms $M	Servicing Flight Costs: OTV Type	Servicing Flight Costs: No. of Flights	Servicing Flight Costs: Cost Per Flight $M	Servicing Flight Costs: Service Flight Costs $M	Total Transportation Costs $M
(79)	66lC'	7		X		124	0	0	124	868	1	2	126	252	1120
138	66kC	7			X	184	1	41	225	1575	–	–	–	–	1575
(80)	67mC	6			X	184	1	41	225	1350	–	–	–	–	1350
139	68jB	6 (×2)		X		124	0	0	124	1488	–	–	–	–	1488
140	68jE	6		X		124	0	0	124	744	1	7	126	882	1625
(81)	68lB	6 (×2)		X		124	0	0	124	1488	–	–	–	–	1488
141	68lE	6		X		124	0	0	124	744	1	7	126	892	1626
142	99kC'	5			X	184	1	41	225	1125	1	2	156	312	1437
(82)	69mC'	4			X	184	1	41	225	900	1	2	126	252	1152
143	100kB	4 (×2)			X	184	1	41	225	1800	–	–	–	–	1800
144	100kE	4			X	184	1	41	225	900	1	7	126	882	1782
(83)	70mB	3 (×2)			X	184	1	41	225	1350	–	–	–	–	1350
(84)	70mE	3			X	184	1	41	225	675	1	7	126	882	1557

2.4.2.7 Program Costs. The total program acquisition and operational costs were the evaluation criteria used to compare the alternative system concepts. These costs were in three primary categories:

a. Bus costs.

b. Payload costs.

c. Transportation costs.

Other operational costs that would be common to all of the concepts, e.g., ground station operations for platform control, earth station operations for communiations payloads, etc., were not included because these would not influence the comparative results. Tables 2-29 and 2-30 summarize the comparative program costs computed for each of the 144 platform system concepts defined for buildup mode K. The development of each of the cost elements in Tables 2-29 and 2-30 is discussed in the following sections.

Each row across the page is identified by an item number that corresponds to a specific payload set accommodated on a platform bus synthesized for that set. The platform is sized for optimum use of a specific OTV. For example, Item 1 accommodates Payload No. 51 on a platform sized for transfer vehicle code a, the low thrust reusable single stage OTV, and operations in mode C. Sixty-seven platforms are required to accommodate all of the payloads of mission set N. For platform concepts operating in mode B, the number of platforms produced and delivered to orbit is doubled because of the 8 year platform life, e.g., Item 8.

Bus Costs. Bus development and production costs were estimated using General Dynamics Convair's computerized life cycle cost model. Inputs to the model are the operational life, number of units produced, and the subsystem descriptions developed using the platform synthesis model (Reference Appendix G). A sample of the cost model output is shown in Figure 2-7. The complete set of output data sheets is included in Appendix I. The cost model is discussed in detail in Vol. III. Bus servicing items were estimated as discussed in Section 2.4.2.5.

The development cost tends to be higher, as expected, for the larger platforms. It also varies considerably with mode. The mode b throwaways, of course, are the cheapest to develop. The highly redundant unserviced version (mode C) and the highly modularized frequently serviced version (mode E) are intermediate in development cost. The hybrid mode C', which involves both redundancy and servicing, is the most expensive to develop. The range of development costs for the nominal traffic model was from \$112M for aB to \$406M for mE. The high traffic model makes very little difference in these costs, since the platforms are very similar - there are just more of them. Here the range of development costs is from \$112M for aB to \$470M for mE.

Table 2-29. Program Cost Summary, Nominal Traffic Model - Western Hemisphere, Mission Set N

Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Payload Costs: Development: P/L SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: P/L Prod. $M	Payload Costs: Production: P/L IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Production: Total P/L Prod. $M	Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Costs $M	Total Program Costs $M	Alternate @ $50M
1	51aC	67	124.12	1023.31	0	1147	539	55.9	595	330	19.8	0	349.8	945	2092	2479		2479	4571	
2	31qC	39	135.50	753.34	0	889	515	56.0	571	242	14.5	0	256.5	828	1716	1443		1443	3159	
3	52aC'	31	170.80	696.58	15	882	537	59.5	597	210	12.6	0	222.6	820	1702	1147		1363	3065	
4	32rC	26	156.17	691.56	0	848	510	57.4	567	194	11.6	0	205.6	773	1621	1612	216	1612	3233	
5	33aE	19	168.03	338.27	79	585	498	57.6	556	158	9.5	158	325.5	882	1467	703		1396	2863	(2921)
6	33pC	19	158.16	530.37	0	689	535	61.9	597	173	10.4	0	183.4	780	1469	1482	693	1482	2951	
7	53qC'	19	179.48	488.22	10	678	535	61.9	597	173	10.4	0	183.4	780	1458	703		919	2377	
8	34aB	16 (×2)	112.12	554.27	0	666	464	54.5	519	274	16.4	0	290.4	809	1475	1184	215	1184	2659	
9	34bC	16	154.24	432.23	0	586	525	61.8	588	163	9.8	0	172.8	761	1347	992		992	2339	
10	34fC	16	161.63	470.70	0	632	526	61.8	588	163	9.8	0	172.8	761	1393	944		944	2337	(2147)
11	55qE	15	175.05	369.49	84	629	538	63.6	602	152	9.1	152	313.1	915	1544	555		1248	2792	
12	55vC	15	169.76	486.55	0	656	574	67.8	642	182	10.9	0	192.9	835	1491	2010	593	2010	3501	
13	35qB	14 (×2)	119.80	553.44	0	673	467	55.5	523	262	15.7	0	277.7	800	1473	1036		1036	2509	
14	35eC	14	171.89	469.26	0	641	527	62.7	590	156	9.4	0	165.4	755	1396	938		938	2334	
15	53eC	13	162.2	395.77	0	556	536	64.2	600	161	9.7	0	170.7	771	1327	767		767	2094	
16	36rC'	12	195.79	383.71	7	587	535	64.5	600	151	9.1	0	160.1	760	1347	744		870	2217	
17	37pC'	9	204.96	323.6	7	536	566	70.0	636	143	8.6	0	151.6	788	1324	702	126	828	2152	(2073)
18	54bC'	10	198.07	335.96	8	542	554	67.9	622	140	8.4	0	148.0	770	1312	620	126	746	2058	
19	37dC	9	177.32	331.66	0	509	566	70.0	636	143	8.6	0	152.0	786	1297	603	126	603	1900	(1938)
20	38oC	9	188.28	369.04	0	557	549	67.9	617	143	8.6	0	152.0	769	1326	900		900	2226	
21	38rE	9	195.9	288.65	64	549	514	63.5	578	130	7.8	130	268.0	845	1394	558		1195	2589	
22	38fC'	9	207.85	332.46	7	547	549	67.9	617	143	8.6	0	152.0	769	1316	531	637	657	1973	(2481)
23	38rB	9 (×2)	132.94	445.47	0	578	486	60.1	546	238	14.3	0	252.0	798	1377	1116	126	1116	2493	
24	39eC'	8	212.49	315.05	74	602	569	71.1	640	135	8.1	0	143.0	783	1385	472		598	1983	(2277)
25	39bE	8	201.79	277.92	62	542	531	66.3	597	124	7.4	124	255.0	853	1395	496	126	1133	2528	
26	39pE	8	205.71	286.94	63	556	531	66.3	597	124	7.4	124	255.0	853	1409	624	637	1261	2670	(2432)
27	56bB	7 (×2)	136.89	375.62	0	513	491	62.1	553	228	13.7	0	242.0	795	1307	860	637	860	2175	
28	56pB	7 (×2)	141.13	393.64	0	535	491	62.1	553	228	13.7	0	242.0	795	1330	1092		1092	2422	(2007)
29	56eC'	7	218.28	291.76	7	517	559	70.7	630	134	8.0	0	142.0	772	1289	469	120	595	1884	

Table 2-29. Program Cost Summary, Nominal Traffic Model - Western Hemisphere, Mission Set N, Contd

Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Payload Costs: Development: P/L SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: P/L Prod. $M	Payload Costs: Production: P/L IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Production: Total P/L Prod. $M	Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Trans-portation Costs $M	Total Program Costs $M	Alternate @ $50M
30	56vC'	7	221.67	299.81	7	528	559	70.7	630	134	8.0	0	142.0	772	1300	938	126	1064	2364	
31	56gC	7	190.91	300.14	0	491	559	70.7	630	134	8.0	0	142.0	772	1263	700		700	1963	
32	40nC	6	211.6	310.71	0	522	563	72.1	635	135	9.1	0	143.9	778	1301	648		648	1949	
33	40eE	6	212.69	234.64	53	500	525	67.3	592	125	7.5	125	258.0	850	1350	354	637	991	2341	
34	40dC'	6	223.48	226.23	6	496	563	61.6	625	135	8.1	0	143.0	768	1264	402	126	528	1792	
35	40fE	6	216.58	241.71	54	512	525	67.3	592	125	7.5	125	258.0	850	1362	354	637	991	2353	
36	40eB	6 (×2)	142.62	350.23	0	493	496	63.5	560	228	13.7	0	242.0	801	1294	708		708	2002	
37	40fB	6 (×2)	146.97	366.64	0	514	496	63.5	560	228	13.7	0	242.0	601	1315	708		708	2023	
38	41hC	5	210.19	260.76	0	471	574	74.7	649	137	8.2	0	145.0	794	1265	540		540	1805	
39	41eE	5	221.18	211.65	48	481	536	69.8	606	126	7.6	126	260.0	865	1346	335	637	972	2310	
40	41eB	5 (×2)	154.0	335.7	0	490	504	65.6	570	232	13.9	0	246.0	816	1305	673		670	1975	
41	41oC'	5	236.05	248.56	6	491	574	74.7	649	137	8.2	0	145.0	794	1285	500	126	626	1911	
42	41dE	5	218.76	208.96	47	475	536	69.8	606	126	7.6	126	260.0	865	1340	335	637	972	2312	
43	41vE	5	225.69	219.89	49	495	536	69.8	606	126	7.6	126	260.0	865	1368	670	637	1307	2667	
44	41vB	5 (×2)	157.05	345.91	0	503	504	65.6	570	232	13.9	0	246.0	816	1318	1340		1340	2658	
45	41dB	5 (×2)	149.59	321.38	0	471	504	65.6	570	232	13.9	0	246.0	816	1286	670		670	1956	
46	42gC'	5	230.29	238.39	6	475	574	74.7	649	137	8.2	0	145.0	794	1269	500	126	626	1895	
47	43nC'	4	258.53	239.66	6	504	572	75.9	648	138	8.3	0	146.0	794	1298	432	126	558	1856	
48	43oE	4	243.79	207.23	47	498	535	71.0	606	125	7.5	125	258.0	864	1362	400	637	1037	2399	
49	43oB	4 (×2)	171.78	329.08	0	501	504	66.9	571	232	13.9	0	246.0	817	1318	800		800	2118	
50	43lC	4	245.14	274.08	0	519	572	75.9	648	138	8.3	0	146.0	794	1313	496		496	1889	
51	43kC'	4	251.89	229.75	6	488	572	75.9	648	138	8.3	0	146.0	794	1282	432	126	558	1640	
52	43gE	4	239.16	201.12	46	486	535	71.0	606	125	7.5	125	258.0	864	1350	400	637	1037	2387	
53	43gB	4 (×2)	166.73	315.21	0	482	504	66.9	571	232	13.9	0	246.0	817	1299	800		800	2099	
54	43jC'	4	236.39	258.94	0	495	572	75.9	648	138	8.3	0	146.0	794	1290	496		496	1786	
55	44nB	3 (×2)	197.06	316.94	0	514	496	67.5	564	228	13.7	0	242.0	605	1319	648		648	1967	
56	44nE	3	273.03	195.75	44	513	526	71.8	598	124	7.4	124	255.0	853	1366	324	637	961	2327	
57	44hB	3 (×2)	191.64	305.2	0	497	496	67.5	564	228	13.7	0	242.0	805	1302	648		648	1950	
58	44hE	3	267.95	190.28	43	501	526	71.6	598	124	7.4	124	255.0	853	1354	324	537	961	2315	

Table 2-29. Program Cost Summary, Nominal Traffic Model - Western Hemisphere, Mission Set N, Contd

Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Payload Costs: Development: P/L SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: P/L Prod. $M	Payload Costs: Production: P/L IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Production: Total P/L Prod. $M	Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Cost $M	Total Program Costs $M	Alternate ● $50M
59	47jC''	2	321.4	185.0	6	512	564	76.8	641	136	8.2	0	144.0	785	1297	248	126	374	1671	
60	47lC''	2	327.1	189.9	6	523	564	76.8	641	136	8.2	0	144.0	785	1308	248	126	374	1682	
61	45kC	3	271.61	247.74	0	519	564	76.8	641	136	8.2	0	144.0	785	1304	552		552	1856	
62	46mC	2	313.82	212.27	0	526	576	81.3	657	130	7.8	0	138.0	795	1321	458		458	1771	
63	47jH	2 (×2)	220.82	262.10	0	483	508	71.7	580	218	13.1	0	231.0	811	1294	496		496	1798	
64	47jE	2	302.55	161.47	37	501	538	75.9	614	119	7.1	119	245.0	859	1360	248	574	822	2182	
65	47lH	2 (×2)	226.16	270.3	0	496	508	71.7	580	218	13.1	6	231.0	811	1307	495		496	1803	
66	47lE	2	307.41	165.07	37	509	538	75.9	614	119	7.1	119	245.0	859	1368	[illegible]	574	822	2190	
67	48kC''	2	322.60	186.96	6	515	576	81.3	657	130	7.8	0	138.0	795	1310	368	126	494	1804	
68	48mC''	2	322.60	186.06	6	515	576	81.3	657	136	7.8	0	136.0	795	1310	368	126	494	1804	
69	49kH	2 (×2)	220.82	262.10	0	483	508	71.7	580	218	13.1	0	231.0	811	1294	736		736	2030	
70	49kE	2	302.55	161.47	37	501	538	75.9	614	119	7.1	119	245.0	859	1360	368	574	942	2302	
71	50mH	1 (×2)	309.65	225.95	0	536	523	78.5	602	198	11.9	0	218.0	811	1347	456		458	1797	
72	50mE	1	406.91	136.78	32	576	555	83.3	638	107	6.4	107	220.0	859	1435	225	574	799	2234	

Table 2-30. Program Cost Summary, High Traffic Model - Western Hemisphere, Mission Set V

Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Development: P/L SE&I $M	Development: Total Devel. $M	Production: P/L Prod. $M	Production: P/L IA&CU $M	Production: Servicing Items $M	Production: Total P/L Prod. $M	Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Costs $M	Total Program Costs $M	Alternate @ $50M
85	72aC	225	124.88	3,215.88	0	3,341	1,168	110	1,278	1,037	62	0	1,099	2,377	5,718	9,325	0	8,325	14,043	
86	73qC	163	135.46	2,830.49	0	2,966	1,401	136	1,537	950	57	0	1,007	2,544	5,510	6,031	0	6,031	11,541	
87	74aC'	145	171.41	2,928.35	63	3,163	1,667	163	1,830	942	57	0	999	2,829	5,992	5,365	882	6,247	12,239	
88	75rC	121	154.45	2,812.77	0	967	1,697	168	1,865	934	56	0	990	2,855	5,822	7,502	0	7,502	13,324	(11,872)
89	76aE	95	175.48	1,984.32	446	2,606	1,603	163	1,766	735	44	735	1,513	3,281	5,887	3,515	2,016	5,531	11,418	
90	77pC	90	157.89	2,230.20	0	2,388	1,659	169	1,828	773	46	0	819	2,647	5,035	7,020	0	7,020	12,055	
91	78qC'	87	160.81	2,043.57	40	2,264	1,669	170	1,839	777	[illegible]	0	824	2,663	4,927	3,219	756	[illegible]	8,902	
92	79aB	79 (×2)	112.09	2,430.69	0	2,543	1,511	156	1,667	1,284	77	0	1,361	3,028	5,571	5,846	0	5,846	[illegible]	
93	80bC	70	155.57	1,723.73	0	1,879	1,604	167	1,771	719	43	0	762	2,533	4,412	4,340	0	4,340	8,752	(7,912)
94	80fC	70	164.99	1,925.34	0	2,090	1,604	167	1,771	719	43	0	762	2,533	4,623	4,130	0	4,130	8,753	
95	81qE	62	183.34	1,466.00	325	1,974	1,493	157	1,650	609	37	609	1,254	2,904	4,878	2,294	1,638	3,932	8,810	
96	82vC	58	170.35	1,710.93	0	1,881	1,504	159	1,663	690	41	0	731	2,394	4,275	7,772	0	7,772	12,047	
97	83qB	52 (×2)	118.13	1,802.75	0	1,921	1,293	138	1,431	1,029	62	0	1,091	2,522	4,443	3,848	0	3,848	8,291	
98	84eC	51	170.25	1,522.90	0	1,693	1,417	152	1,569	606	36	0	642	2,211	3,904	3,417	0	3,417	7,321	
99	85cC	50	162.89	1,381.25	0	1,544	1,309	140	1,449	595	36	0	631	2,080	3,624	2,950	0	2,950	6,574	
100	86rC'	47	194.04	1,335.02	26	1,555	1,292	139	1,431	565	34	0	599	2,029	3,584	2,914	504	3,418	7,002	(6,438)
101	61pC'	33	208.76	1,124.50	25	1,358	1,339	149	1,488	480	29	0	509	1,997	3,355	2,574	432	3,006	6,361	
(73)	60bC'	34	198.20	1,044.11	24	1,266	1,338	148	1,485	490	29	0	519	2,004	3,271	2,108	378	2,486	5,757	(5,349)
(74)	61dC	33	176.76	1,099.97	0	1,277	1,339	149	1,488	486	29	0	509	1,997	3,273	2,211	0	2,211	5,484	
102	67oC	30	189.19	1,131.48	0	1,321	1,350	151	1,502	464	28	0	492	1,993	3,314	3,000	0	3,000	6,314	
103	87rE	30	204.37	941.29	206	1,352	1,241	139	1,380	434	26	434	894	2,274	3,626	1 860	1,134	2,994	6,620	(6,260)
104	88fC'	29	209.63	1,004.43	22	1,236	1,357	152	1,510	460	28	0	487	1,997	3,233	1,711	378	2,089	5,322	
105	89rB	27 (×2)	136.35	1,292.85	0	1,429	1,230	139	1,369	737	44	0	781	2,150	3,579	3,348	0	3,348	6,927	(6,279)
(75)	62cC'	26	206.83	886.71	20	1,114	1,390	157	1,547	435	26	0	461	2,008	3,122	1,534	378	1,912	5,034	
106	62bE	26	197.06	784.66	178	1,160	1,288	146	1,434	393	24	393	810	2,244	3,494	1,612	1,008	2,620	6,024	(5,712)
107	90pE	25	209.74	836.36	182	1,228	1,271	145	1,416	389	23	389	801	2,217	3,445	1,950	1,008	2,958	6,403	
108	90bB	25 (×2)	134.68	1,181.09	0	1,316	1,235	141	1,376	750	45	0	795	2,171	3,487	3,100	0	3,100	6,587	(5,987)
109	91pB	24 (×2)	140.98	1,230.94	0	1,372	1,232	141	1,373	723	43	0	766	2,139	3,511	3,744	0	3,744	7,255	
110	91eC'	24	217.22	903.02	21	1,141	1,376	157	1,534	438	26	0	464	1,997	3,138	1,608	378	1,986	5,124	

Table 2-30. Program Cost Summary, High Traffic Model - Western Hemisphere, Mission Set V, Contd

Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Payload Costs: Development: P/L SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: P/L Prod. $M	Payload Costs: Production: P/L IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Total P/L Prod. $M	Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Costs $M	Total Program Costs $M	Alternate @ $50M
111	92vC'	23	225.24	914.40	20	1,156	1,375	158	1,533	424	25	0	449	1,982	3,140	3,082	378	3,460	6,600	
112	93gC	[illegible]	196.40	912.69	0	1,109	1,361	159	1,540	416	25	0	441	1,981	3,090	2,200	0	2,200	5,290	
113	[illegible]	20	210.18	935.86	0	1,146	1,394	162	1,556	404	24	0	428	1,984	3,130	2,160	0	2,160	5,290	
114	[illegible]	20	210.80	704.31	159	1,074	1,312	152	1,464	367	22	367	756	2,220	3,294	1,180	882	2,062	5,356	
(76)	[illegible]	20	220.53	790.87	20	1,031	1,394	162	1,556	404	24	0	428	1,984	3,015	1,340	312	1,652	4,667	
115	[illegible]	20	220.45	749.74	165	1,135	1,318	153	1,471	368	22	368	758	2,229	3,364	1,180	1,008	2,188	5,552	
116	[illegible]	20	144.28	1,093.30	0	1,238	1,259	145	1,404	580	41	0	721	2,125	3,362	2,360	0	2,360	5,722	
117	101hB	20 (×2)	153.02	1,203.76	0	1,357	1,229	142	1,371	758	45	0	803	2,174	3,531	2,360	0	2,360	5,891	
118	94hC	17	227.66	923.36	0	1,151	1,377	162	1,539	418	25	0	443	1,982	3,133	1,836	0	1,836	4,969	
119	94eE	17	242.34	779.23	167	1,189	1,300	153	1,45	376	23	376	784	2,237	3,426	1,139	1,008	2,147	5,573	
120	94eB	17 (×2)	166.80	1,204.89	0	1,372	1,233	145	1,378	708	43	0	751	2,129	3,501	2,278	0	2,278	5,779	
121	94oC'	17	250.27	861.62	24	1,136	1,377	162	1,539	418	25	0	443	1,982	3,118	1,700	378	2,078	5,196	
122	95dE	16	242.67	739.46	159	1,141	1,307	155	1,462	371	22	371	764	2,226	3,367	1,072	1,008	2,080	5,447	
123	95vE	16	248.66	764.00	164	1,182	1,307	155	1,462	371	22	371	764	2,226	3,408	2,144	1,008	3,152	6,560	
124	95vB	16 (×2)	172.75	1,203.96	0	1,377	1,240	147	1,387	685	41	0	726	2,113	3,490	4,288	0	4,288	7,778	
125	95dB	16 (×2)	165.47	1,133.09	0	1,298	1,240	147	1,387	685	41	0	726	2,113	3,411	2,144	0	2,144	5,555	
(77)	64gC'	14	254.47	745.65	22	1,022	1,396	167	1,563	370	22	0	392	1,955	2,977	1,400	312	1,712	4,689	
126	65nC'	12	282.37	767.65	23	1,073	1,384	168	1,552	348	21	0	369	1,921	2,994	1,296	378	1,674	4,668	
127	65oE	12	266.34	677.52	146	1,090	1,333	161	1,494	321	19	321	661	2,155	3,245	1,200	882	2,082	5,327	
128	65oB	12 (×2)	191.41	1,096.7	0	1,288	1,229	148	1,377	591	36	0	627	2,064	3,292	2,400	0	2,400	5,692	
(78)	65lC	12	269.67	875.35	0	1,145	1,384	168	1,552	348	21	0	369	1,921	3,066	1,488	0	1,488	4,554	
129	96hC'	12	276.97	753.22	23	1,053	1,384	168	1,552	348	21	0	369	1,921	2,974	1,296	312	1,608	4,582	
130	96gE	12	264.99	674.32	147	1,086	1,[illegible]	157	1,454	381	23	381	785	2,239	3,325	1,200	882	2,082	5,407	
131	96gB	12 (×2)	188.16	1,073.97	0	1,262	1,233	149	1,382	710	43	0	753	2,135	3,397	2,400	0	2,400	5,797	
132	97jC	11	273.17	827.15	0	1,100	1,373	168	1,541	397	24	0	421	1,961	3,061	1,364	0	1,364	4,425	
133	98nB	9 (×2)	214.70	1,005.95	0	1,221	1,251	155	1,406	641	38	0	679	2,085	3,306	1,944	0	1,944	5,250	
134	98nE	9	294.55	619.62	134	1,048	1,317	164	1,481	350	21	350	721	2,202	3,250	972	882	1,854	5,104	
135	98hB	9 (×2)	209.38	973.92	0	1,183	1,251	155	1,406	641	38	0	679	2,085	3,268	1,944	0	1,944	5,212	
136	98hE	9	289.65	605.44	132	1,027	1,317	164	1,481	350	21	350	721	2,202	3,229	972	882	1,854	5,083	
137	66[illegible]C'	7	325.47	600.26	21	947	1,433	182	1,615	320	19	0	339	1,954	2,901	868	252	1,120	4,021	

Table 2-30. Program Cost Summary, High Traffic Model - Western Hemisphere, Mission Set V, Contd

Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Payload Costs: Development: P/L SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: P/L Prod. $M	Payload Costs: Production: P/L IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Production: Total P/L Prod. $M	Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Cost $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Costs $M	Total Program Costs $M	Alternate
(79)	66lC'	7	331.48	615.93	21	968	1,433	182	1,615	320	19	0	339	1,954	2,922	868	352	1,120	4,042	
138	66kC	7	317.76	683.25	0	1,001	1,433	182	1,615	320	19	0	339	1,954	2,955	1,575	0	1,575	4,530	
(80)	67mC	6	348.21	676.71	0	1,025	1,433	184	1,617	320	19	0	339	1,956	2,981	1,350	0	1,350	4,331	
139	68jB	6 (×2)	260.61	925.98	0	1,186	1,262	162	1,424	536	32	0	568	1,992	3,178	1,488	0	1,488	4,666	
140	68jE	6	348.81	563.54	126	1,038	1,341	172	1,513	298	18	298	614	2,127	3,165	744	882	1,626	4,791	
(81)	68lB	6 (×2)	264.81	946.49	0	1,211	1,262	162	1,424	536	32	0	568	1,992	3,203	1,488	0	1,488	4,691	
141	68lE	6	348.72	568.0	125	1,042	1,341	172	1,513	298	18	298	614	2,127	3,169	744	882	1,626	4,795	
142	99kC'	5	418.46	649.10	26	1,094	1,366	178	1,545	410	25	0	435	1,980	3,074	1,125	312	1,437	4,511	
(82)	69mC'	4	443.80	575.19	23	1,042	1,468	195	1,663	299	18	0	317	1,980	3,022	900	252	1,152	4,174	
143	100kB	4 (×2)	337.06	914.73	0	1,252	1,224	163	1,387	685	41	0	726	2,113	3,365	1,800	0	1,800	5,165	
144	100kE	4	440.47	551.83	121	1,113	1,293	172	1,465	371	22	371	764	2,229	3,342	900	882	1,782	5,124	
(83)	70mB	3 (×2)	362.35	772.89	0	1,135	1,243	170	1,413	523	31	0	554	1,967	3,102	1,350	0	1,350	4,452	
(84)	70mE	3	470.80	465.57	102	1,038	1,358	185	1,543	274	16	274	564	2,107	3,145	675	882	1,557	4,702	

SYSTEM LEVEL UNITS PRODUCED 10.00 7.00

13.34.58. 01/25/80

ITEM 137 BUS TYPE GEO* CASE III

GEOSTATIONARY PLATFORM PROGRAM COSTS (1980$M)

	RDT&E PHASE COST	FIRST UNIT COST	PROD PHASE COST	RDT&E PLUS PROD
1.1. GEOPLATFORM (BUS) -TOTAL	325.47	99.03	600.26	925.73
1.1.1. STRUCTURE	14.69	3.24	19.63	
1.1.1.1. STRUCTURE (PRIMARY)	6.83	2.79	16.94	
1.1.1.2. STRUCTURE (SECONDARY)	6.48	.44	2.69	
1.1.1.3. STRUCTURE (TOOLING)	1.38			
1.1.2. THERMAL CONTROL	3.40	.71	4.29	
1.1.3. ATTITUDE CONTROL	34.52	8.51	51.57	
1.1.3.1. ATTITUDE CONTROL (AVIONICS)	32.68	6.79	41.15	
1.1.3.2. ATTITUDE CONTROL (AMCD)	1.84	1.72	10.42	
1.1.4. REACTION CONTROL	22.69	8.80	53.35	
1.1.5. ELECTRICAL POWER	41.79	38.38	232.64	
1.1.5.1. SOLAR ARRAY	19.05	27.28	165.36	
1.1.5.2. BATTERIES	.44	3.49	21.14	
1.1.5.3. POWER COND & DIST	22.30	7.61	46.14	
1.1.6. TT&C	11.89	13.58	82.28	
1.1.7. RENDEZVOUS & DOCKING	25.77	3.91	23.72	
1.1.7.1. RENDEZVOUS (AVIONICS)	20.37	3.21	19.44	
1.1.7.2. DOCKING (MECHANICAL)	5.39	.71	4.28	
1.1.8. INTEGRATION, ASSEMBLY, & C&O		9.26	56.13	
1.1.9. PROGRAM MANAGEMENT	11.41	6.17	37.40	
1.1.10. SYSTEMS ENGRG & INTEGRATION	26.96	6.48	39.27	
1.1.11. SYSTEMS TEST ARTICLE	86.38			
1.1.12. SYSTEM TEST OPERATIONS	21.38			
1.1.13. GSE	15.41			
1.1.14. FSE				
1.1.15. FACILITIES	9.79			

264 352 30

Figure 2-7. Sample Cost Model Output

Production costs understandably follow an opposite trend. Even with appropriate allowance for the learning curve and volume production, it is much more expensive to make many small platforms than to make a few big ones. For the nominal traffic model, total production costs range from about $136M for one mE platform to $1.023B for 67 aC platforms. For the high traffic model, the range is from $471M for 3 mE platforms to $3.125B for 225 aC platforms.

Total bus costs for the nominal traffic model range from $471M for dB and hC to $1.147B for aC. For the high traffic model, the range is from $947M for jC' to $3.341B for aC.

Payload Costs. The costs of each payload set is dependent upon a number of factors including the degree of subdivision of large payloads, the duplication of antennas and other components, the redundancy required to obtain high availability/reliability over the mission lifetime, and the modularity required for servicing. These factors all influence the payload development and production costs. The total development cost also includes the analytical efforts required for system engineering and integration.

The total production cost includes payload physical integration and checkout as well as payload servicing items, i.e., one set of new payloads for operational mode E. A more detailed discussion of payload cost estimating relationships is given in Vol. III.

Although all elements of payload costs are affected by platform option, those options leading to higher payload development costs tend to have lower payload production costs, and vice versa. Thus, for the nominal traffic model the total of all payload costs is relatively insensitive to platform option. For mission set N, the total payload costs range from $755M for eC to $945M for aC, and 70 of the 72 options vary only between $755M and $882M.

For the high traffic model, the range of payload costs was much wider. For mission set V, payload costs range from $3.28B for aE to $1.92B for nC', lC, and hC'. The null occurs for three-platform system concepts that employ 12 platforms to accommodate the high traffic model payloads at the Western Hemisphere and Atlantic locations.

Transportation Costs. Platform launch costs and servicing flight costs are discussed in Section 2.4.2.6 and are developed in Tables 2-26 and 2-27. The results are reflected in Tables 2-28 and 2-29.

For the nominal traffic model, total transportation costs range from $374M for jC' and eC' to $2.479B for aC. For the high traffic model, the figures go from $1.120B for jC' and lC' to $8.325B for aC.

The high traffic model is large enough that all the OTV candidates can be used efficiently and therefore get fair consideration in the trades. Singularities peculiar to the mission model are significant, and basic model-independent trends appear clearly. Some of the clear messages of the total transportation costs analysis are:

a. There is significant economy of scale. While there is scatter in data because of the varying efficiencies of OTV candidates, the envelope of data points is essentially linear. It shows dramatic cost savings as the size of the platforms increases. The 15 least expensive options all involve case III or III' platforms (one or two Shuttle loads) mated on orbit to large two-stage OTVs. The lowest cost case II, single-stage OTV ground-mated to the platform and launched together in a single Shuttle, costs about 40 percent more than the best case III option.

b. The IUS is not economical for delivery of large space systems. At about \$20/gram, even its most capable four-stage version adds billions to program cost.

c. Reusability becomes practical only for large two-stage OTVs.

d. Transportation costs are minimized by mode C' regardless of OTV class. Servicing is cost-effective if done only when necessary.

Total Program Costs. The bus, payload, and transportation costs for each set are summed to yield the total program cost for each candidate system concept.

For the nominal traffic model, the program costs range from \$1.671B for jC' to \$4.571B for aC. For the high traffic model, the range is from \$4.021B for jC' to \$14.043B for aC.

Histograms of the program cost elements are plotted in Figures 2-8 and 2-9 for mission sets N and V, respectively.

Transfer vehicles j, l, and m are nearly identical in cost for all modes. Usually j has a slight advantage. These are all versions of a new two-stage OTV, with j being the reusable version with a low-thrust engine.

Figures 2-10 and 2-11 present plots of total program cost versus number of modules in each set. The economy of scale gained by using larger modules is clearly evident, with nulls around two for the nominal traffic model and seven for the high traffic model. The figures are coded to identify the operational mode for each concept.

Mode C' is the least expensive mode in every case for all possible transfer vehicles (ignoring the small OTVs a, q, and r, which cannot handle some of the larger

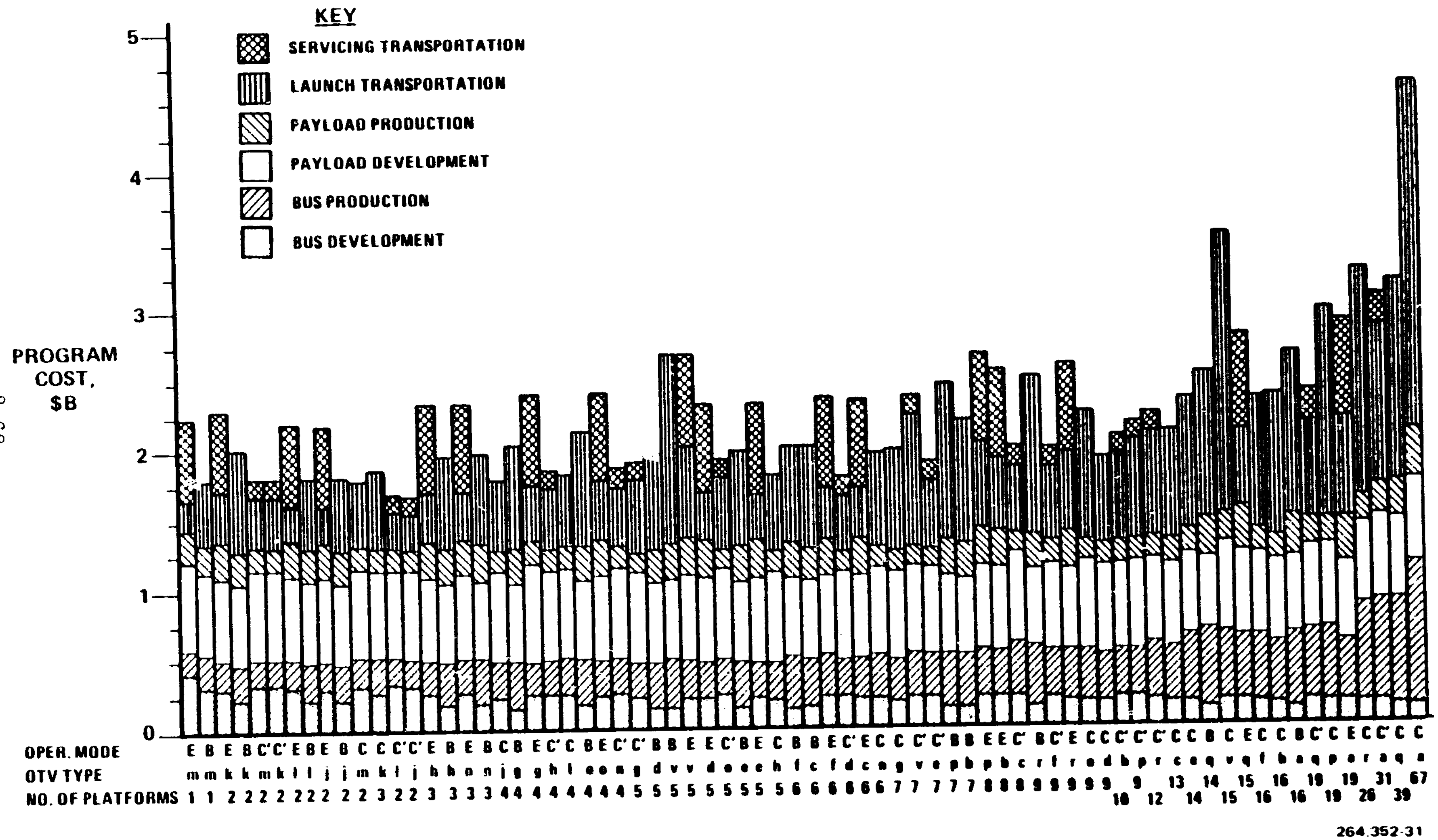

Figure 2-8. Program Cost Elements - Mission Set N

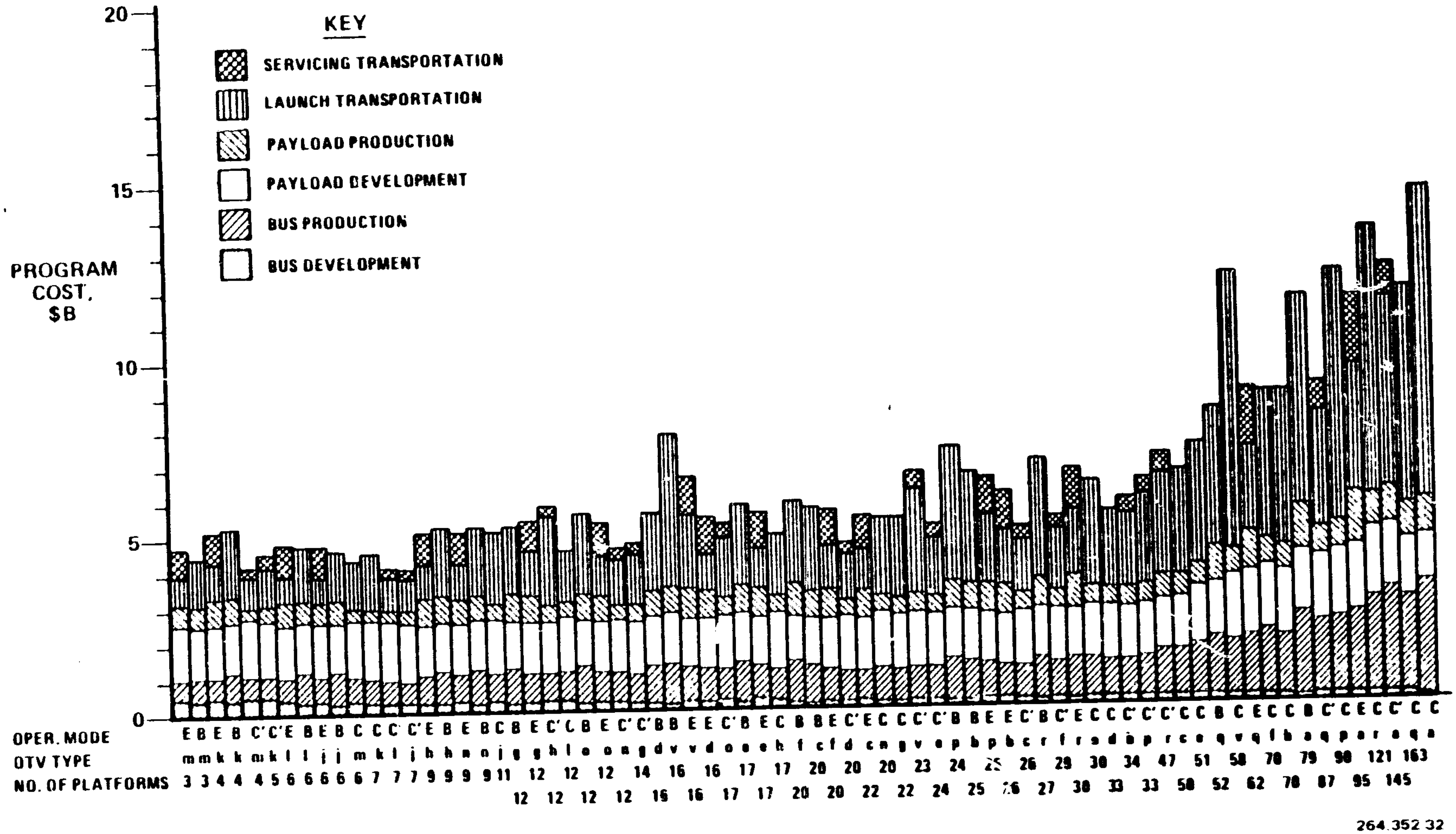

Figure 2-9. Program Cost Elements - Mission Set V

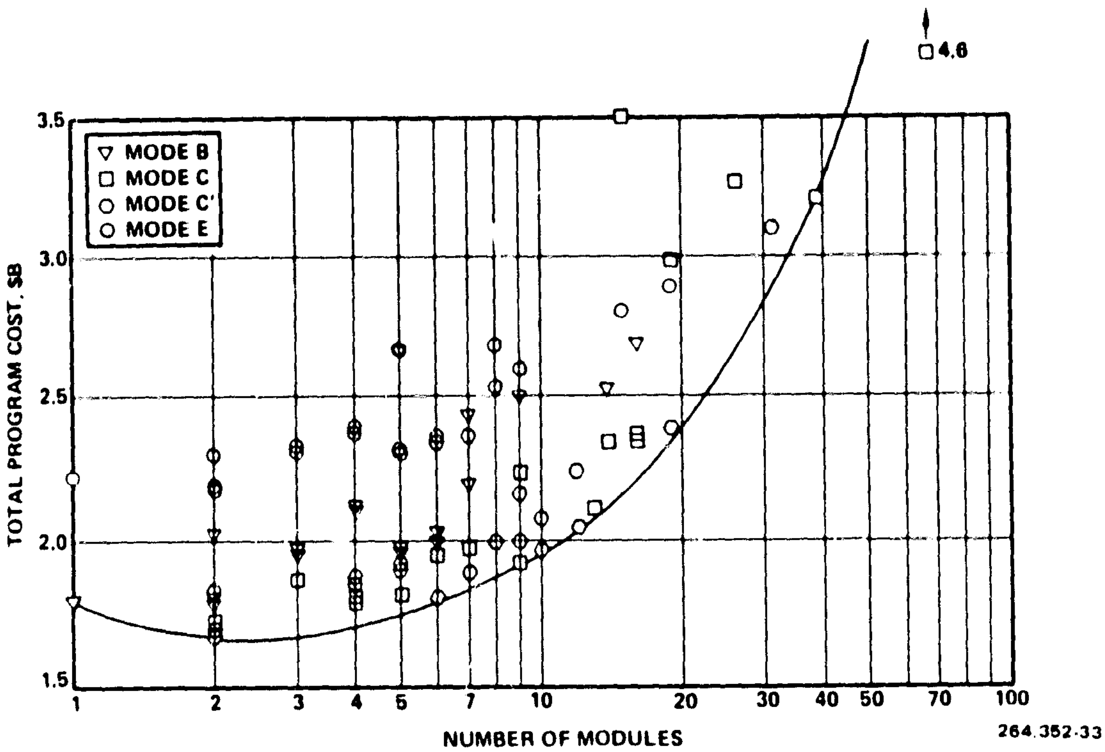

Figure 2-10. Total Program Costs - Mission Set N

payloads and which have extremely high program costs). For some options, mode C' savings over the other modes is small, for others it is large. A good comparison of the four modes is to average the total program costs over all the options and mission models for each mode. The results are:

B	C	C^1	E
$4.185B	$5.09B	$3.87B	$4.22B

2.4.3 INDIVIDUAL SATELLITES. To further investigate the economy of scale effects, concepts and system costs were also developed for accommodating the same payload sets on a variety of conventional small, individual satellites (case I) and on larger IUS-launched individual satellites (case I').

2.4.3.1 Launch Case I. In the preliminary trade studies, a first approximation for the individual satellite mode was made, based on the payload model and costs used in the MSFC economic analysis (Reference 2.3). It was determined that the new Western Hemisphere payload model was about 16 percent heavier than the sum of payload masses in the previous model, so the number of satellites required and the cost of spacecraft and payloads was scaled up according to mass ratios. For

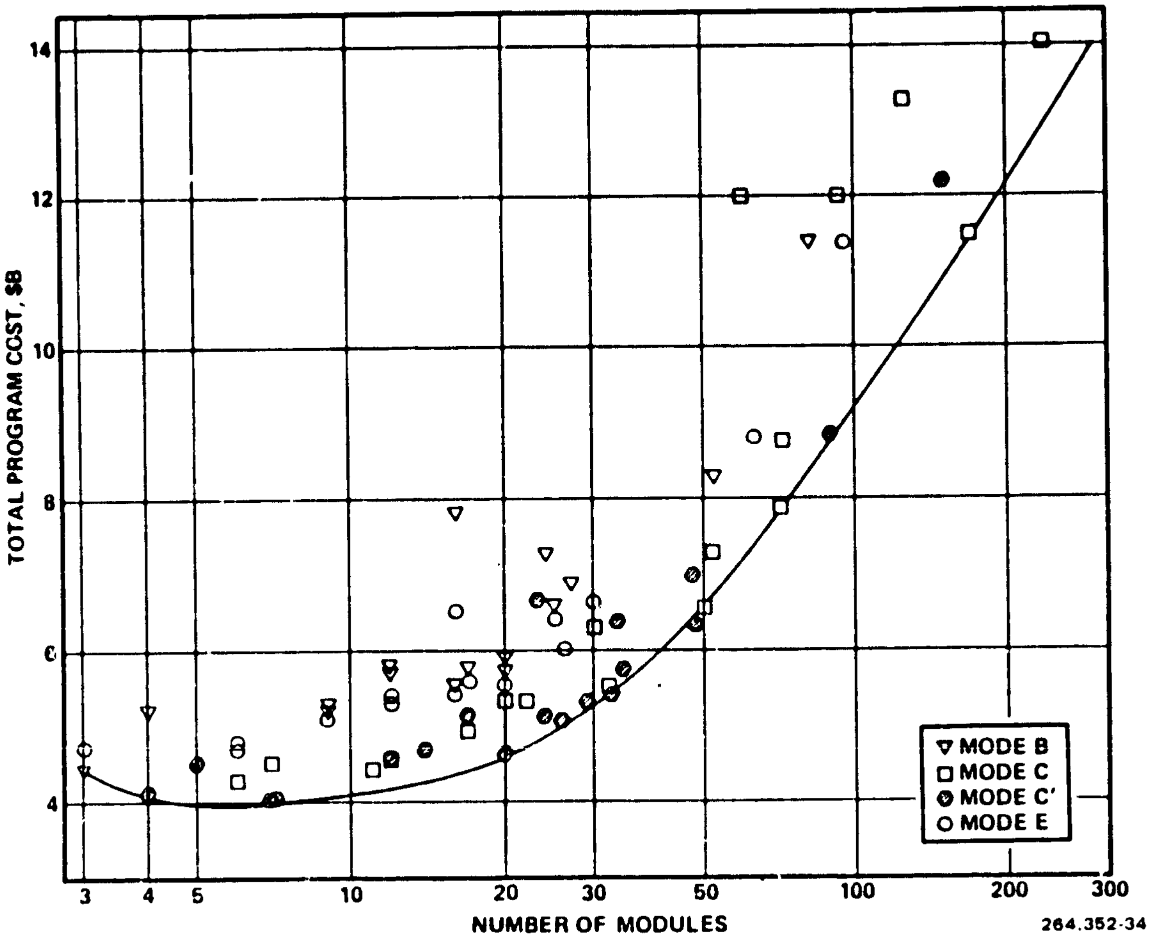

Figure 2-11. Total Program Costs - Mission Set V

transportation costs, the new number of SSUS A&D upper stages and two-stage IUS were determined and these costs estimated. Table 2-31 lists the original MSFC estimates (adjusted from 1978 to 1980 dollars) and the extrapolated cost element estimates for the new mission set N payload complement. A total of 62 satellites would be required to accommodate the new payload set. The satellites, per conventional design philosophy, would have a life of 8 years and would therefore be replaced by 62 more satellites to complete the 16 year mission. No on-orbit servicing is possible in this mode of operation (mode B). The total program cost estimate for this individual satellite concept was $8.363B.

2.4.3.2 Launch Case I'. At the first formal program review, it was determined that launch case I would not be a realistic operating environment in the 1990s. Therefore, a new concept was developed that employs a standard bus design (TDRS-derived, but with 1990 technology incorporated). Transportaion is provided by the Shuttle and two-stage IUS. Again, the satellite would have an

Table 2-31. Launch Case I Cost Elements

(Costs in 1980 dollars)

Cost Element	MSFC I/S Mode		Mission Set N I/S Mode		Comments
	Quantity	Cost,* $M	Quantity	Cost,* $M	
Spacecraft	106	2,900	124	3,378	Quantities & Costs Extrapolated Using MR = 1.1647.
Payload Equipment	106	1,827	124	2,128	
TOTAL SATELLITE	106	4,727	124	5,506	$44.4M per Satellite Development & Production
Shuttle	54	1,780	63	2,073	Sum Cost = $7,579M in LEO
SSUS A&D	84	339	98	395	$784M LEO + GEO Cost
2-Stage IUS	22	334	26	389	
TOTAL TRANSPORTATION		2,453		2,857	$23M per Satellite Transportation
TOTAL PROGRAM		7,180		8,363	$67.4M per Satellite in Orbit

*Costs are for a 16 year mission duration.

eight year life and be replaced to complete a 16 year mission (operational mode B). Table 2-32 summarizes the design characteristics of the Case I' standard bus. Theoretically, the cluster of individual satellites would share a single orbital slot, and be interconnected by microwave links (buildup mode K).

The margined payload weight for the case I' satellite bus was established at 340 kg (allowing for payload mass contingency). Specific payloads were then assigned for both mission sets within the allowable payload weight and power criteria. The payloads could be accommodated by 39 satellites for mission set N and by 163 satellites for mission set V.

Table 2-32. Case I' Individual Satellite Description

Standard Spacecraft Bus

- Based on TDRS design (with 1990 technology)
- Launched by shuttle/IUS (OTV Types)
- Total satellite weight is 2268 kg (5000 lb)
- Mission life is 8 years for each satellite
- Replaced after 8 years by a new satellite

Payload Accommodations

- Payload mass = 420 kg
- Payload power = 2700W

Weight and Power Summary	Mass, kg	Power, W
Payloads	420	2700.0
Subsystems		
TTC	45	41.0
ACS	100	212.0
Structure	411	0.0
EPS	367	300.0
Thermal	58	344.0
Propulsion (dry)	85	0.4
Contingency margin	114	302.6
S/C totals	1600	3900.0
Residuals	21	
S/C EOL:	1621	
Hydrazine (8 years)	526	
S/C BOL:	2147	
Adapter	121	
IUS payload:	2268	

The bus, payload and transportation costs were estimated for the individual satellite (I/3) mode and are summarized in Table 2-33, along with the launch case I data. Operational mode C, 16 year life without servicing, was also investigated, but it was found that the additional propellant mass required for this long-term mission was excessive. Platform synthesis resulted in a negative payload margin; therefore, this mode was determined to be infeasible.

The cost elements for launch case I' have been added to Figures 2-12 and 2-13. The economy of scale afforded by the platforms is readily apparent. This is especially evident for mission V, the high traffic model.

2.4.4 TRANSFER VEHICLE COMPARISON. It is apparent in Figures 2-12 and 2-13 that transportation costs are a substantial fraction of the total program costs, and are the most variable of any of the cost elements. The total program cost histograms are again presented in Figures 2-14 and 2-15, with annotations added to identify the important OTV features as follows: R = reusable, L = low thrust, 2 = two-stage. Where such annotations do not appear, the OTV is expendable, high thrust, and single-stage.

These figures make evident the cost advantages of the two-stage, low thrust, reusable OTV options, for both the nominal and high traffic models. The program cost data versus number of modules required to accommodate the payloads of mission set V are also plotted in Figure 2-16 with each of the OTV code letters added (Reference Table 2-6). In addition, the data points for the reusable transfer vehicles are shaded. Several observations that may be made from this figure follow:

a. Two-stage OTVs produce lowest total program costs.

b. Reusable mode is only economical for two-stage vehicles; for single-stage vehicles costs are much higher.

c. Liquid propellant stages yield lower program costs than solids for a given module size.

The program cost data for mission set V are plotted again in Figure 2-17, this time with the applicable launch mode indicated. The cost null at seven modules indicates that launch case III yields the lowest cost system concept. The next lowest cost concept would be four modules, launched in mode III'.

2.4.5 EVOLUTIONARY BUILDUP OPTIONS. Of the four evolutionary buildup options defined in Table 2-9, only mode K has thus far been discussed. The major system trade study results for mode K identified the most promising concepts and provided the data base to evalute the other three evolutionary options.

2.4.5.1 Mode H - Payload Addition. For this option, a very large platform bus, i.e., structure and all subsystems, would be constructed and checked out in

Table 2-33. Individual Satellite Mode Program Cost Summary

Item	Launch Case (Mission Set)	Bus Type	No. of Platforms	Bus Costs: Total Devel $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Total Bus Costs $M	Payload Costs: Development: Payload Devel. $M	Payload Costs: Development: Payload SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: Payload Prod. $M	Payload Costs: Production: Payload IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Total Payload Prod. $M	Payload Costs: Total Payload Costs $M	Total Platform Costs (Bus & Payload) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Costs $M	Total Program Costs $M
146	I(N)	25xB	62 (×2)				3,378								2,128	5,506	2,857	0	2,857	8,363
145	I'(N)	31sB	39 (×2)	120.9	1,264	0	1,385	455	45.5	501	196	11.8	0	2-9	709	2,094	3,588	0	3,588	5,682
148	I (V)	71sB	163 (×2)	120.9	4,545	0		1,030	103.0	1,133	815	48.9	0	864	1,997	6,663	14,996	0	14,996	21,655

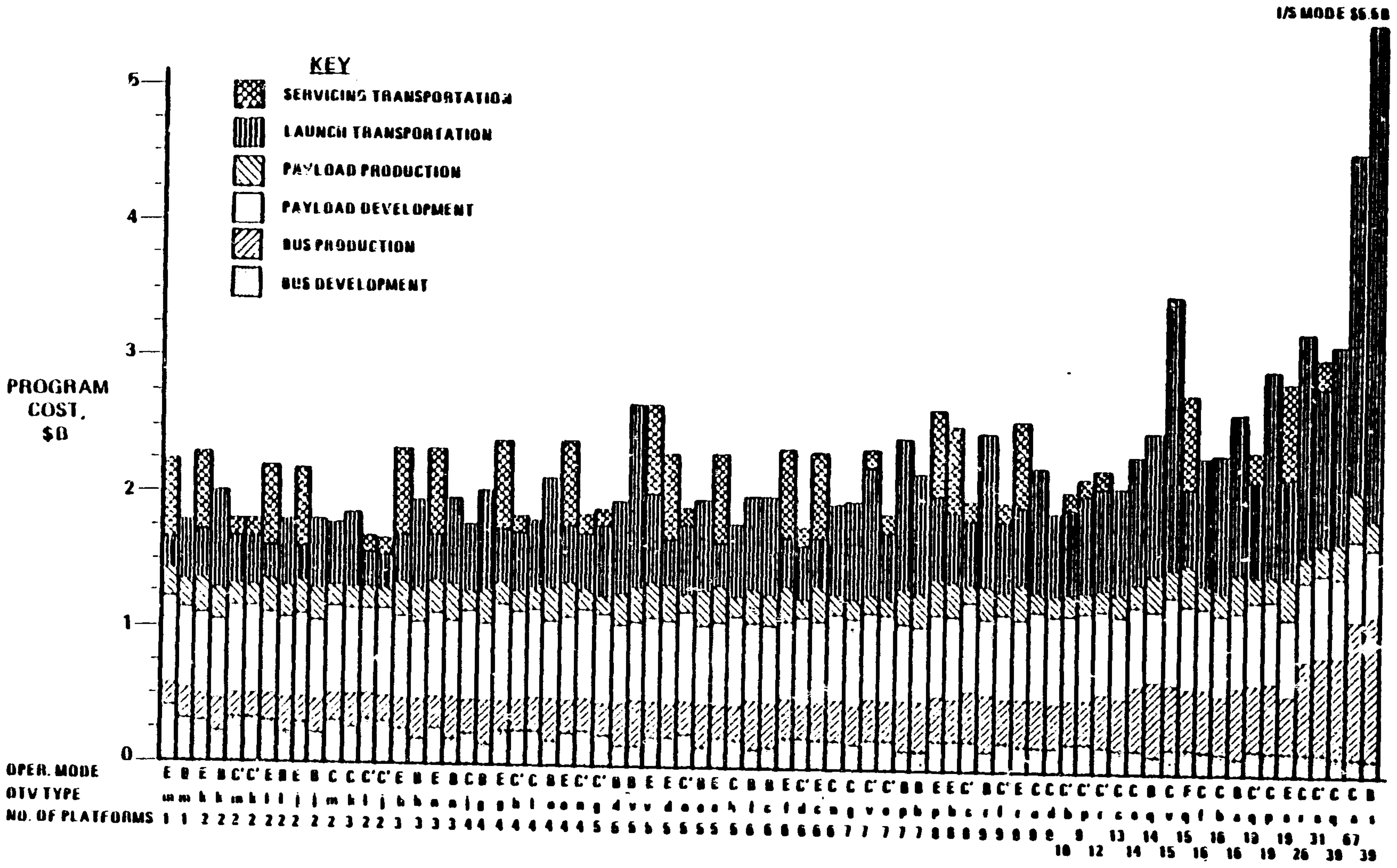

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Figure 2-12. Mode K Cost Summary - Mission Set N

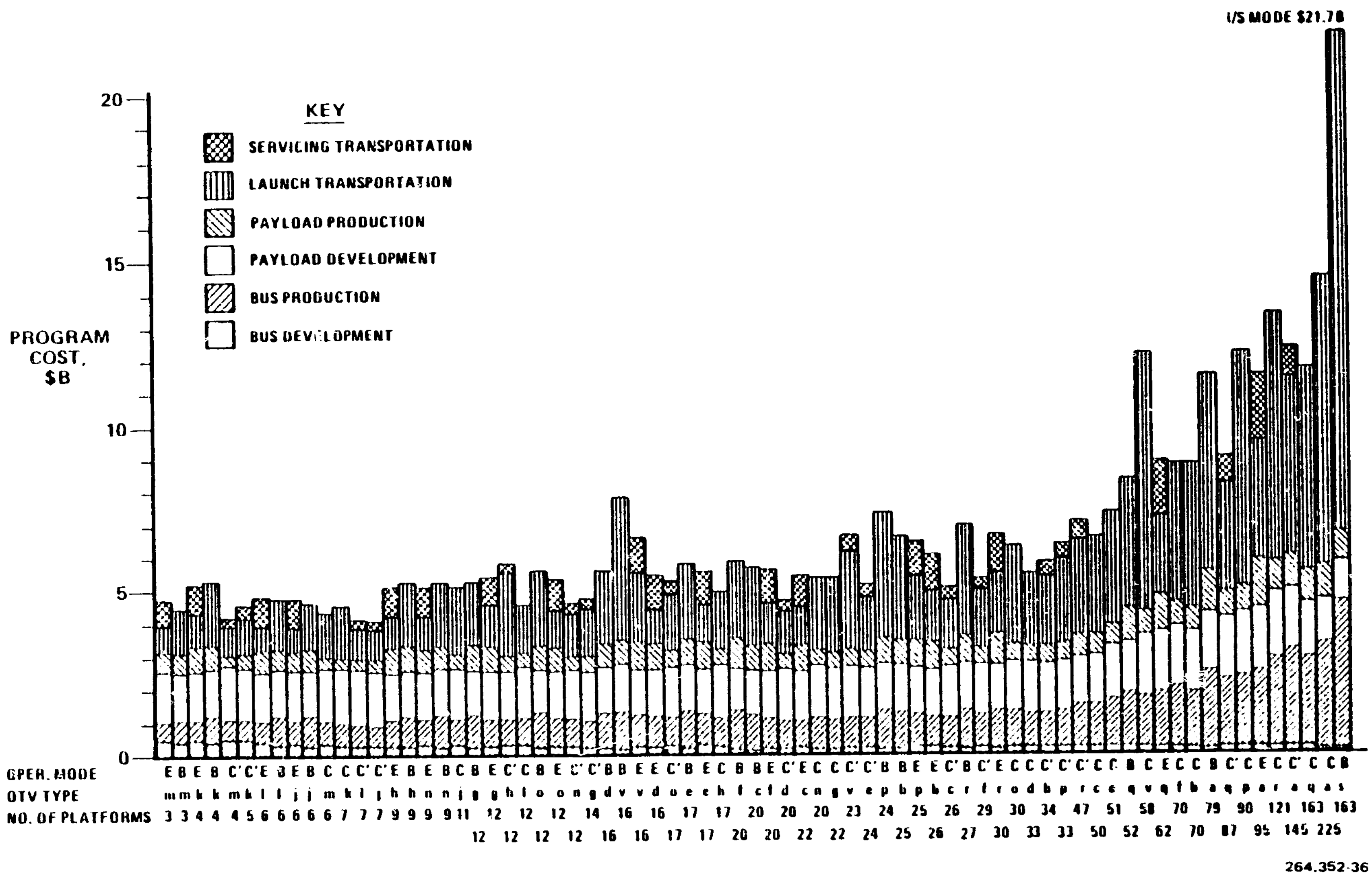

Figure 2-13. Mode K Cost Summary - Mission Set V

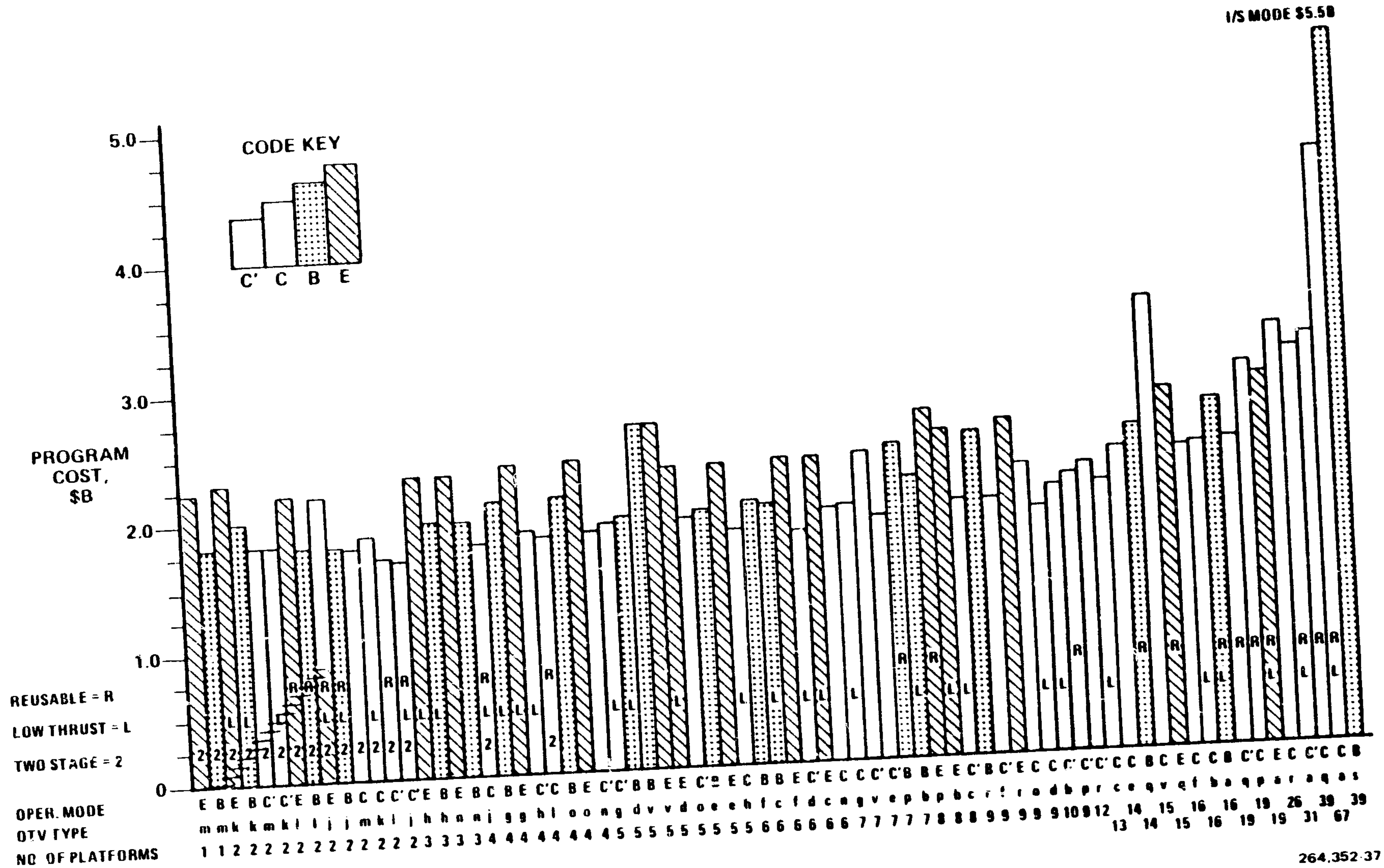

Figure 2-14. OTV Characteristics and Effects - Mission Set N

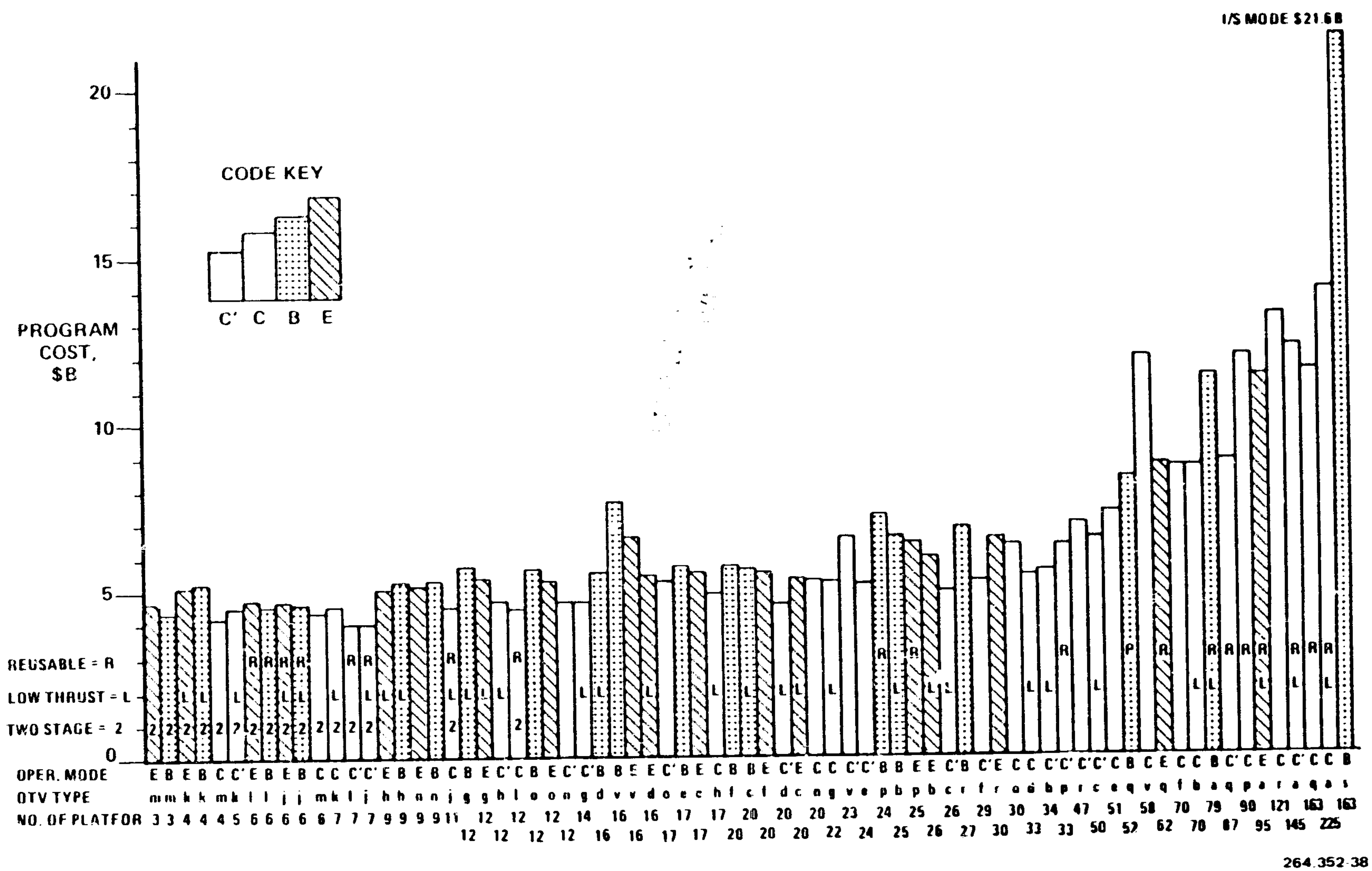

Figure 2-15. OTV Characteristics and Effects - Mission Set V

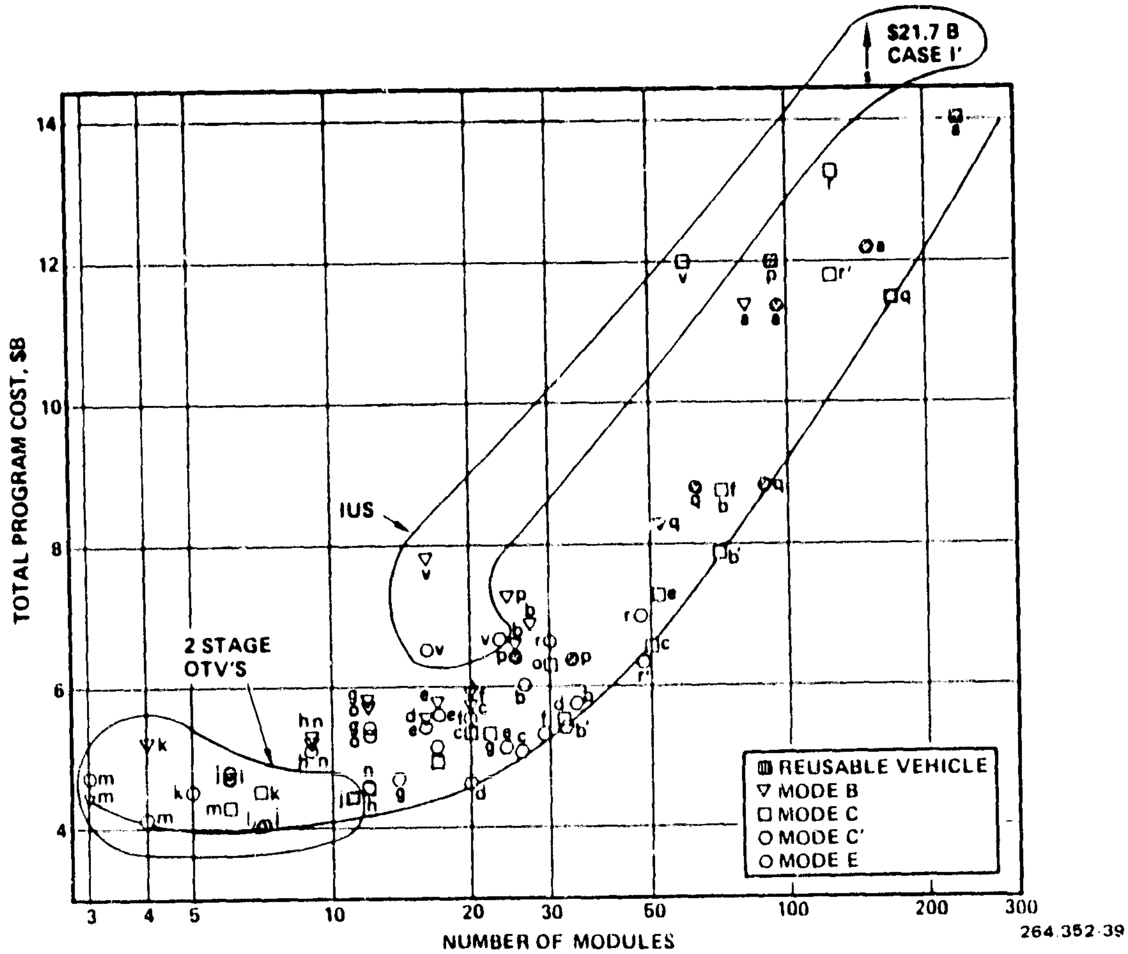

Figure 2-16. Transfer Vehicle Comparison

LEO with a small fraction of the total payload complement installed. The platform would then be transferred to GEO, where it would initially operate with the small payload set. The platform would be designed for 16 year life, with periodic servicing visits by the TMS.

Over a period of time, as new demands for communications capacity and new services are encountered, new user equipment is delivered and installed on the platform via the servicing vehicle. The frequency of servicing flights could be variable, but the maximum interval would be governed by the sizing of the RCS propellant storage capacity.

Buildup mode H is inherently coupled to operational mode E, because of the necessity for servicing flight availability to build up the payload complement.

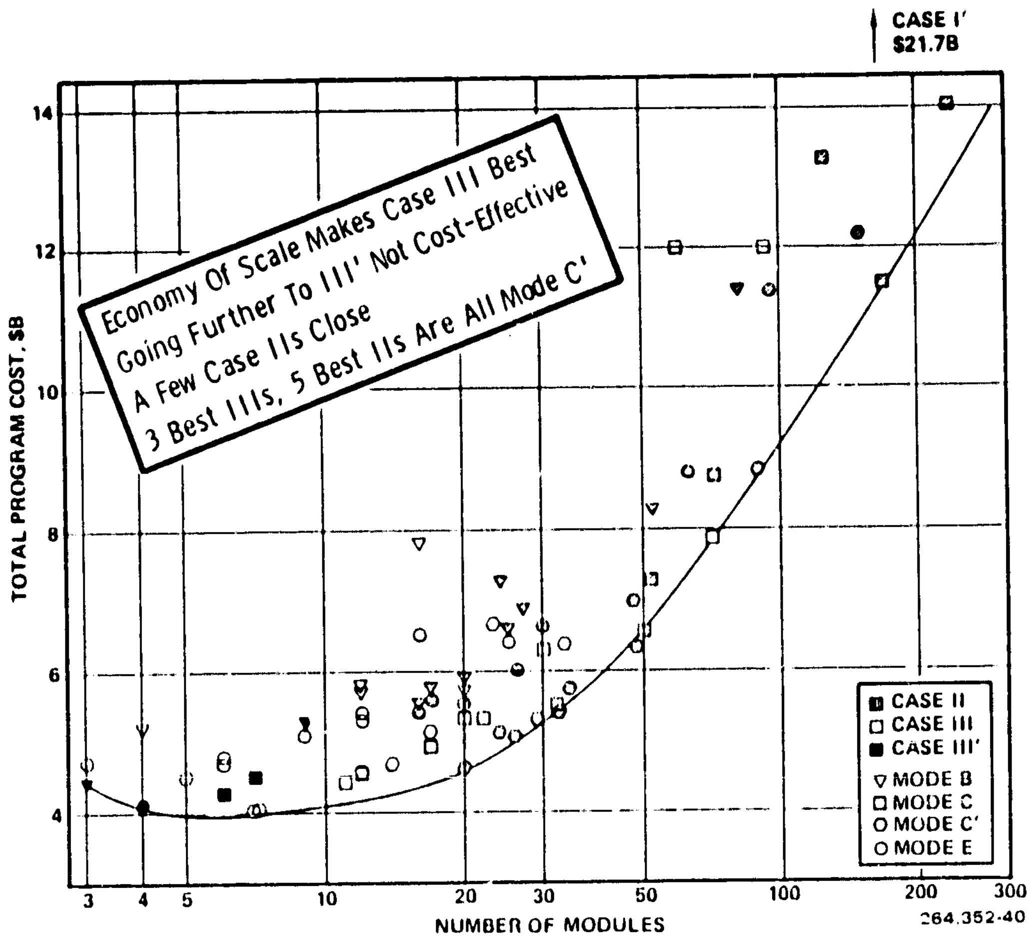

Figure 2-17. Launch Mode Comparison

Ten options utilizing buildup mode H were defined and compared to mode K. The results are shown in Table 2-34. Servicing flight intervals varying from six months to three years for mode H were evaluated for the nominal traffic model and at two year intervals for the high traffic model. In all 10 cases, mode H total program costs were higher than those for mode K. However, for the two and three year service interval, the mode H cost was within a few percent of mode K. When compared to operational mode C for similar platform concepts, the buildup mode H costs were $0.58 to $1.0B higher.

2.4.5.2 Mode J - Docked Dependent Modules. To further investigate the effects of economy of scale, buildup mode J was devised. In this mode, several modules would be constructed in LEO, transferred to GEO, and then docked together at GEO to form a single large platform at each orbital location, with subsystems shared between modules.

Buildup of each platform would take place over a period of years, to meet the time-phased payload accommodation requirements for each orbital location. These modules would not each be self-sufficient, as were those evaluated for mode K. Instead, the first module launched to each orbital location would contain the power generation and energy storage portions of the electrical power subsystem (EPS) and would also house the bulk of the elements of the telemetry, tracking, and command (TTC) subsystem and the thermal control subsystem (TCS). The first module would contain a relatively small payload complement.

The succeeding modules would accommodate a relatively large payload complement but would require just a few elements of the EPS, TTC, and TCS subsystems, e.g., power distribution cabling and switching, data bus and multiplexer-demultiplexers, etc. Sharing of these subsystems by all modules permits less duplication of components and decreases development and production costs.

Other subsystems, e.g., attitude control subsystems (ACS) and reaction control subsystem (RCS) would be included on each module and would be interconnected via the TTC subsystem to act as large, distributed systems under control of the central computer.

Since operational mode C' had been determined to be the least costly mode, buildup mode J concepts were developed for 16 year life, coupled with servicing as necessary, but at least every eight years to replenish consumables and exchange batteries or other equipment. Launch cases II and III were both evaluated.

Three concepts were synthesized for buildup mode J, two for launch case II (Items 234 and 276) and one for launch case III (Item 337). Item 234 was for the nominal traffic model and Items 276 and 337 were for the high traffic model. The same basic methodology that was used for mode K was employed (Reference Figure 2-1), but with new ground rules added as follows:

Table 2-34. Evolutionary Buildup Options — Mode H Versus Mode K

A range of servicing frequencies was examined, from every 6 months to every 3 years.

Variations of Item 64, IIIjEKN (2) (Baseline cost $2.182 B)

a. IIIjEHN (1) (6 months) cost $2.768 B
b. IIIjEHN (1) (1 year) cost $2.759 B
c. IIIjEHN (1) (2 years) cost $2.196 B
d. IIIjEHN (1) (3 years) cost $2.189 B

Variations of Item 72, III'mEKN (1) (Baseline cost $2.234 B)

a. III'mEHN (1) (6 months) cost $2.869 B
b. III'mEHN (1) (1 year) cost $2.860 B
c. III'mEHN (1) (2 years) cost $2.297 B
d. III'mEHN (1) (3 years) cost $2.290 B

Compare to Item 59 IIIjC'KN (2) $1.671 B

Variations of Item 84, III'mEKV (3) (Baseline cost $4.702 B)

a. III'mEHV (3) (2 years) cost $5.039 B

Variations of Item 140, IIIjEKV (6) (Baseline cost $4.790 B)

a. III'jEHV (3) (2 years) cost $4.859 B

Compare to Item 137 IIIjC'KV (7) $4.021 B

Conclusion – no cost reduction in changing from Mode K to Mode H.

a. No savings in structural weight allowed (basic bus same as K).

b. No savings in consumables allowed.

c. No savings in RCS or ACS subsystems allowed.

d. Power, TT&C, and thermal control systems can be shared, with their weight and cost reflecting the total payload and subsystem set on all modules supported.

e. Modules without prime power will have 100 kg for distribution.

Specific payload assignments were again made to each module, taking into account the time-phased needs for each type of communications service. Direct to user (DTU) and high volume trunking (HVT) payloads were accommodated in accordance with the following temporal priority (in descending order) whenever possible:

a. HVT, C-band.

b. DTU, Ku-band.

c. HVT, Ka-band.

d. DTU, Ka-band.

For each of the three mode J concepts, it was found that fewer platform modules were required to accommodate the payload sets than for mode K. This resulted in lower bus and delivery transportation costs and lower overall total program costs. Table 2-35 presents a summary of the mode J concepts along with a comparison with the best of the mode K concepts.

Bus costs are always lower for mode J because of the reduced number of modules and because of sharing of large EPS, TTC, and TCS subsystems. Payload costs are reduced slightly for the high traffic model because the heavier payloads did not require splitting up, and therefore duplication of antennas, switches, etc., was not required. Delivery transportation was reduced about 30 percent for the high traffic model because of the reduced number of modules.

The difference in total program costs, comparing mode K to mode J, is shown in the right column of Table 2-35. The change in costs (savings) ranges from \$110M to \$570M when comparing operational mode C', and extend up to \$1.558B when all operational modes are compared.

Buildup mode J involves some extra complexity and costs associated with docking the modules at GEO. This extra complexity has been reflected in the costs included for rendezvous and docking sensors and mechanisms in the bus cost estimates.

Table 2-35. Buildup Mode J Comparisons

Launch Case	Item No.	Traffic Model	Buildup Mode	OTV Type	Operational Mode	No. of Modules	Bus. Costs $M	P/L Costs $M	Transportation Costs: Delivery $M	Transportation Costs: Servicing $M	Transportation Costs: Total $M	Total Program Costs $M	Δ Costs Re. Mode J $M
II	276	V	J	d	C'	14	872	1875	938	312	1250	3997	–
	76	V	K	d	C'	20	1031	1984	1340	312	1652	4667	+670
	125	V	K	d	B	16 × 2	1298	2113	2144	0	2144	5555	+1558
	74	V	K	d	C	33	1277	1997	2211	0	2211	5485	+1488
	122	V	K	d	E	16	1141	2226	1072	1008	2080	5447	+1450
II	234	N	J	d	C'	5	453	769	335	126	461	1682	–
	34	N	K	d	C'	6	496	768	402	126	528	1792	+110
	45	N	K	d	B	5 × 2	471	816	670	0	670	1957	+275
III	337	V	J	j	C'	5	824	1764	620	252	872	3460	–
	137	V	K	j	C'	7	947	1954	868	262	1120	4021	+561
	139	V	K	j	B	6 × 2	1186	1992	1488	0	1488	4666	+1206
	140	V	K	j	E	6	1048	2127	744	882	1626	4791	+1331
	132	V	K	j	C	11	1100	1961	1364	0	1364	4425	+965

One operational advantage provided by mode J over mode K is the ease of interconnectivity of communications services. A hardwire data bus and a single central switch can provide interservice connectivity instead of the multiple RF links and switches required for mode K.

2.4.5.3 Mode L - Docked Independent Modules. Another option for evolutionary buildup is to sequentially launch independent modules as in mode K, but to physically dock them together in GEO to form one large platform at each orbital location. Again, platform buildup would take place over a number of years, in pace with user needs.

Each of the modules would have a complete complement of subsystems aboard, but after docking with other modules, a control hierarchy would be established to operate the module subsystems as integrated parts of the platform's large, distributed subsystems.

The concept descriptions developed for mode K (independent modules flying in formation) are almost identical to the configurations required for mode L. The only difference in functions is that the mode L concepts would replace the microwave interplatform links that provide interservice connectivity with hardwire links, and would require the addition of sensors and mechanisms for on-orbit docking to an adjacent module.

After a comparative analysis of the buildup modes K and L concepts, the following observations can be made:

a. The weight and cost of the rendezvous and docking mechanism is very nearly the same as the microwave link equipment of mode K.

b. It may be possible to save some stationkeeping propellant weight with L as compared to K. This depends greatly on the configuration of the cluster in K.

c. In the test cases run, the total program costs were identical. There are uncertainties in the development costs of the subsystems peculiar to these modes. These uncertainties far exceed any detectable cost differences.

All of the costs developed for mode K are equally valid for mode L, and thus the program cost summary data presented in Tables 2-29 and 2-30 are applicable for the docked independent module buildup mode as well.

Since subsystems would not be shared, the platform buses and payloads complements would be the same and their costs the same. Also, the numbers of modules required would be the same and thus the transportation costs the same.

Comparing the functions and configurations of the docked modules, the hardware interservice interconnectivity would be operationally advantageous over the RF links used between the free flyers. However, the close proximity of the docked modules tends to cause mutual blockage of solar arrays twice per orbital revolution unless the modules launched later in the mission have their array drives extended considerably above and/or below the earlier-launched arrays. Also, the locations of large antennas mounted at or beyond the edge of a module must be carefully considered when planning the layout of adjacent modules to prevent aperture blockage or field-of-view obscuration of other sensors.

2.4.6 COMPARISON OF BEST OPTIONS. Having evaluated all of the viable combinations of launch case, OTV type, operational mode, and evolutionary buildup mode, the best overall options were identified and a few were selected for funding spread analysis. Table 2-36 lists the selected options, total program costs and selection rationale. The symbols of the identifying code are summarized in Table 2-37 and the definitions are given in Table 2-10.

Four options that cover a wide range of launch cases and operational modes were selected for funding spread analysis. The selected options are:

a. Item 148 - Best satellite option (IUS/standard TDRSS bus/multiple payload).

b. Item 84 - Best frequency serviced option.

c. Item 276 - Best case II (module and OTV in single Shuttle).

d. Item 337 - Best overall option.

Funding spreads were generated for the four selected candidates. The cost of each major cost element was spread according to a top level milestone schedule and then accumulated to provide annual funding requirements. The details of the funding analysis are included in Appendix J.

The final cost results of the candidate options are shown in Table 2-38 together wtih the individual satellite case for comparis n. Total program costs are shown as are program cost excluding the cost of the payloads themselves. Costs are shown in 1980 constant dollars together with the net present value assuming a 10 percent discount rate. Item 337 shows minimum cost followed by Items 276 and 84. This trend is also confirmed when discounted dollars are considered.

All of the potential options are at least a factor of four cheaper than the individual satellite case for the accomplishment of the assumed mission model.

2.5 SELECTED CONCEPTS

The system concept options and definitions that were developed in Secton 2.4 of this report were presented at the second formal program progress meeting for NASA review and concurrence per the study plan. However, following the review, it was determined that an additional mission set should be evaluated and

Table 2-36. Best Overall Options -- Mission Set V

Item No.	Code	Total Program Cost	Selection Rationale
*337	IIIjC'JV (5)	$ 3.460 B	Best option overall
*276	IIdC'JV (14)	3.997	Best case II
137	IIIjC'KV (7)	4.021	Best cluster (K) or docked (l)
80	III'mCKV (6)	4.331	Best 16-year throwaway
83	III'mBKV (3×2)	4.452	Best 8-year throwaway
76	IIdC'KV (20)	4.667	Best case II K or L
* 84	III'mEKV (3)	4.702	Best frequently serviced
440	III'jEHV (3)	4.859	Best payload addition option
*148	I'sBKV (163×2)	21.659	Best satellite option

*Selected for funding spread analysis.

Table 2-37. Key to Coding of Options

Each option has an item number and a code.

The item numbers are our computer designations and have little intrinsic meaning.

Option codes tell a great deal. For example:

Item 337, Option III jC'JV (5)

III	Launch mode	Medium platforms, space mated to transfer vehicle
j	Transfer vehicle	New 2-stage reusable OTV, low thrust engine, used in reusable mode, space-mated
C'	Operating mode	Hybrid, highly redundant 16 year life, serviceable, 8 year consumables capacity
J	Buildup mode	Docked dependent modules, shared subsystems
V	Mission set	Payloads satisfying high traffic model, both western hemisphere and atlantic locations
(5)	Number required	It takes 5 such modules individually launched to GEO to satisfy the mission set

Table 2-38. Funding Spread Analysis Results

Item No.	Total Program Costs 1980 \$M	Total Program Costs NPV \$M	Cost Without Payloads 1980 \$M	Cost Without Payloads NPV \$M
*337	3,460	1,564	1,696	787
†276	3,997	1,740	2,122	893
84	4,703	2,285	2,870	1,283
148	21,659	7,790	19,662	6,858

*Recommended baseline concept.
†Recommended backup concept.

some additional logistics flights should be added to the operational mode C' concepts to afford more payload changeout capability as a user option.

2.5.1 MISSION SET P. Program costs were developed for 72 additional platform system concepts to accommodate mission set P - the nominal traffic model payloads for both the Western Hemisphere and Atlantic locations. The data base developed for mission set N was employed, with appropriate factors applied to quantities and learning curves. The total program costs are summarized in Table 2-39. The OTV/operating mode trends previously described for mission set V also apply to mission set P.

2.5.2 OPERATIONAL PLATFORM ALTERNATIVES. In cooperation with NASA, four alternative platform system concepts were selected for further definition in Task 3 - conceptual design. The selected concepts are as follows:

Alternative No.	Item No.	Code					
1	401	II	d	C'	K	P	(12)
2	402	II	d	C'	J	P	(12)
3	403	III	j	E	K	V	(6)
4	404	III	l	C'	J	V	(5)

Descriptions of each of the concept options are given in Figures 2-18 through 2-21.

Using the data base previously established for the system trade studies, preliminary program cost estimates were developed for operational platform alternatives 1 through 4. The program costs are summarized in Table 2-40.

Figures 2-22 and 2-23 present plots of total program cost versus number of modules for mission sets P and N, with platform alternatives 1 through 4 added to indicate their positions relative to the other concepts evaluated.

2.6 CONCLUSIONS

A wide variety of platform sizes, operating modes, and delivery methods was investigated and the impact of these factors quantified to guide the selection of system concepts for platform definition in Task 3. The results of the system trade studies are summarized in Table 2-41.

The basic trade studies, performed for buildup mode K, illustrate the economy of scale advantages of larger platforms, considering the total program costs. Economy of scale is achieved in two ways - through lower platform costs for a

Table 2-39. Program Cost Summary - Mission Set P

Nominal Traffic Model, Western Hemisphere and Atlantic Locations

			Bus Costs				Payload Costs								Total Platform Costs (Bus & P/L) $M	Transportation Costs			Total Program Costs $M
							Development			Production									
Item	Bus Type	No. of Platforms	Total Devel. $M	Total Prod. $M	Bus Servicing Items $M	Total Bus Costs $M	P/L Devel. $M	P/L SE&I $M	Total Devel. $M	P/L Prod. $M	P/L IA&CU $M	Servicing Items $M	Total P/L Prod. $M	Total P/L Costs $M		Launch Costs $M	Servicing Flight Costs $M	Total Transportation Costs $M	
501	aC	134	124	2046	0	2170	792	184	977	660	40	0	700	1676	3846	4958	-	4958	8804
502	qC	78	136	1507	0	1643	757	185	942	484	29	0	513	1455	3098	2886	-	2886	5984
503	aC'	62	171	1393	30	1594	789	196	986	420	25	0	445	1431	3025	2294	432	2726	5751
504	rC	52	156	1383	0	1539	750	189	939	388	23	0	411	1350	2889	3224	-	3224	6113
505	zE	38	168	677	158	1003	732	190	922	316	19	316	651	1573	2376	1406	1386	2792	5268
506	pC	38	158	1061	0	1219	786	204	991	346	21	0	367	1358	2577	2964	-	2964	5541
507	gC'	38	179	976	20	1175	786	204	991	346	21	0	367	1358	2533	1406	432	1838	4371
508	aB	32	112	1109	0	1221	682	180	862	548	33	0	581	1443	2664	2368	-	2368	5032
509	bC	32	154	864	0	1018	773	204	977	326	20	0	346	1323	2341	1934	-	1984	4825
510	fC	32	161	941	0	1102	773	204	977	326	20	0	346	1323	2425	1888	-	1888	4313
511	gE	30	175	739	168	1082	791	210	1001	304	18	304	626	1627	2709	1110	1386	2496	5205
512	vC	30	170	973	0	1143	844	224	1068	364	22	0	386	1453	2596	4020	-	4020	6616
513	qB	28	120	1107	0	1227	686	183	870	524	31	0	555	1425	2652	2072	-	2022	4724
514	cC	28	172	939	0	1111	775	206	981	312	19	0	331	1312	2423	1876	-	1876	4299
515	cC	26	162	788	0	950	788	212	1000	322	19	0	341	1341	2291	1534	-	1534	3825
516	rC'	24	196	767	14	977	786	213	999	302	18	0	320	1320	2297	1488	252	1740	4037
517	pC'	18	205	647	14	866	832	231	1063	286	17	0	303	1366	2232	1404	252	1656	3888
518	bC'	20	198	672	16	886	814	224	1038	280	17	0	297	1335	2221	1240	252	1492	3713
519	dC	18	177	663	0	840	832	231	1063	286	17	0	303	1366	2206	1206	-	1206	3412
520	oC	18	188	738	0	926	807	224	1021	286	17	0	303	1334	2260	1800	-	1800	4060
521	rE	18	196	577	128	901	756	210	965	260	16	260	536	1501	2402	1116	1274	2390	4792
522	fC'	18	208	665	14	887	807	224	1031	286	17	0	303	1334	2358	1062	252	1314	4672
523	rB	18	133	891	0	1024	714	198	913	476	29	0	505	1417	2441	2232	-	2232	4673
524	eC'	16	212	630	148	990	836	235	1071	270	16	0	286	1357	2347	994	252	1196	3543
525	bE	16	202	556	124	882	781	219	999	248	15	248	511	1510	2392	992	1274	2266	4658
516	pE	16	206	574	126	906	781	219	999	248	15	248	511	1510	2416	1248	1274	2522	4938
527	bB	19	137	751	0	888	722	205	927	456	27	0	483	1410	2298	1736	-	1736	4034
528	pB	14	141	787	0	928	722	205	927	456	27	0	483	1410	2338	2184	-	2184	4522
529	eC'	14	218	584	14	816	822	233	1055	268	16	0	284	1339	2155	938	252	1190	3345
530	vC'	14	222	600	14	836	822	233	1055	268	16	0	284	1339	2175	1876	252	2128	4503
531	gC	14	191	600	0	791	822	233	1055	268	16	0	284	1339	2175	1400	-	1400	3575

Table 2-39. Program Cost Summary - Mission Set P, Contd

Nominal Traffic Model, Western Hemisphere and Atlantic Locations

Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Bus Costs: Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Payload Costs: Development: P/L SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: P/L Prod. $M	Payload Costs: Production: P/L IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Production: Total P/L Prod. $M	Payload Costs: Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Costs $M	Total Program Costs $M
532	nC	12	212	321	0	533	828	238	1066	270	16	0	286	1352	1885	1296	-	1296	3181
533	cE	12	213	469	106	788	772	222	994	250	15	250	515	1509	2297	708	1274	1982	4279
5[illegible]	dC	12	223	532	12	767	829	205	1034	274	16	0	290	1324	2091	804	252	1056	3147
535	fE	12	217	483	108	808	772	222	994	250	15	250	515	1509	2317	708	1274	1982	4299
536	cB	12	143	700	0	843	729	210	939	456	27	0	483	1422	2265	1416	-	1416	3681
537	fB	12	147	733	0	880	729	210	939	456	27	0	483	[illegible]	2302	1416	0	1416	3718
538	hC	10	210	522	0	732	844	247	1060	274	16	0	240	1381	2113	1050	0	1080	3193
539	cE	10	221	423	96	740	788	230	1018	252	15	252	219	1537	2277	670	1274	1944	4221
540	cB	10	154	671	0	825	741	216	957	464	28	0	492	1449	2274	1340	0	1340	3614
541	cC'	10	236	497	12	745	844	247	1090	274	16	0	290	1531	2126	1000	252	1252	3378
542	dE	10	219	418	94	731	788	230	1018	252	15	252	519	1537	2268	670	1274	1944	4212
543	vE	10	226	440	48	763	788	230	1018	252	15	252	519	1537	2300	1340	1274	2614	4914
544	vB	10	157	692	0	849	741	216	957	464	28	0	492	1449	2298	2680	0	2680	4978
545	dB	10	150	643	0	792	741	216	957	464	28	0	492	1449	2241	1340	0	1340	3581
546	gC'	10	230	477	12	719	844	247	1090	274	16	0	290	1381	2100	1000	252	1252	3352
547	nC'	8	259	479	12	750	841	250	1091	276	17	0	293	1354	2134	864	252	1116	3250
548	oE	8	244	414	94	752	786	234	1021	250	15	250	515	1536	2288	800	1274	3074	4362
549	oB	8	172	658	0	830	741	221	962	464	28	0	492	1453	2283	1600	0	1600	3883
550	lC	8	245	548	0	793	841	250	1091	276	17	0	293	1384	2177	992	0	992	3169
551	hC'	8	252	460	12	723	841	250	1091	276	17	0	293	1384	2107	864	282	1116	3223
552	gE	8	239	402	92	733	786	234	1021	250	15	250	515	1536	2269	800	1274	2074	4343
553	gB	8	167	630	0	797	741	221	962	464	28	0	492	1453	2250	1600	0	1600	3850
554	jC	8	236	518	0	754	841	250	1091	276	17	0	293	1384	2138	892	0	992	3130
555	nB	6	197	634	0	831	729	223	952	456	27	0	483	1435	2266	1296	0	1296	3562
556	nE	6	273	392	88	753	773	236	1010	248	15	248	511	1520	2273	648	1274	1922	4195
557	hB	6	192	610	0	802	729	223	952	456	27	0	483	1435	2237	1296	0	1296	3533
558	hE	6	268	381	86	735	773	236	1010	248	15	248	511	1520	2255	648	1274	1922	4177
559	jC'	4	321	370	12	703	829	253	1083	272	16	0	288	1371	2074	496	252	748	2822
560	lC'	4	327	380	12	719	829	253	1083	272	16	0	288	1371	2090	496	252	748	2838
561	kC	6	272	495	0	767	829	253	1083	272	16	0	288	1371	2138	1104	0	1104	3242
562	nC	4	314	425	0	738	847	268	1115	260	16	0	276	1391	2129	900	0	900	3029

Table 2-39. Program Cost Summary - Mission Set P, Contd

Nominal Traffic Model, Western Hemisphere and Atlantic Locations

Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Bus Costs: Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Payload Costs: Development: P/L SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: P/L Prod. $M	Payload Costs: Production: P/L IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Production: Total P/L Prod. $M	Payload Costs: Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Costs $M	Total Program Costs $M
563	jB'	4	221	524	0	745	947	237	983	436	24	0	462	1446	2191	992	0	992	3183
564	jE	4	303	323	74	699	791	250	1041	238	14	238	490	1532	2231	496	1148	1644	3875
565	lB	4	226	541	0	767	747	237	983	436	26	0	462	1446	2213	992	0	992	3205
566	lE	4	307	330	74	712	791	250	1041	238	14	238	490	1532	2244	496	1148	1644	3888
567	kC'	4	323	372	12	707	847	268	1115	260	16	0	276	1391	2098	736	232	988	3006
568	mC'	4	323	372	12	707	847	268	1115	260	16	0	276	1391	2098	736	232	988	3086
569	kB	4	221	524	0	745	747	237	983	436	26	0	462	1446	2191	1472	0	1472	3663
570	hE	4	303	323	74	699	791	250	1041	236	14	238	490	1532	2231	736	1148	1884	4115
571	mB	2	310	452	0	762	769	259	1028	396	24	0	420	1448	2210	900	0	900	3110
572	mE	2	407	273	64	744	816	275	1091	214	13	214	441	1332	2276	450	1148	1578	3874

Code: H d C' K P (12) q (16)

Description:

1. H – Launch Mode II. Single shuttle launch for mated OTV and platform.
2. d – Single stage OTV, expendable mode, low thrust engine (T/W = 0.07); P/L length = 26 feet. Mass capability to GEO is 6,895 kg, cost is $67M per flight (including shuttle).
3. C' –
   - Highly redundant; subsystems life designed for 16 years; (weight includes 29 percent penalty for triple redundancy over 8-year life subsystem design).
   - Eight year consumables capacity.
   - Serviceable as necessary during lifetime (mass of servicing items estimated by requiring consumables and all batteries to be replaced every eight years, plus a modest allowance for selected subsystems and payloads).
   - Payload total mass increased by 29 percent to allow either triple redundancy or modularity (some payloads will incorporate neither; others may incorporate both).
   - Payload update through launch of new modules and as part of servicing flights (user option).
4. K – Platforms fly in formation; interconnectivity is provided by interplatform links.
5. P – Nominal traffic model; both Western Hemisphere and Atlantic locations.
6. (12) – Twelve platforms accommodate the total payload set (6 for Western Hemisphere and 6 for Atlantic).
7. q – Servicing provided using OTV q (1 stg., single shuttle flight, reusable mode); mass delivery capability is 1169 kg per flight if OTV and TMS are both reused. Cost is $39M/flight.
8. (16) – Number of servicing flights planned over the 16 year mission duration.

264.352-41

Figure 2-18. Operational Platform Concept Definition - Alternative #1

Code: II d C' J P (8) q (12)

Description:

1\. II – Launch Mode II. Single shuttle launch for mated OTV and platform module.

2\. d – Single stage OTV, expendable mode, low thrust engine (T/W = 0.07); P/L length = 26 feet. Mass capability to GEO is 6,895 kg; cost is $67M per flight (including shuttle).

3\. C' –
- Highly redundant; subsystems life designed for 16 years; weight includes 29 percent for triple redundancy over 8-year life subsystem design).
- Eight year consumables capacity.
- Serviceable as necessary during lifetime (mass of servicing items estimated by requiring consumables and all batteries to be replaced every eight years, plus a modest allowance for selected subsystems and payloads).
- Payload total mass increased by 29 percent to allow either triple redundancy or modularity (some payloads will incorporate neither; others may incorporate both).
- Payload update through launch of new modules and as part of servicing flights (user option).

4\. J – Platform modules are physically docked at GEO; interconnectivity is provided by hardwire. Subsystems are shared between modules.

5\. P – Nominal traffic model; both Western Hemisphere and Atlantic locations.

6\. (8) – Eight platform modules accommodate the total payload set (4 for Western Hemisphere and 4 for Atlantic).

7\. q – Servicing provided using OTV q (1 stg., single shuttle flight, reusable mode); mass delivery capa[illegible]ty is 1169 kg per flight if OTV and TMS are both reused. Cost is $[illegible]M/flight.

8\. (12) – Number of servicing flights planned over the 16 year mission duration.

264.352-42

Figure 2-19. Operational Platform Concept Definition - Alternative #2

Code: III j E K V (6) e (16)

Description:

1. III – Launch Mode III. Multiple shuttle launches. The OTV and platform are mated in LEO.

2. j – Two stage OTV, reusable mode, low thrust engine (T/W = 0.03), P/L length = 60 feet. Mass capability to GEO is 16,878 kg; cost is $124M per flight (including shuttle).

3. E –
   - Subsystems life designed for 8 years; (weight includes 12-1/2 percent penalty for dual redundancy and modularity for on-orbit servicing).
   - Three year consumables capacity.
   - Serviced at intervals ≤ 3 years (mass of servicing items estimated by requiring batteries, subsystem modules and payloads to be replaced once during 16 year lifetime).
   - Payload total mass increased by 12-1/2 percent to allow for dual redundancy and modularity.
   - Payload update through servicing flights.

4. K – Platforms fly in formation; interconnectivity is provided by interplatform links.

5. V – High traffic model; both Western Hemisphere and Atlantic locations.

6. (6) – Six platforms accommodate the total payload set (3 for Western Hemisphere and 3 for Atlantic).

7. e – Servicing provided using OTV e (1 stg., single shuttle flight, expendable mode); mass delivery capability is 5629 kg per flight if OTV and TMS are both expended. Cost is $99M/flight.

8. (16) – Number of servicing flights planned over the 16 year mission duration.

264.352-43

Figure 2-20. Operational Platform Concept Definition - Alternative #3

Code: III ℓ C' J V (5) q (16)

Description:

1. III – Launch Mode III. Multiple shuttle launches. The OTV and platform module are mated in LEO.
2. ℓ – Two stage OTV, reusable mode, standard engine (T/W = 0.31), P/L length = 60 feet. Mass capability to GEO is 19,505 kg; cost is $124M per flight (including shuttle).
3. C' –
   - o Highly redundant; subsystems life designed for 16 years; (weight includes 29 percent penalty for triple redundancy over 8-year life subsystem design).
   - o Eight year consumables capacity.
   - o Serviceable as necessary during lifetime (mass of servicing items estimated by requiring consumables and all batteries to be replaced every eight years, plus a modest allowance for selected subsystems and payloads).
   - o Payload total mass increased by 29 percent to allow either triple redundancy or modularity (some payloads will incorporate neither, others may incorporate both).
   - o Payload update through launch of new modules and as part of servicing flights (user option).
4. J – Platform modules are physically docked at GEO; interconnectivity is provided by hardwire. Subsystems are shared between modules.
5. V – High traffic model; both Western Hemisphere and Atlantic locations.
6. (5) – Five platforms accommodate the total payload set (3 for Western Hemisphere and 2 for Atlantic).
7. q – Servicing provided using OTV q (1 stg., single shuttle flight, reusable mode); mass delivery capability is 1169 kg per flight if OTV and TMS are both reused. Cost is $39M/flight.
8. (16) – Number of servicing flights planned over the 16 year mission duration.

264.352-44

Figure 2-21. Operational Platform Concept Definition – Alternative #4

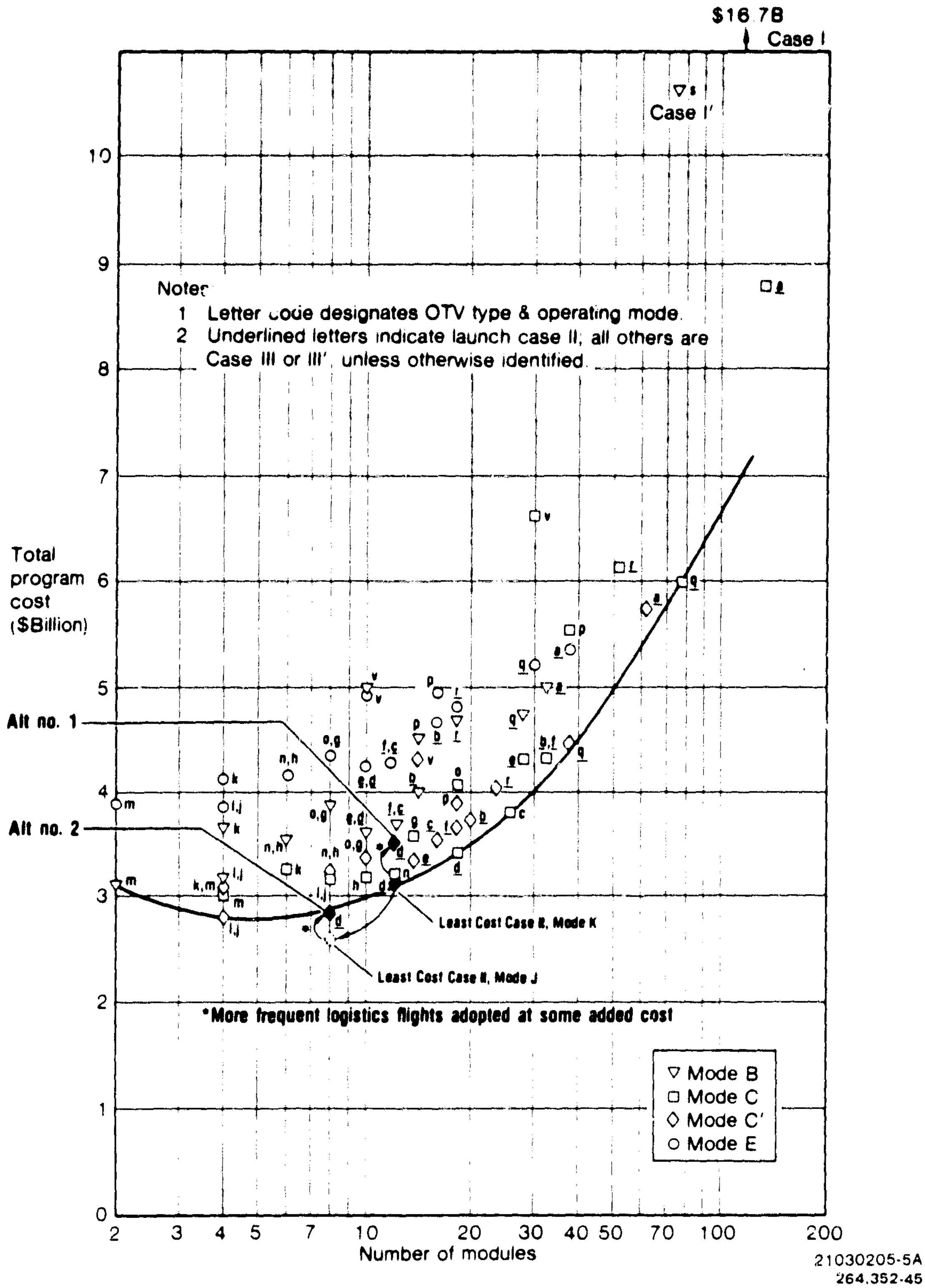

Figure 2-22. Cost Comparison - Mission Set P

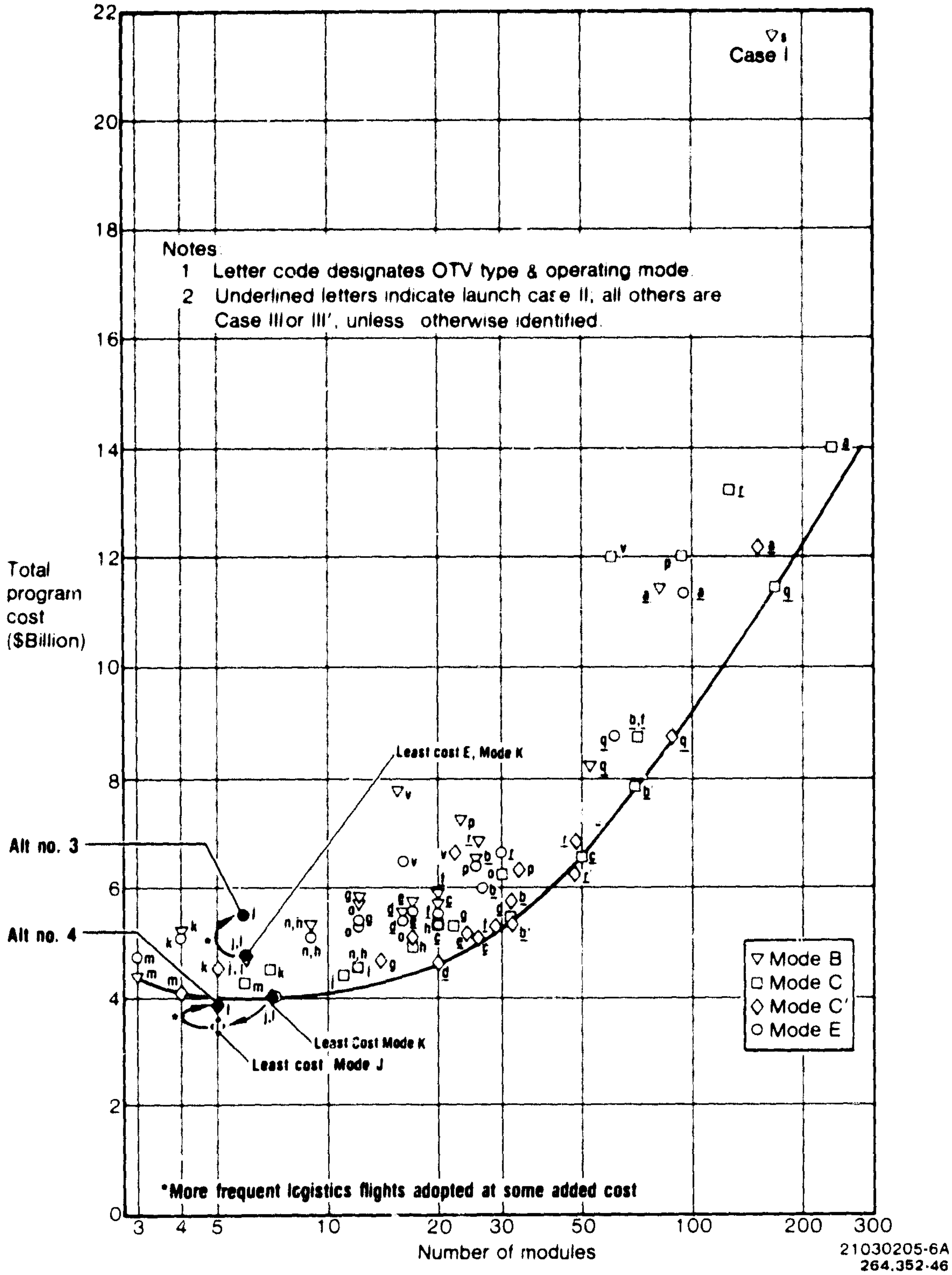

Figure 2-23. Cost Comparison - Mission Set V

Table 2-40. Preliminary Program Costs, Alternatives #1 through #4

Alt. No.	Item	Bus Type	No. of Platforms	Bus Costs: Total Devel. $M	Bus Costs: Total Prod. $M	Bus Costs: Bus Servicing Items $M	Bus Costs: Total Bus Costs $M	Payload Costs: Development: P/L Devel. $M	Payload Costs: Development: P/L SE&I $M	Payload Costs: Development: Total Devel. $M	Payload Costs: Production: P/L Prod. $M	Payload Costs: Production: P/L IA&CU $M	Payload Costs: Production: Servicing Items $M	Payload Costs: Production: Total P/L Prod. $M	Payload Costs: Total P/L Costs $M	Total Platform Costs (Bus & P/L) $M	Transportation Costs: Launch Costs $M	Transportation Costs: Servicing Flight Costs $M	Transportation Costs: Total Transportation Costs $M	Total Program Costs $M
1	401	40 dC' (II dC' kP 12 q 16)	12	223	532	12	767	829	205	1034	274	16	0	290	1324	2091	804 (13 × 61)	624 [16 × (37 + 21]	1428	3519
2	402	dC' (II dC' JP 8 q 12)	8	323	318	8	649	783	175	958	235	14	0	249	1207	1856	536 (8 × 67)	468 [12 × (37 + 21]	1004	2860
3	403	65 jE (II j E k v 6 e 16)	6	344	563	126	1038	1341	172	1513	298	18	296	614	2127	3165	744 (6 × 124)	1584 [16 × (67 + 321]	2328	5493
4	404	99 IC' (III 1 C' J V 5 q 16)	5	433	430	21	884	1277	166	1443	294	18	0	312	1764	2648	620 (5 × 124)	624 [16 × (37 + 21]	1244	3892

Table 2-41. Trade Study Results Summary

Platforms enjoy significant economic advantage over individual satellites.

Platforms represent a logical extension of current trends toward larger, more complex, multifrequency satellites.

Shuttle-optimized platform design greatly reduces transportation costs.

High energy orbit transfer vehicles maximize transportation economies.

- Reusable, 2-stage OTV yields lowest absolute program costs.
- Significant economy of scale can be achieved with single shuttle launched platforms.

Extended life through high reliability components, redundancy, and limited automated revisit has economic advantages.

Limited automated revisit is beneficial.

- Replenish consumables.
- Exchange predictable wearout components.
- Update payloads; add capacity to match demand and growth.

set of larger size platforms accommodating the mission model, and through use of larger, more economical orbit transfer vehicles (OTV).

The platform (bus plus payload) costs are relatively constant over about 75 percent of the size range evaluated. For example, Figure 2-24 shows that 54 of the 73 concepts evaluated for the high traffic model are within the \$3 to \$3.5B range. The biggest variable in total program costs was in the transportation (launch and servicing) costs. Therefore, platform economy of scale can be compounded by optimizing platform designs for the larger OTVs, which have a lower specific cost, i.e., dollars per kilogram of payload delivered to GEO.

The very significant cost advantage of platforms versus individual satellites is also illustrated in Figure 2-24. Approximately 28 percent of the concepts shown have total program costs that are less than 1/4 the individual satellite (I/S) costs.

Although the large, two-stage reusable OTV promises the lowest absolute total program cost in operational mode C', the single stage expendable OTV is very cost competitive when used in the single Shuttle launch per platform mode (mode II). Figure 2-25 illustrates the relatively small differential in program costs for these two concepts.

One clear output of this study is that OTV reusability, either for delivery or servicing, is only economical with large, two-stage vehicles. Single-stage vehicles are in every case more expensive in the reusable mode than in the expendable mode. Reusability will, of course, be required for other than economic reasons - satellite retrieval and manned operation for example. But economic advantages should not be expected for vehicles with delivery capability from LEO to GEO of less than about 10,000 kg in the reusable (OTV returns empty) mode.

Operational mode C' (16 year subsystem life with consumables resupplied at 8 years) yielded the lowest program costs. Although weight/cost penalties are incurred to obtain redundancy and longer life, the reduced transportation costs more than outweigh the penalties and yield an overall economic advantage.

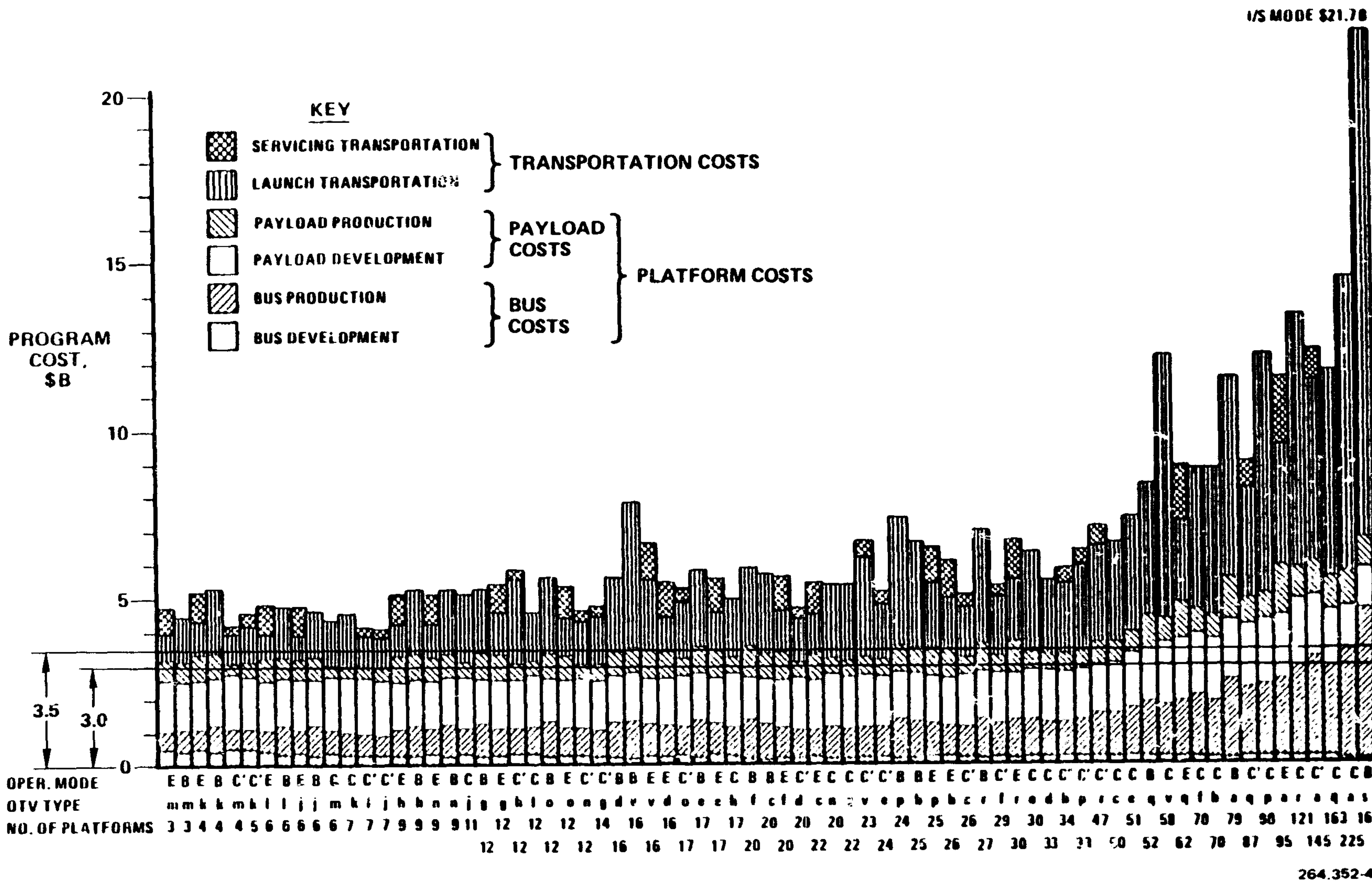

Figure 2-24. Platform (Bus Plus Payload) Cost Uniformity

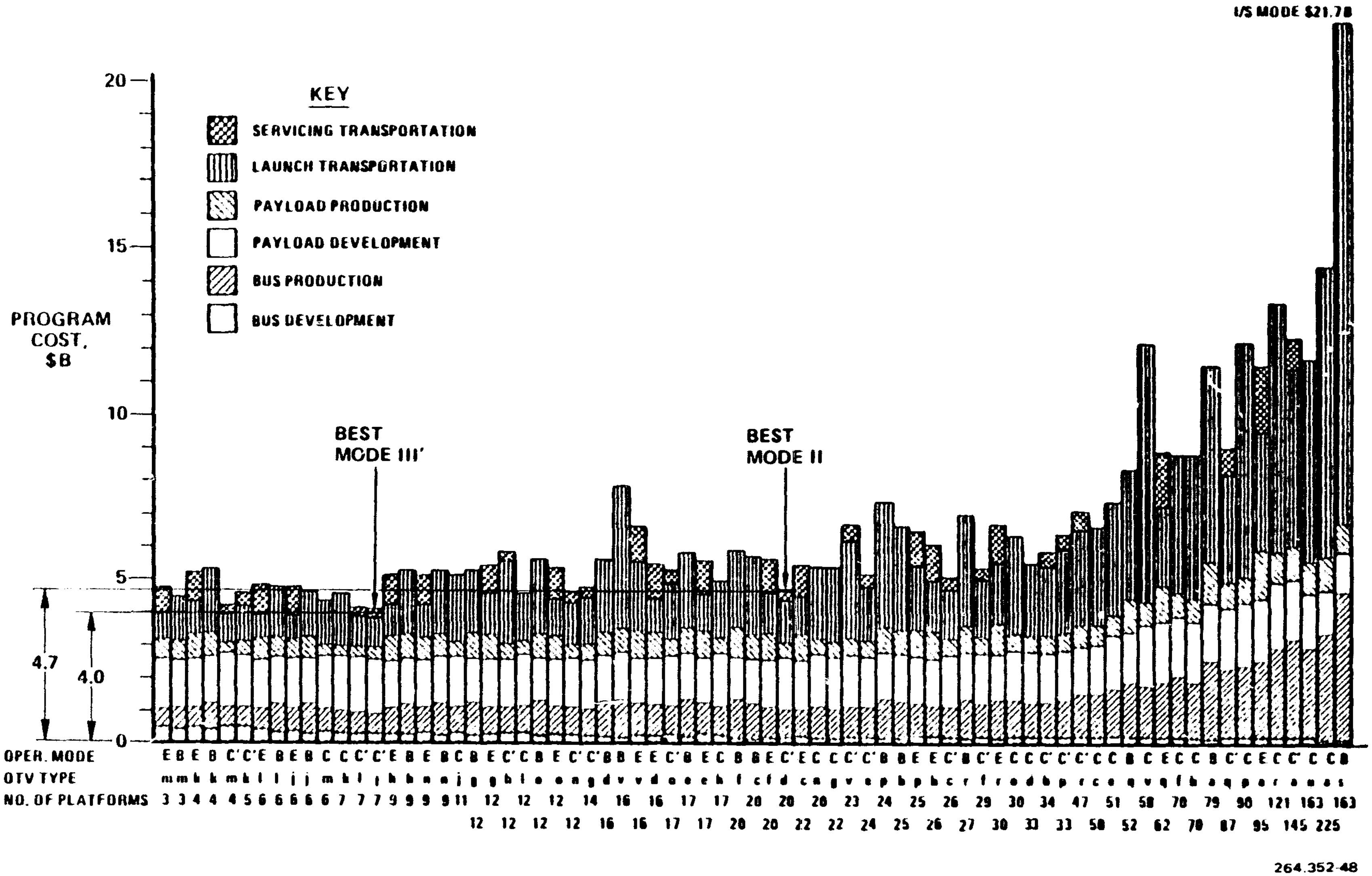

Figure 2-25. Mode II Versus Mode III'

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