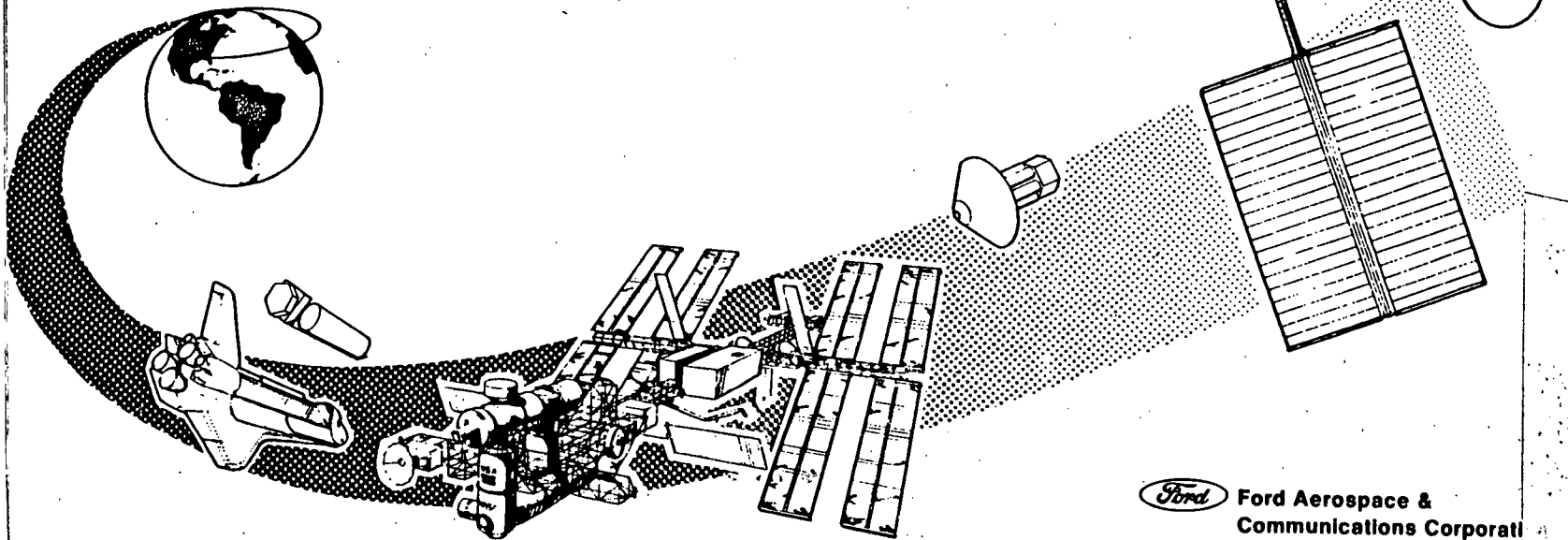


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COMMUNICATION PLATFORM PAYLOAD DEFINITION STUDY FINAL REPORT

VOLUME I
EXECUTIVE SUMMARY
MARCH 1986

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 Ford Aerospace &
Communications Corporation

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1.0 OVERVIEW

1.1 Purpose

This study was accomplished by Ford Aerospace & Communications Corporation in support of the NASA Communications Platform Payload Definition (CPPD) Study Program.

This program consists of two parallel payload studies sponsored by NASA Lewis-Research Center (LeRC) and two parallel studies under the sponsorship of NASA Marshall Space Flight Center (MSFC) to examine the non-communications aspects of a large geostationary facility in the mid- to late 1990's.

The specific goals of the payload study were to: (1) determine the types of communications payloads that would be appropriate for a large geostationary facility initially operational in the late 1990's; (2) provide conceptual designs and descriptions of, and intercomparisons between such payloads when implemented on a single spacecraft; (3) provide indications as to the enabling and supporting high risk technology development efforts required for their implementation; and (4) produce a report detailing the foregoing efforts.

The study established a data base of prior geostationary platform study efforts and evaluated the impacts of new traffic forecasts, regulatory changes and updated institutional information on their results. The aggregation of services and the resulting payloads were to provide NASA with guidance to answering the following questions:

*See Section 2.2

- o Is the existence of one or more large scale geostationary facilities, each consisting of a payload providing a single communications service or a variety of communications services, desirable in the mid to late 1990's?
- o If so, what are the most viable operational systems (payload, spacecraft, transportation, and space operations) for that time frame?
- o For those operational systems, what enabling and supporting technologies are required prior to implementation and, in particular, which of those technologies is of high technical and/or economic risk?

1.2 Approach

The study was organized into the following orderly sequence of tasks:

- Task 1: Assemble a data base consisting of traffic models, market forecasts, technology forecasts, criteria for selection of aggregation scenarios and evaluation of payload concepts, and cost estimating methodology to be used for the remainder of the study tasks. Task 2: Using the data base and criteria, select at least six service aggregation scenarios for development and evaluation. Task 3: Develop a payload concept for each of four* of the service aggregation scenarios developed in Task 2.

* See Section 2.2.



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- Task 4: Develop four* detailed payload system configurations, and define the payload to the component level.
- Task 5: Provide system cost estimates and identify cost drivers for the payload configurations.
- Task 6: Identify both enabling and supporting technologies critical to the eventual implementation and operation of each of the concepts.
- Task 7: Provide system comparisons between the communications payloads.

The output documentation of this study consists of Volume I Executive Summary, Volume II Final Technical Report, and Volume III Addendum to Final Report.

1.3 Major Findings

The major findings of the study were: (1) Although satellite traffic is not growing at the rate some of the earlier studies projected, it is in fact increasing. (2) The use of ISL's (Inter-satellite Links) to link high capacity east and west satellites over CONUS did not appear attractive because of the ISL's required high capacity. (3) Large capacity communications platforms appear to be economically sound for reducing cost per equivalent capacity. (4) The highest payoff technology development item identified is a method of polarization tracking at Ka-band to maintain isolation during rainstorms. This would allow simultaneous reuse of the entire 2.5 GHz bandwidth from high traffic density areas.

* See Section 2.2

1.4 Selected Concepts

The study describes five scenarios which provide an increasing capability to serve projected Region 2 traffic. Briefly, these scenarios are:

- o A medium capacity CONUS FSS and medium power DBS capability. (Scenario II)
- o A high capacity CONUS FSS capability. (Scenario V)
- o A large capacity medium and high power video distribution and broadcast satellite. (Scenario IV)
- o A complementary pair of satellites with a high capacity CONUS FSS payload, and incorporating ISL's to "European" and "Asian" platforms to carry all Region 2 international traffic, plus providing all non-U.S. domestic and maritime coverage in the Western Hemisphere. (Scenarios VI-A and VI-B)

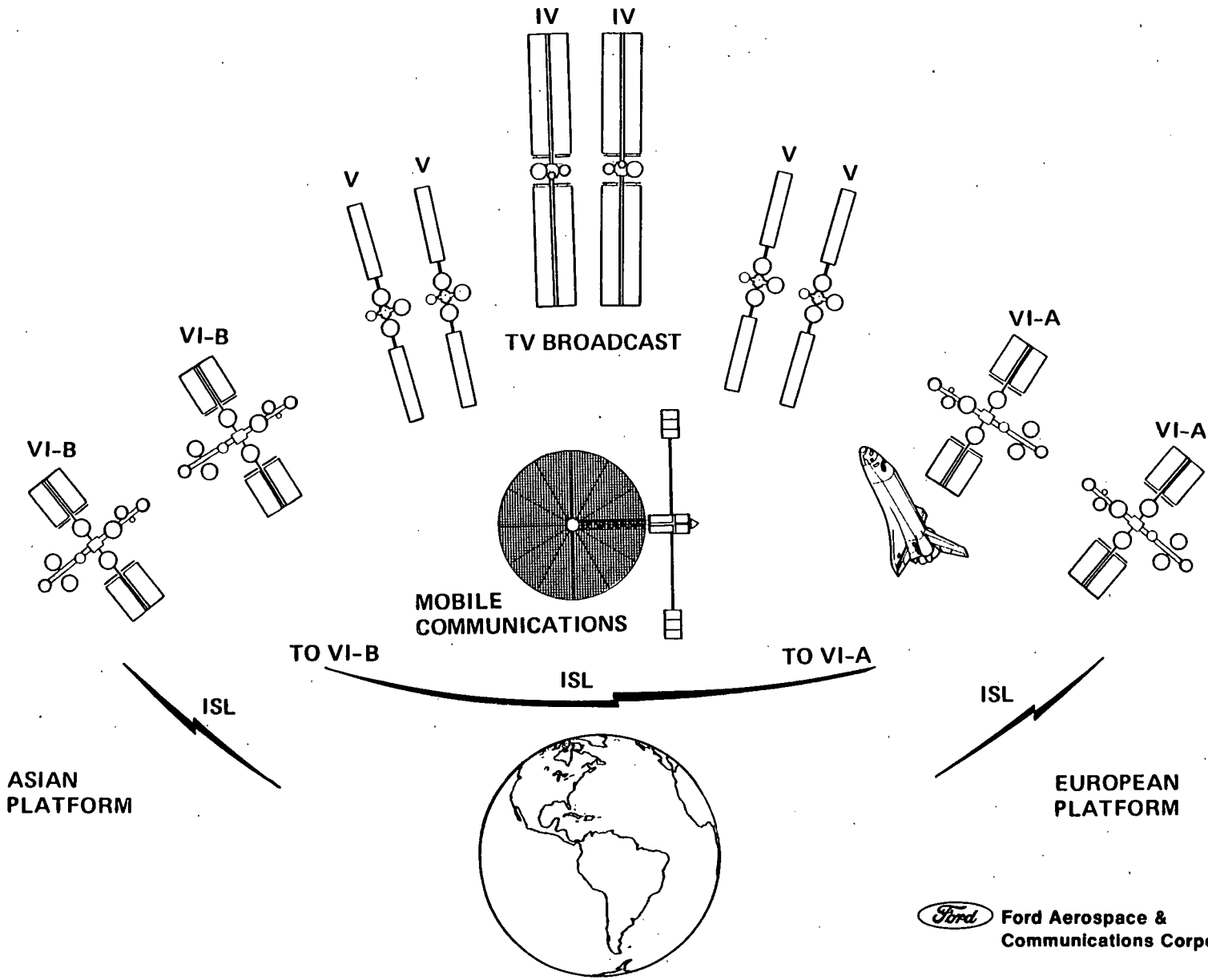
1.5 Future Region 2 Network

Figure 1 below shows a possible constellation of eleven large platforms that would accommodate all of the WARC Region 2 projected traffic in the year 2008. The constellation is comprised of two each Scenario VI-A and VI-B satellites that provide the 2 for 1 sparing of capacity for international and regional services; four Scenario V satellites, that with the CONUS package on the VI-A and VI-B satellites provide all of the CONUS capacity; two of the Scenario IV video distribution satellites for Region 2 and a mobile communications satellite to operate in the northern hemisphere of Region 2. This constellation would exist at saturation in the year 2008.



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Figure 1 FUTURE NETWORK OF PLATFORMS FOR REGION 2



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2.0 DATA BASE DEVELOPMENT

As part of the data base development task, traffic forecasts and distribution models for all of Region 2 were established.

2.1 Traffic Forecasts

Several satellite demand forecasts have indicated a growing pressure on arc/spectrum resources. More efficient use of this scarce resource will be required to meet projected demands in the year 2000 and beyond. In addition, economic pressure from terrestrial systems such as fiber optics will require a significant reduction in per-circuit costs in order for satellite systems to remain competitive, especially for point-to-point high density routes.

A potential solution to these problems is the use of large geostationary platforms which can provide significant improvement in the communications capacity of an orbital slot as well as economies of scale. These improvements are obtained through a high degree of frequency reuse at multiple bands - C, Ku, and Ka - and by aggregating multiple payloads -- e.g. FSS, DBS and International -- on a single platform.

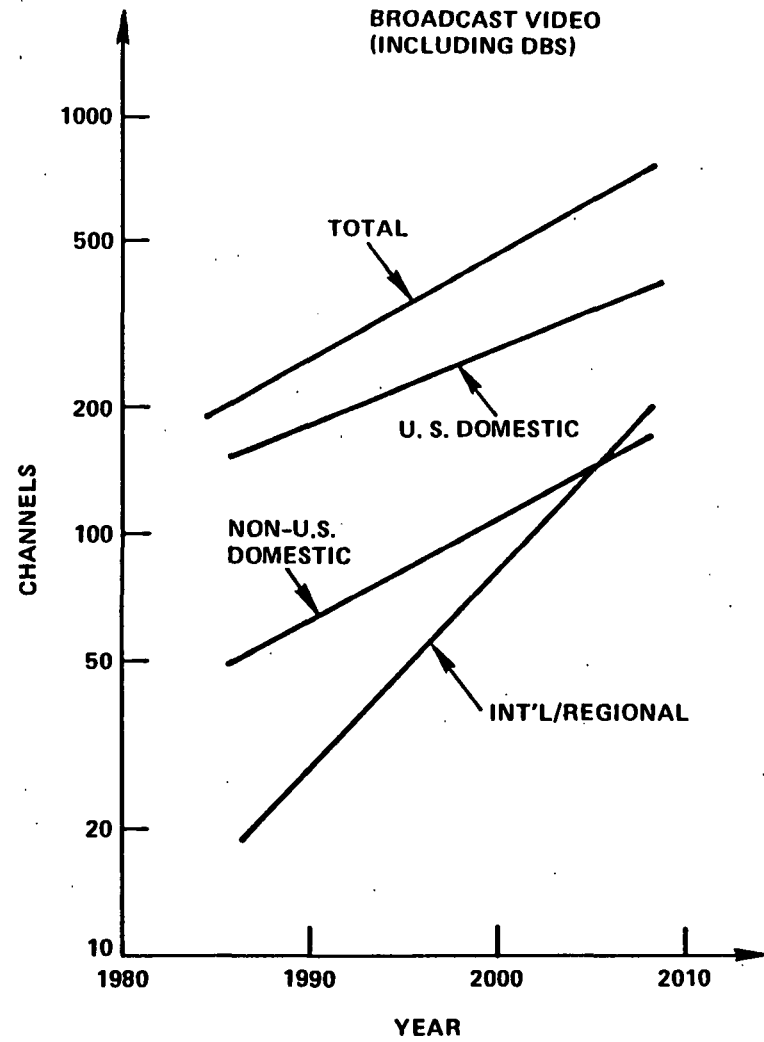
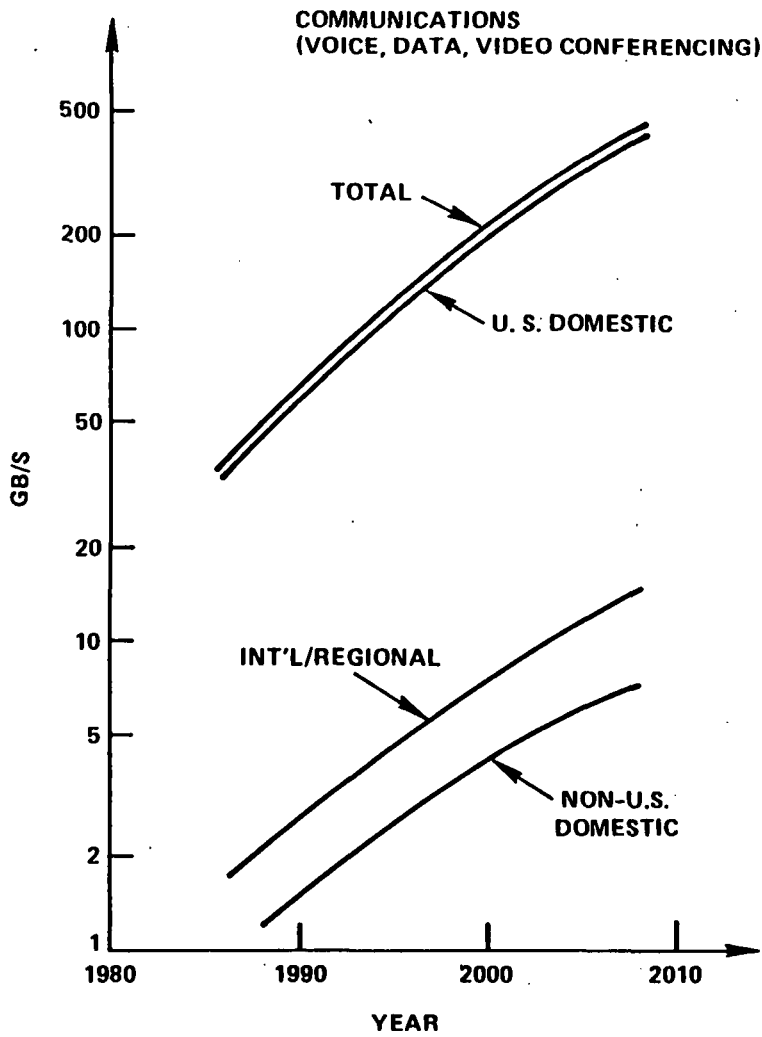
Overall, traffic demand is growing and will continue to grow over this time frame of interest. The actual rate at which it will grow is and always will be a question that is difficult to answer. The forecasts used in the study are identified below with the resulting summary graphs shown in Figure 2.

Traffic forecasts used in the study utilized the NASA synthesis (Ref. 1) of Western Union (Ref. 2 & 3) and ITT (Ref. 4) studies, Intelsat forecasts (Ref. 5), and various sources for non-U.S. domestic requirements. Growth rates in the different categories for the period 2000-2008 were estimated. All traffic loadings utilized were relative to year 2008 based on an assumed 10 year life and 1998 launch date.

The traffic forecasts show that communications services (voice, data and video conferencing) dominate broadcast video. Within communications services, U. S. domestic requirements account for most of the total. The distribution of U. S. domestic traffic is skewed significantly to the Northeast and Midwest areas. This complicates the design of payloads which use a high degree of frequency reuse to increase the capacity provided by a single orbital slot.



Figure 2 WARC REGION 2 TRAFFIC FORECASTS



2.2 Guidelines and Constraints

The study was conducted on the basis that the payloads would be launched in 1998 as an operational system. Therefore, the use of 1994-mature technology was assumed to allow a four year development period for the platform. The system was to provide a minimum 10 years on-orbit life and not require any in-orbit payload assembly to achieve the mission. The system should also conform to "anticipated" regulatory requirements.

The scenarios to be developed were to consider at least two "baseline" and two "variation" payloads as defined in Table 1. A minimum of six service aggregation scenarios were to be developed. In fact, eight scenarios were provided to NASA for selection. From the service aggregation scenarios evaluated, four were to be recommended by FACC to NASA for development. FACC recommended four scenarios, II, IV, V and VI-A, to meet all the study constraints. NASA elected to add development of a fifth scenario, scenario VI-B. This scenario completes the complementary pair of payloads developed as scenarios VI-A and VI-B. These two payload scenarios handle all the international and regional communications for all of WARC Region 2

and also provide a high capacity CONUS FSS service.

An additional constraint on the study was that of the four scenarios to be developed, two were to be compatible with launch concept 1 and two with launch concept 2, defined as follows:

Launch Concept 1: Up to a maximum single shuttle launch of combined spacecraft and upper stage, with a spacecraft weight of up to 12,000 pounds.

Launch Concept 2: Allows a separate spacecraft (without upper stage) of size and weight up to a full shuttle launch capability (65,000 pounds).

After the five scenarios were selected for development, the detailed concept development and definition proceeded.



Table 1 BASELINE AND VARIATION SCENARIO REQUIREMENTS

Communications service aggregation scenario baseline requirements

- Up to CONUS coverage
- Domestic FSS and DBS services (only)
- C/Ku/Ka frequency bands

Service aggregation scenario requirements variations

- Service coverage area up to entire Western Hemisphere
- Additional services: mobile (land, sea, air), data collection
- C/Ku/Ka and other frequency bands
- Intersatellite link capability to international satellites or other non-U.S. satellites or platforms.



2.3 Approach to Payload Concept Development

All traffic forecasts were established as computer data bases so that a set of programs could be used in developing payload concepts. Additional programs to process the NASA-provided 316X316 SMSA distribution tape, were developed.

The traffic forecasts can be manipulated in several ways. For example, the original 316X316 matrix was reduced to a 20X20 matrix for traffic between the twenty Ka-band fixed spot beams. A given distribution matrix could be used to generate forecasts for voice, data, etc.

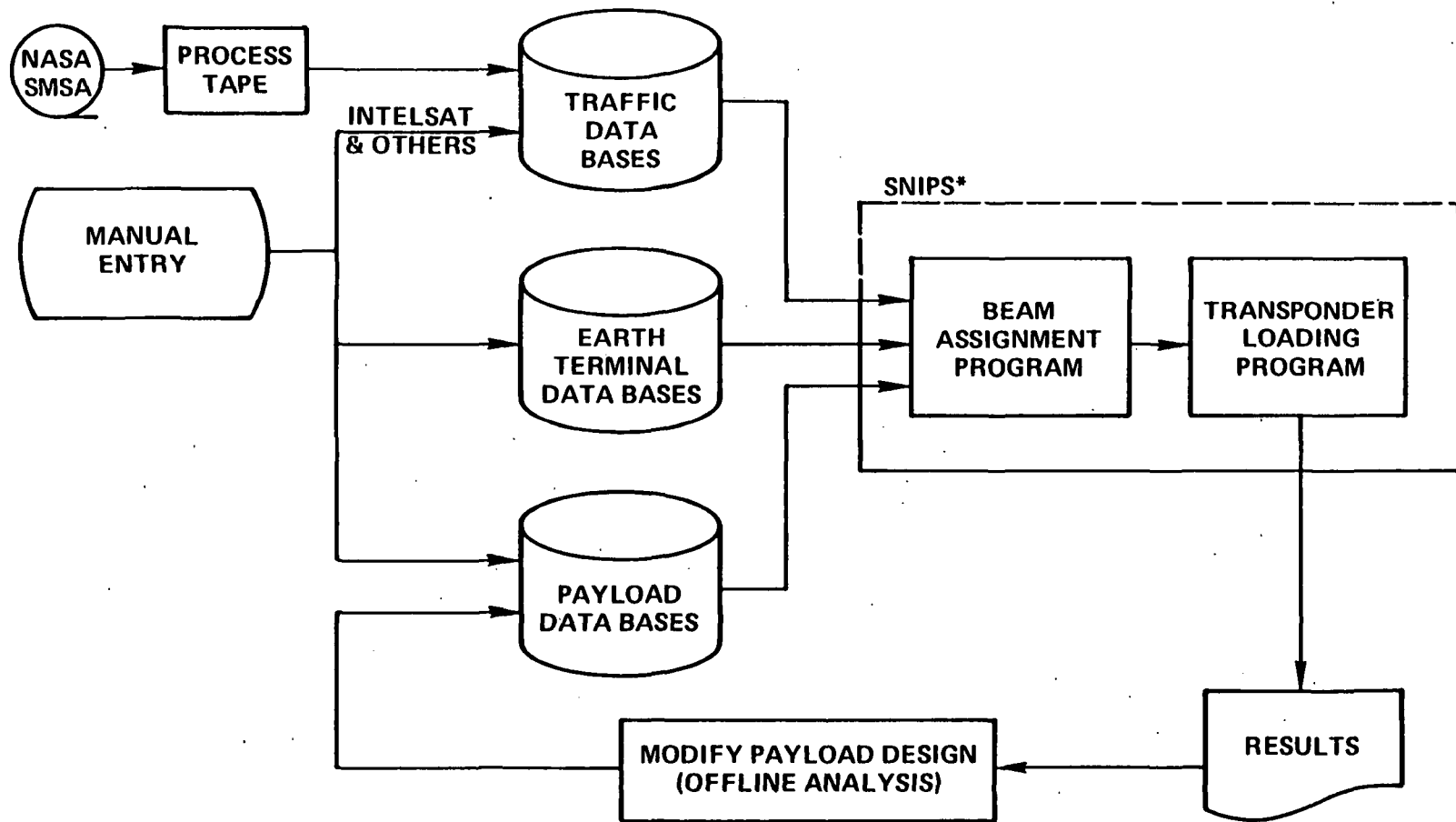
The earth station data base is a file of earth stations that will be operating with the payload being evaluated. The capabilities (such as frequency bands and access/modulation type) of each earth station are also contained in this data base. A spacecraft payload data base is required, consisting of such elements as beam coverages, transponders, and connectivity capabilities.

The system, called Satellite/Network Integration Planning System (SNIPS), consists of two interac-

tive computer programs. The first program translates point-to-point traffic to a set of beam-to-beam traffic matrices by type (modulation, frequency band, etc.). The second program utilizes a combination of user input from the terminal and an optimization routine. The information the user must supply is how each transponder is operated (e.g., FDMA, TDMA) and the interconnection or switching of transponders, including SS-TDMA. A maximal flow algorithm is used to find the optimum loading using the set of beam-to-beam matrices discussed above. Outputs are available at the terminal which guide the user in determining a better transponder usage and interconnect plan. These outputs include such items as transponders with low fill, or unsatisfied demands. This iterative process continues until the traffic satisfied is maximized. The final output gives the complete loading and can be used to evaluate the efficiency of a particular payload design. Based on this evaluation, the earth station or spacecraft data bases can be altered and the process repeated. A flow diagram depicting the above process is shown in Figure 3.



Figure 3 APPROACH TO DEVELOPING PAYLOAD CONCEPTS



*SATELLITE/NETWORK INTEGRATION PLANNING SYSTEM

3.0 PAYLOAD CONCEPT DESCRIPTIONS

Once the concepts were approved for development to handle the scenario for the types of service, modulation and access, and coverage areas, more detailed definition of the five payloads was performed:

3.1 Overview

The study describes five scenarios which provide an increasing capability to serve projected Region 2 traffic.

Each of the five selected scenarios was reduced to a simplified block diagram. The simplified block diagram and the required coverages were then provided to the antenna, transponder and baseband processing subsystem organizations for development of the block diagram to the component level. These organizations provided weight and power estimates for 1984 and 1994 technology. They also provided inputs to the cost modeling. From this data an estimate of the total payload weight was established. The total platform weight was

estimated based on standard rules of thumb discussed later.

The first three scenarios are sized such that the platform (payload and bus), upper stage and fuel can be carried to low earth orbit (LEO) with a single shuttle launch; the last two scenarios would require multiple shuttle launches with in-orbit assembly and/or fueling at the Space Station or GEO servicing. The currently planned versions of OTVs could be used as a transfer stage for all of the scenarios.

Table 2 is a summary of the scenario configurations showing the types of service, class of service, coverage area and estimate of transition from a single shuttle launch to larger payloads which require assembly of platform or transfer stages in space, or fueling at LEO.

Each of the five scenarios is subsequently defined in more detail.



Table 2 SUMMARY OF SCENARIO CONFIGURATIONS

	DIRECT BROADCAST	COMMUNICATIONS			OTHER SERVICES
		C-BAND	Ku-BAND	Ka-FIXED Ka-SCAN	
II	MED # CHAN MED POWER	CONUS	CONUS	CONUS	
IV	HIGH # CHAN HIGH POWER		CONUS		
V		CONUS	CONUS	CONUS	
TRANSITION TO ----- LARGE PLATFORMS					
VI-A		CONUS & INT'L	CONUS	CONUS	MARITIME PAYLOAD WESTERN ATLANTIC INTERSATELLITE LINKS INTELSAT AOR
VI-B		REGION 2 NON-CONUS	CONUS. & REGION 2	CONUS	MARITIME PAYLOAD EASTERN PACIFIC INTERSATELLITE LINKS INTELSAT POR

3.2 Scenario II

Scenario II can be described as a transition satellite containing current conventional, two times re-use C-band and three times re-use Ku-band payloads. In addition, it provides a high capacity Ka-band fixed and scanning beam payload and an introductory level Ku-band DBS payload. The services provided are listed below:

- o 24 channels, 36 MHz, standard C-band FSS payload, 2 times re-use
- o 24 channels, 54 MHz, standard Ku-band FSS payload, 3 times re-use
- o 20 beams, 38 channels, 500 MHz, Ka-band FSS trunking payload, 7.6 times re-use
- o 6 area scan beam, 18 channels - 240 MHz, and 14 channels - 500 MHz, Ka-band CPS/thin route trunking, 5.76 times re-use
- o 16 channels, 24 MHz, Ku-band, DBS payload, 2 beams, 8 channels each

The satellite is primarily intended as a Fixed Satellite Service (FSS) satellite although it also contains a Direct Broadcast Satellite (DBS) payload. The payload would require an 87% digital traffic base to effectively utilize the Ka-band capacity. Given the projected digital traffic in the 60-70% range this satellite would only be usable for the transition phase to some subsequent configuration presented in this study.

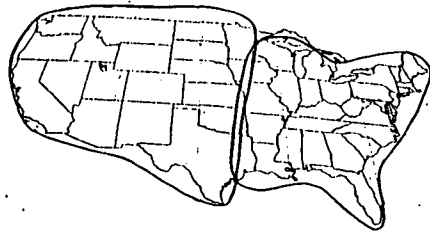
Even with the high capacity Ka-band, this is the lowest capacity satellite considered in this study.

Figure 4 below presents a summary of the coverage areas, capacities, weight and power of the DBS and FSS payloads. This combination of payloads puts severe limitations on its orbital location since currently only 101° and 110°W longitude are compatible for all the payloads. This location constraint is primarily a regulatory one and could possibly be changed if significant economic benefit could be shown.



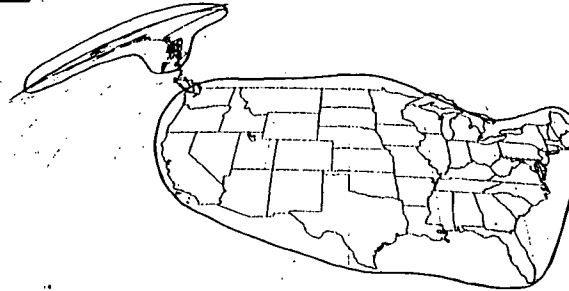
Figure 4 SCENARIO II – SERVICES ALLOCATION

DIRECT BROADCAST - 16 CHANNEL

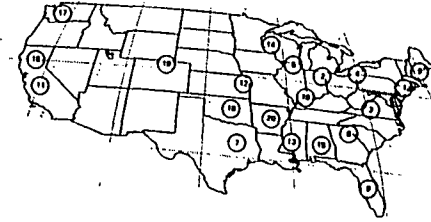


**Ku: 100 W PER CHANNEL OF 24 MHz
MEDIUM POWER**

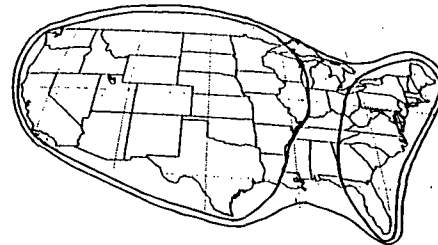
COMMUNICATIONS - 65 Gb/s



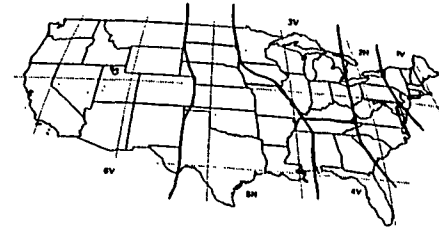
**C-BAND: 24 CHANNEL OF 36 MHz
(1.7 Gb/s)**



**Ka FIXED: 20 BEAM
38 CHANNEL OF 500 MHz
(38 Gb/s)**



**Ku: 24 CHANNEL OF 54 MHz
(2.6 Gb/s)**



**Ka SCAN: 6 AREAS
18 CHANNELS OF 240 MHz
14 CHANNELS OF 500 MHz
(23 Gb/s)**

POWER: 3,900 watts

MASS: 223 kg

POWER: 8814 watts

MASS: 1,841 kg

**COMMUNICATIONS PAYLOAD
OF ~ 2064 kg
12714 watts**

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3.3 Scenario IV

Scenario IV can be described as a high capacity, high power video distribution satellite containing a current design replacement payload at the Ku-band FSS and a new direct-to-home Ku-band DBS payload. Each payload is broken down to 24 MHz bandwidth channels to allow interconnectivity between bands for on-board networking. The services provided are listed below:

- o 48 channels, medium power, Ku-band, FSS payload
 - 3 beams - 1 CONUS & 2 regional CONUS
 - 16 channels per beam
 - 3 times re-use
- o 64 channels, high power, Ku-band, DBS payload
 - 4 beams - approx. time zone coverage
 - 16 channels per beam
 - 4 times re-use
- o Interconnectivity for half the channels from FSS to DBS.

The on-board interconnectivity for half of the channels provides the networking necessary for a broadcast mode, one uplink to all downlinks or one uplink to each downlink. This flexibility eliminates the switching for local identification and advertising in national broadcasts, and also

allows ground users to have only one antenna for both cable and direct-to-home distribution on only one satellite.

The satellite would have to be considered as a national resource for video distribution and would take a consortium of major networks, cable companies, and other operators to utilize the total capacity of the satellite.

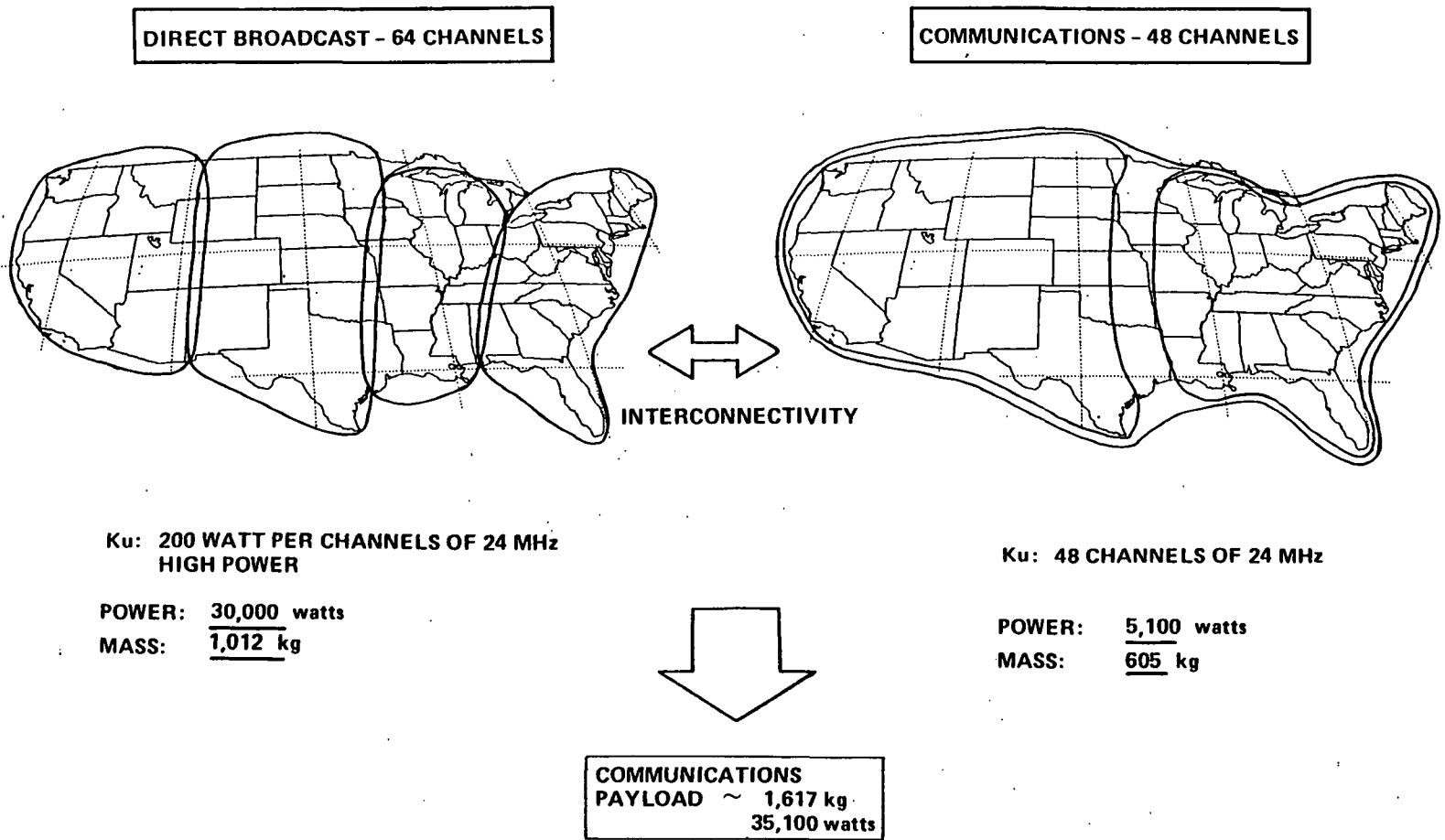
Figure 5 below presents a summary of the coverage areas, capacities, weight and power of the DBS and FSS payloads. This combination of payloads puts limitations on its orbital positioning since currently only 101° and 110°W longitude are compatible locations for both the payloads.

The beam designs for this satellite attempt to provide uniform flux densities over the coverage areas.

Because of the high power direct-to-home DBS payload, the overall power requirements for this platform are significantly higher than for any of the other platform scenarios of comparable weight. This characteristic makes this platform unique compared to the other platform scenarios.



Figure 5 SCENARIO IV – SERVICES ALLOCATION



3.4 Scenario V

This scenario has many features in common with Scenario II -- in fact the Ka-band payload is identical. The frequency reuse of Ku-band FSS and C-band payloads has been significantly increased. Scenario II provided a poor balance between serving analog vs. digital users. The vast majority of the bandwidth is at Ka-band, which requires the terminal to use digital modulation because of the SS/TDMA switches and scan beams. Approximately 90% of the traffic would have to be digital in an optimal constellation of Scenario II platforms, whereas Scenario V requires only about 68% digital.

An optimal constellation is assumed to replicate the same payload to serve all of the projected traffic in the year 2008.

The following table summarizes this scenario:

- o High capacity CONUS FSS
- o Reuse factors
 - C-band 4 times 500 MHz
 - Ku-band 9 times 500 MHz
 - Ka-band 12.2 times 2500 MHz
- o Optimized to 68% digital traffic
- o Seven satellites accommodate 100% of year 2008 projected CONUS traffic
- o Design addresses the distributional characteristics of traffic
- o All antennas fit STS envelope as rigid reflectors

Subsequent discussion will only cover those payloads not previously discussed.

A decision was made that this scenario would be limited to rigid reflectors with a diameter of 15 feet in order to fit in the shuttle bay. This limited the Ku-band beamwidths to about 0.45° and C-band to about 1.25° . As discussed previously, the traffic distribution is such that it is important to obtain as much reuse as possible in the Northeast and Midwest areas. This was done in the Ku-band payload by a North-South as well as an East-West split of the coverage. Figure 6 illustrates the coverages and it can be seen there are four beams in the north and three in the south in the eastern part of the U.S. Some areas could not be covered in order to provide beam to beam isolation. It should be noted that the uncovered areas are low traffic density areas. It was assumed that this traffic could overflow to the C-band payload.

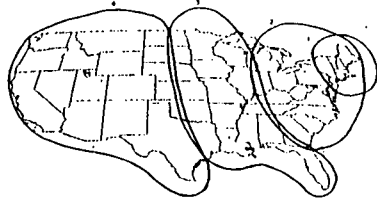
Ku-band transponder bandwidths are 36 MHz; two channels were further divided into 2 or 3 subchannels. With 9 beams, the use of 54 MHz channels, as in Scenario II, would have precluded complete connectivity between beams. Most of the traffic carried by this payload is analog, so static switching must be used. All channels are connected with 9X9 switches.

Four beams are provided at C-band, as shown in Figure 6. Subchannelization was provided in exactly the same manner as at Ku-band to improve fill factors. Each channel may be interconnected among the four beams by means of 4X4 switches.

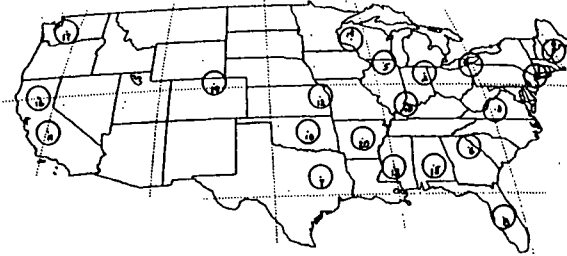


Figure 6 SCENARIO V – SERVICES ALLOCATION

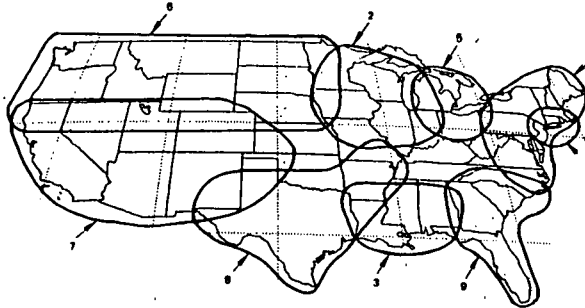
COMMUNICATIONS - 72 Gb/s



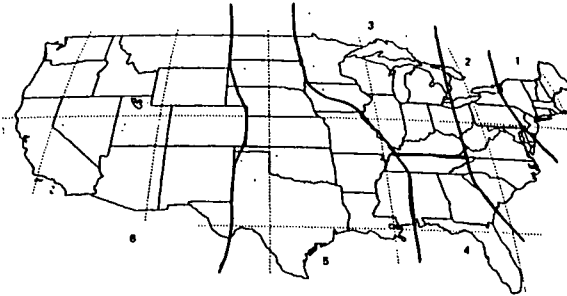
C-BAND: 48 CHANNELS OF 36 MHz
(3.5 Gb/s)



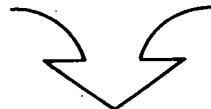
KA FIXED: 20 BEAM
38 CHANNELS OF 500 MHz
(38 Gb/s)



KU-BAND: 108 CHANNELS OF 36 MHz
(7.8 Gb/s)



KA SCAN 6 AREAS
18 CHANNELS OF 240 MHz
14 CHANNELS OF 500 MHz
(23 Gb/s)



COMMUNICATIONS PAYLOAD
OF ~ 2,261 kg
7,426 watts

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3.5 Non-U.S. Coverage

Before describing the next two scenarios in detail, an overall view of the concepts is presented. The two scenarios are really a complementary pair of platforms which use inter-satellite links between themselves and European and Asian platforms. A summary of the traffic types served is as follows:

A. SCENARIO VI-A

1. United States
 - a. Domestic
 - b. Regional
 - c. International
2. Latin America-Caribbean
 - a. Regional
 - b. International
3. Inter-satellite Links
 - a. European Platform
 - b. Scenario VI-B
4. Other
 - a. Western Atlantic Maritime

B. SCENARIO VI-B

1. United States
 - a. Domestic
2. Canada
 - a. Domestic
 - b. Regional
 - c. International

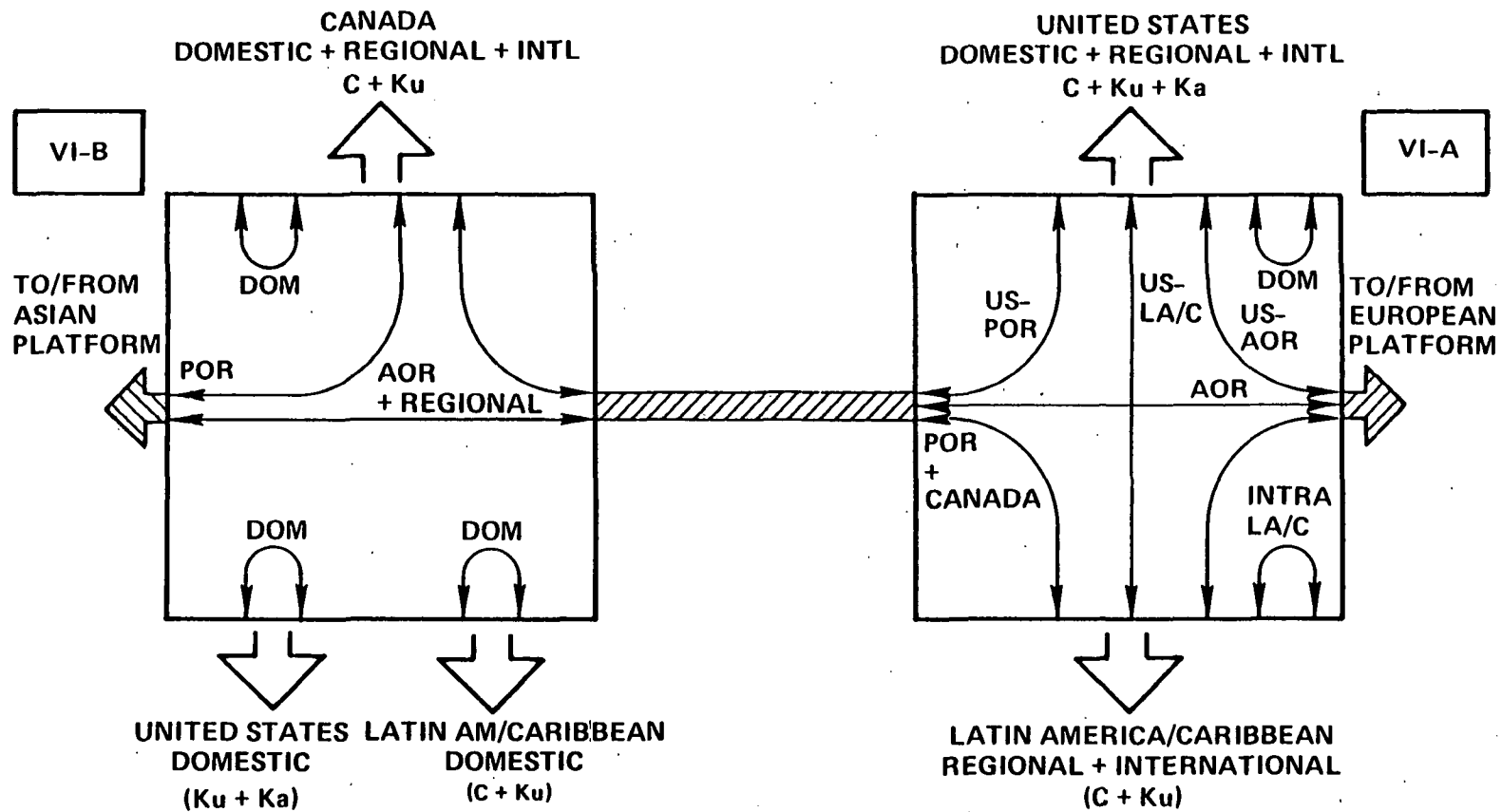
3. Latin America-Caribbean
 - a. Domestic
4. Inter-satellite Links
 - a. Asian Platform
 - b. Scenario VI-A
5. Other
 - a. Eastern Pacific Maritime

The primary reason for separating regional and international coverage from domestic is the existence of a problem equivalent to the one faced in the Ka-band designs: in overlaying a broad coverage over small spot beams, it is very difficult to allocate the capacity in a manner which meets the traffic distributions one is likely to encounter. In the non-U.S. applications, it was desirable to cover Intelsat gateways with small beams to obtain high reuse. At the same time, it was also necessary to provide domestic capacity over the entire country.

The necessary routing between the various coverages and inter-satellite links is provided by on-board processing as described in Figure 7. For example, a circuit from Canada to Brazil would be uplinked on Scenario VI-B, routed to Scenario VI-A via the ISL, and downlinked on the beam covering Brazil's gateway stations.



Figure 7 TRAFFIC FLOW FOR SCENARIOS VI-A AND VI-B



3.5.1 Scenario VI-A - This scenario consists of the entire Scenario V U.S. payloads, a C-band Latin America-Caribbean package, and a maritime payload. Two ISLs provide Atlantic Ocean Region (AOR) and Scenario VI-B connectivity. Since connectivity between the U.S. and either the ISLs or Latin America-Caribbean region is via the BBP, gateway stations are not required for this traffic; a customer could uplink both domestic and international circuits together. The following table summarizes the characteristics of this scenario.

- o High capacity CONUS FSS, Region 2 international FSS, ISL to Scenario VI-B and European platform, plus Western Atlantic Maritime
- o Reuse factors

C-Band	Dom.	4 times	500 MHz
C-band	Intl.	9 times	500 MHz
Ku-band	Dom.	9 times	500 MHz
Ka-band	Dom.	12.2 times	2500 MHz
Maritime	Intl.	1 time	35 MHz
- o CONUS international traffic (nongateway station) on Ka-band
- o Maritime payload and ISLs for Region 2 Intelsat traffic
- o On board processing of FDMA signals
- o All Intelsat traffic projected to 2008 (except Canada)
- o Major institutional issues and regulatory problems
- o Requires assembly in orbit and candidate for GEO servicing
- o Highest capacity scenario considered

The C-band regional-international payload provides a total of nine beams which cover all of the Intelsat gateway stations for Central America, South America, and the Caribbean. Figure 7 shows the coverages provided from 85°W longitude.

The distinguishing feature of this payload is the inclusion of baseband processing, in particular A/D and D/A conversion. It is assumed that the modulation used by most of the countries involved would be analog. There are two primary reasons why conversion to digital format on board was necessary.

1. Circuits are routed to/from ISLs, which are assumed to be digital, or the U.S. Ka-band BBP.
2. Many of the traffic requirements between the 9 beams are very low; with analog access, very low fills would have resulted.

Each FDMA FM uplink access is converted to a digital stream which can be buffered; on-board control would then perform framing and synchronization to interface with the BBP. Of the 108 channels provided in the nine beams, only 27 are processed; the remainder are switched in the usual manner.

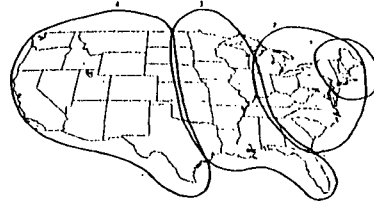
The remaining package, providing Western Atlantic maritime service, consists of 125 L/C-band circuits equivalent to an Inmarsat second generation system.



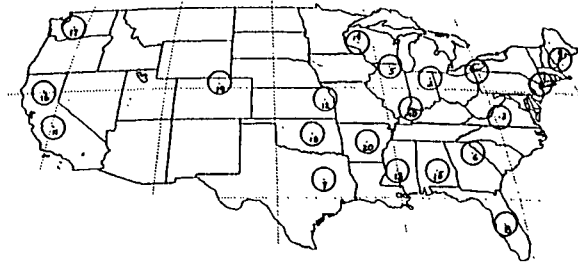
Figure 8 SCENARIO VI-A SERVICES ALLOCATION

INTER SATELLITE LINKS

- TO/FROM EUROPEAN PLATFORM
 - TO/FROM WESTERN PLATFORM
- POWER: 160 watts
 MASS: 110 kg



COMMUNICATIONS - 80 Gb/s



Ka FIXED: 20 BEAM
38 CHAN OF 500 MHz
(38 Gb/s)

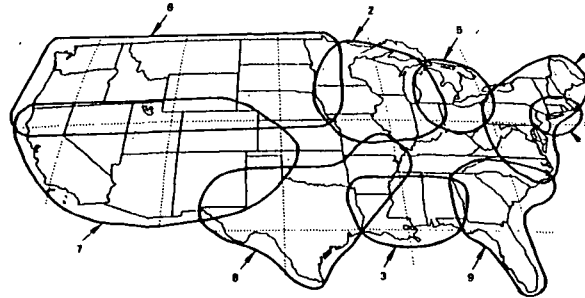
MARITIME PAYLOAD



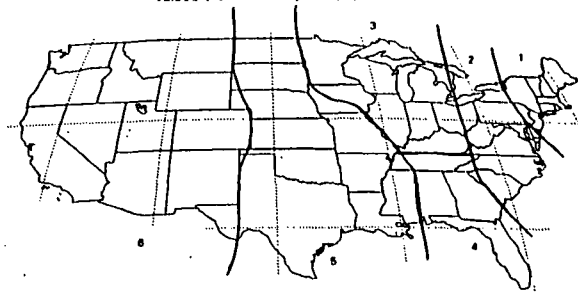
C/L - BAND: 125 VOICE CIRCUITS

POWER: 650 watts
 MASS: 80 kg

C-BAND: 48 CHAN OF 36 MHz
(3.5 Gb/s)



Ku-BAND: 108 CHAN OF 36 MHz
(7.8 Gb/s)



Ka-SCAN 6 AREAS
18 CHAN of 240 MHz
14 CHANNELS of 500 MHz
(23 Gb/s)

POWER: 9,600 watts
 MASS: 3,010 kg



C-BAND: 108 CHAN OF 36 MHz
(7.8 Gb/s)

COMMUNICATIONS PAYLOAD
 OF ~ 3,200 kg
 10,400 watts



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3.5.2 Scenario VI-B - This scenario also has the Scenario V payloads, except C-band, plus domestic coverage for Canada, Latin America and the Caribbean, and a maritime payload. Ku-band coverage is provided in Canada, Mexico (optional) and Brazil. Adequate spatial and/or frequency separation exists between the U.S. Ku coverages. Ku-band coverage was required in Canada and Brazil to meet year 2008 requirements. The two ISLs provide Pacific Ocean Region and Scenario VI-A connectivity. The following table summarizes the characteristics of the payloads assigned to Scenario VI-B:

- o High capacity CONUS FSS, Region 2 non-CONUS domestic FSS, ISLs to Scenario 3 and Asian platform, plus Eastern Pacific maritime
- o Reuse factors

C-band	Non-US	9 times	500 MHz
Ku-band	Dom.	9 times	500 MHz
Ku-band	Non-US	3.2 times	500 MHz
Ka-band	Dom.	12.2 times	2500 MHz
Maritime	Intl.	1 time	35 MHz
- o All projected year 2008 non-CONUS domestic traffic at C- or Ku-band
- o Canadian Intelsat traffic (nongateway) on C- or Ku-band
- o Maritime payload and ISLs for Region 2 Intelsat traffic
- o On board processing for Canadian and ISL traffic
- o Major institutional issues regarding operation and ownership
- o Requires assembly in orbit and is a candidate for GEO servicing
- o Coverages for all services are shown in Figure 9.

Canada faces the same problem of traffic skewness to an even greater extent than the U.S. The Toronto-Montreal area is the obvious problem. A single Ku-band spot beam was placed near the two major cities. This spot beam is polarized to match the Scenario V beams 4 and 5, and utilizes spatial separation to obtain a full 500 MHz of reuse.

Ku-band coverage for Mexico is provided because the Morales satellite has Ku-band capacity. Finally, Brazil has Ku-band coverage with a full two times (polarization) reuse.

Canada has three C-band beams, with an intentional overlap of the Central and Eastern beams in the Toronto area. Mexico coverage consists of two beams, again with an overlap in the high density areas of Mexico City and Guadalajara. A Central America-Caribbean beam has also been provided. The remaining three beams provide the South American coverage.

In the Canadian system, three channels in each beam are processed for routing to the ISLs. As with the U.S., no gateway stations are required for regional or international traffic. The networking is on-board the payload.

The Eastern Pacific Maritime payload is identical to the Scenario VI-A maritime package, except for the beam shape.



Figure 9 SCENARIO VI-B – SERVICES ALLOCATION

INTER SATELLITE LINKS

- TO/FROM ASIAN PLATFORM
- TO/FROM EASTERN PLATFORM

POWER: 130 WATTS

MASS: 106 g

MARITIME PAYLOAD



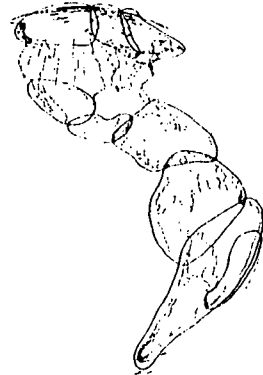
C/L-BAND: 125 VOICE CIRCUITS

POWER: 650 watts

MASS: 44 kg



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C-BAND: 108 CHAN OF 36 MHz
(7.8 Gb/s)



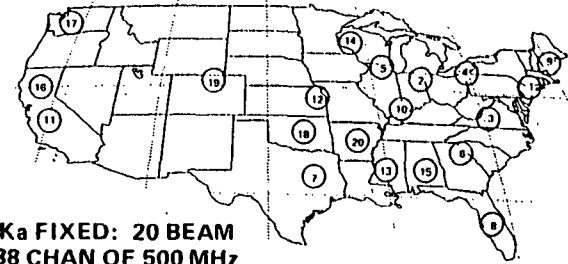
Ku-BAND: 38 CHAN OF 36 MHz POWER: 10,400 watts
(2.7 Gb/s)

MASS: 2,775 kg

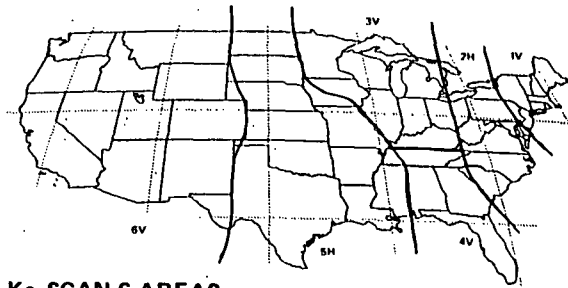


COMMUNICATIONS PAYLOAD
OF 2,925 kg and 11,200 watts

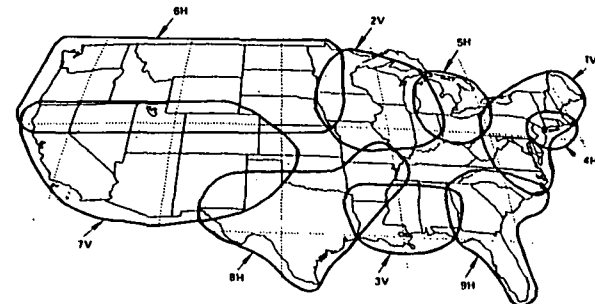
COMMUNICATIONS – 80 Gb/s



Ka FIXED: 20 BEAM
38 CHAN OF 500 MHz
(38 Gb/s)



Ka-SCAN 6 AREAS
18 CHAN OF 240 MHz
14 CHAN OF 500 MHz
(23 Gb/s)



Ku-BAND: 108 CHAN OF 36 MHz
(7.8 Gb/s)

4.0 COMPARISON OF CONCEPTS

4.1 Comparison of Payload Physical Characteristics and Cost

The payload bandwidth, mass, power, additional features, and estimated recurring costs are compared in Table 3. The bandwidth capacity of each of the payloads is determined by actual channel bandwidth times the number of channels. Thus, the 500 MHz bandwidth at C-band is only 12 times 36 MHz or 432 MHz of utilized bandwidth for a payload that uses 36 MHz channels.

The mass of each payload is determined based on estimates of the 1994 technology base for each of the components. The quantities were determined from the detail block diagrams on a component-by-component basis.

The power required for each of the payloads is also based on estimates of the 1994 technology. The radiated power required is based on the feasibility link calculation performed for each of the modulation and access types by frequency band. The power requirements are then summed on a component-by-component basis.

The recurring cost of each payload was then estimated using the PRICE-H computer model (Ref. 6) and correlation to current day component costs. The PRICE-H output was correlated to three current spacecraft programs at Ford Aerospace to establish operating factors and then used to prepare projected costs for each of the elements of the payloads on a component-by-component basis. In addition, the PRICE-H outputs were evaluated against engineering estimates for reasonableness. The Ka-band payload element is the highest uncertainty area. However, estimates were made based on extrapolations of engineering estimates for the RF equipment and for the antenna and baseband processor were based on information obtained from the NASA LeRC work for the 30/20 GHz program.

It should be reiterated that the payload cost is "recurring" cost only. It does not include any recovery of allocated non-recurring effort nor does it include any profit on the work effort.



Table 3 COMPARISON OF SERVICES

Scenario	B.W. Capacity (GHz)	Mass (kg)	Power (kW)	Broadcast Video/ Other	Recurring Payload Cost (\$M)
II	32.5	2063	12.7	16 channels	81
IV	—	1617	35.1	112 channels	67
V	36	2260	7.5	—	90
VI-A	44.5*	3200	10.4	125 Voice Cir. Maritime	126
VI-B	42.5*	2925	11.2	125 Voice Cir. Maritime	132

*Includes ISLs



4.2 Space Segment Cost Comparisons

In order to compare the aggregated platform payloads with individual smaller satellites with separate payloads, it was necessary to determine the space segment cost of each scenario. In order to extend these costs to a total (recurring) cost to place the platform into geosynchronous orbit, the following assumptions were made:

- o No development costs included
- o Spacecraft weight allocation at beginning of life (BOL)
 - Payload 31%
 - Bus 47%
 - Stationkeeping fuel (10 yrs) 22%
- o Bus costs
 - For Scenarios II & V: \$40M recurring + \$20M integration and launch operations
 - For Scenarios VI-A and VI-B: \$60M recurring + \$30M integration and LEO operations
- o Perigee and apogee stage costs included in launch costs
- o Use of Rockwell results (Ref. 7) for estimating launch costs

Table 4 provides the resulting total costs (DBS costs in Scenario II excluded), and also a cost per transponder-year based on a 10 year life. Even doubling these numbers for operating costs and profit show favorable results against the \$200K to \$300K annual lease rates of today.

A second approach was also taken for comparison purposes. Comparing the platforms cost to the cost of providing services equal to the bandwidth capacity provided, using current generation satellites. The costs of current satellites assumed are as follows:

<u>Satellite</u>	<u>Cost (\$M)</u>	<u>Launch (\$M)</u>	<u>Total (\$M)</u>
RCA Satcom	40	35	75
GTE Ku-band	50	35	85
Galaxy Ka-band	90	75	165

The comparison results for the four communications payloads are tabulated:

<u>Scenario</u>	<u>Platform Cost (\$M)</u>	<u>Equiv. Satellite Cost (\$M)</u>
II	237	1185
V	287	1531
VI-A	370	1881
VI-B	372	1901

From both of the above comparisons it appears there is a factor of 4 or 5 to 1 cost advantage of the aggregated platform. The saving of the platform comes from reduced launch costs - approximately 40%, reduced bus costs - approximately 30% and reduced payload costs - approximately 30%. The launch and bus costs are what was anticipated but the reduced payload cost was derived from the re-use of the same antennas and was larger than anticipated.



Table 4 TRANSPONDER COSTS PER YEAR

<u>COMMUNICATIONS</u>	<u>SCENARIO</u>			
	II	V	VI-A	VI-B
COST/SATELLITE (\$M)	237 ^{*1}	287	370	372
EFF B/W (GHz)	32.5	35.9	44.3	42.4
COST/36 MHz/YEAR (\$K) ^{*2}	26	29	30	32
<u>VIDEO CHANNELS</u>		II	IV	
COST/SATELLITE (\$M)		38 ^{*1}	250	
NO. CHANNELS		16	112	
COST/24 MHz/YEAR (\$K) ^{*2}		238	223	

***1 BUS AND LAUNCH COSTS PRORATED BASED ON PAYLOAD COSTS FOR DBS AND COMMUNICATIONS**

***2 10 YEAR LIFE**



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5.0 IMPLEMENTATION ISSUES

5.1 Barriers Counter to Implementation

There are several institutional and regulatory issues involved in large platforms. There is intense competition for long-distance traffic from terrestrial systems. There is also competition for orbital positions. By the time a platform owner is ready to apply to the FCC for construction permits, the available orbital slots in the C and Ku bands will undoubtedly be assigned. The Ka-band slots may also be assigned.

In order to obtain a suitable orbital position, a current licensee, or a number of current licensees, of these slot assignments will have to agree to use their geostationary orbit slot or slots for a platform. An alternative is to persuade the FCC to identify an orbital slot for future platform use, and to make no permanent assignments for this slot. If the case for the platform could be made strong enough, the FCC could refuse to renew the current slot assignments and re-assign a slot to the Platform.

The platform operator would be expected to take the lead in the following activities:

- o Obtaining the financing.
- o Obtaining the regulatory approvals.
- o Enlisting the participation and support of other carriers.
- o Procuring the spacecraft.
- o Integrating the payloads.
- o Arranging for launch services.
- o Obtaining launch, commissioning, and on-orbit insurance.

- o Arranging for tracking, telemetry, and command services.
- o Operating a master control center.
- o Arranging for terrestrial networking.
- o Marketing the communications services.

In addition to the above issues, scenarios VI-A and VI-B face other barriers. The participants to be coordinated include INTELSAT and rival satellite systems, the international cable companies and the INTELSAT signatories (who are usually the government-controlled PTTs). The Department of State and its counterparts abroad are also involved. The FCC authorizations are needed for the ground terminals to be located in the U.S., and for the satellite if it is to be a U.S. registered satellite. Authorizations are needed from the PTTs for the foreign-based ground terminals. The International Telecommunications Union is involved in the assignment of the orbital slots, and the coordination with other administrations that might be affected. Finally, if ISLs are used to European and Asian platforms, the interfaces would have to be coordinated with the owners of those platforms.

A major factor in today's environment would be the ability to insure a large asset for launch and checkout, given the insurance community's recent losses on spacecraft.

The above factors are listed in Table 5.



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Table 5 OTHER IMPLEMENTATION ISSUES

- Institutional Issues
- Regulatory Issues
- Insurance Issues



5.2 Technology Development

A data base of projected 1994 technology was established early in the contract. This data base was bounded by application of emerging technology, as low risk up to high risk, which is development of currently envisioned projections to 1994. For most of the elements of the payload, a nominal projection or expected development was assumed. While there are many areas of assumed improvements in weight, power, and performance, a few of the most critical items that provide potential high economic payoff are listed in Table 6.

The highest economic payoff item is full polarization re-use at Ka-band. The ability to re-use the 2.5 GHz of bandwidth at the saturating nodes allows a 1.8 to 1 reduction in the number of satellites required to service the CONUS distribution characteristics. If a polarization tracking method is developed, the reuse factor for a given platform can be increased 1.8 times.

The next most desirable technology item is high speed, high efficiency baseband processors. Increasing the link capacity for a given bandwidth using 8 PSK or 16 PSK modulation has a similar effect as the Ka-band polarization tracking. High efficiency modulators and demodulators with high speed, lightweight, on-board routing increase link capacity, on-board flexibility to improve fill factors and thus lower equivalent cost per circuit.

In addition to the conventional baseband switching, an approach using a high speed programmable frequency source to shift frequencies between different frequency channels or bands was utilized. This allows a second tier of switching, increases the interconnectivity and provides a more cost effective routing mechanism. This approach can be utilized to route down to the T1 level, (1.544 mb/s).

The next major technology item utilized in the study payloads is the Intersatellite Links (ISLs). There are a number of current developments underway for RF links. However, RF links are limited to about 5 GHz bandwidth and the payloads in this study nearly saturate these links. Development of optical links for the trans-Atlantic ISL is required for any growth of the study payloads.

A number of other items of lesser impact are also identified that increase flexibility and reduce cost. Included is an analog-to-digital (or A/D) on-board format conversion to accept analog uplink and perform digital conversion on-board for digital routing. The complement of that function is also required for the return link. Another item is a method of using large reflectors, ie. greater than 5 meters in diameter, for both receive and transmit functions at both polarizations.



Table 6 ADVANCED TECHNOLOGY DEVELOPMENT

<u>TECHNOLOGY</u>	<u>SCENARIO</u>			
	II	V	VI-A	VI-B
BASEBAND PROCESSING				
- HIGH EFFICIENCY MOD/DEMOD	X	X	X	X
- A TO D FORMAT CONVERSION			X	
ANTENNAS				
- POLARIZATION TRACKING OF Ka-BAND FOR H AND V REUSE	X	X	X	X
- DUAL POLARIZER FOR RECEIVE AND TRANSMIT BANDS			X	X
TRANSPONDERS				
- HIGH SPEED PROGRAMMABLE FREQUENCY SOURCE	X	X	X	X
ISL				
- RF OR OPTICAL			X	X



5.3 STS and Space Station Support

It was determined early in the study that extensive servicing of payloads at GEO was not likely for platforms in the year 2000 to 2010. However, services of the STS and Space Station at LEO, as well as a space-based transfer vehicle system for transfer from LEO to GEO are desired and/or required for implementation of the platforms conceptualized in this study. The use of STS for launch services accommodates the size and weight of the payloads with varying configurations of single orbiter launches and increments of platform fueling and transfer vehicle types.

The platforms described in this study also provide a logical application of the Space Station in performing a series of services for payloads. The simplest of these could be on-orbit assisted deployments to simplify ground test and minimize design of complex deployments. A logical extension of this would be the capability to perform an alignment check of deployed reflectors in the zero-G environment, and subsequently adjust the alignment.

For the larger payloads in the study, as a minimum, the Space Station would have to provide "mating" assembly services for major modules. Once the modules were assembled, some minimum amount of checkout would be required prior to committing the payload to transportation to GEO. If a defect were discovered during the assembly, deployment, alignment, or checkout sequence, the Space Station could provide servicing or repair/replacement of the defective item. Once the checkout validated that the platform was in working order, it would be transported to GEO by a low-thrust, potentially re-useable transfer vehicle.

Large GEO platforms can be a logical application of Space Station attributes and may provide a commercially viable benefit in providing communications services at reduced cost over the conventional satellites of today.

The above tasks are summarized in Table 7.



Table 7 STS AND SPACE STATION SUPPORT

- Deployment
- Assembly
- Alignment
- Servicing
- Checkout at LEO
- Transportation to GEO



6.0 CONCLUSIONS

6.1 Overall Ranking of Scenarios

Established as part of the data base for the study was a set of evaluation criteria and the method of ranking scenarios. Using the criteria, the scenarios ranked as follows: Scenario V ranked significantly higher than the other payloads and intuitively should be the highest ranking given the optimized to CONUS distribution characteristics of the payload. The scenario used all rigid reflectors that minimized cost. It also seemed a good balance of digital to analog capacity based on the ratio of digital to analog demand projected to the year 2008. Since this scenario serves only CONUS it has the minimum barriers to implementation and offers significant cost advantages over current day separate payloads. It is also the most commercially viable scenario since it only requires a large domestic carrier to implement the system.

Scenario IV was the next most viable and provides a couple of unique advantages. First, it simplifies other communications satellites by removing the video distribution from them. Second, it provides a particular class of users a common location in orbit such that the number of ground stations can be minimized. Third, the payload design can be optimized for the video function.

Scenario II as a transition payload ranked third, but because of the high capacity digital Ka-band payload, could not be duplicated as a constellation to satisfy the total traffic demand without essentially eliminating the current analog systems. Also, the constraints of orbital location due to the DBS payload limits the number of platforms that could be accommodated.

The remaining two scenarios are very large payloads that technologically service all of the WARC Region 2 international, regional and domestic demands through the year 2008.. The institutional barriers to implementation are extremely high given the political implications related to providing domestic services from a platform not controlled by the user. Also, the platform would be in competition with the current INTELSAT structure or would be operated by INTELSAT to make it viable. While these payloads are more ambitious and offer a more significant technical challenge than the prior scenarios, the overall economic viability is more questionable. The economies of scale do exist but the cost of implementation may be exorbitant.

The overall ranking of the scenarios is presented in Table 8.



Table 8 OVERALL RANKING OF SCENARIOS

- 1 Scenario V (High Capacity CONUS)
- 2 Scenario IV (High Capacity DBS)
- 3 Scenario II (Medium Capacity CONUS)
- 4+ Scenario VI-A (International Traffic)
- 4- Scenario VI-B (Non-CONUS Domestic)

6.2 Epilogue

Although the results of this study must be considered preliminary, certain conclusions can be drawn:

- o Large platforms may provide significant economies of scale.
- o Scenarios VI-A and VI-B can serve all Region 2 non-U.S. year 2008 traffic with one platform of each type
- o A constellation of seven Scenario V -- or combinations of Scenarios V, VI-A and VI-B -- could serve all U.S. satellite traffic, with the exception of broadcast video, in the year 2008.
- o Major institutional, regulatory and insurance issues exist, especially for Scenarios VI-A and VI-B.

Given the apparent economies of reduction in per-circuit cost the platform warrants further effort even given the significant barriers to be addressed. The demand for efficient utilization of the geostationary arc and ultimately the formation of a Region 2 communications organization could lead to implementation of these large platforms.

The results of the study provide NASA the following guidance in answering the questions raised at the outset of the study:

- o Economically and technologically a constellation of large geostationary facilities is desirable in the mid to late 1990's. However, institutional and other factors may be insurmountable barriers to implementation.
- o The most commercially viable payload would be similar to Scenario V payload. This payload can be replicated as many times as necessary to satisfy the total demand.
- o The major payload technological risks are dual polarization re-use at Ka-band, high efficiency modulators and demodulators, high speed programmable frequency shifters, large rigid reflectors for high frequency dual polarization, lightweight on-board baseband processors and RF equipment, and spacecraft bus technologies to support the large platforms.





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