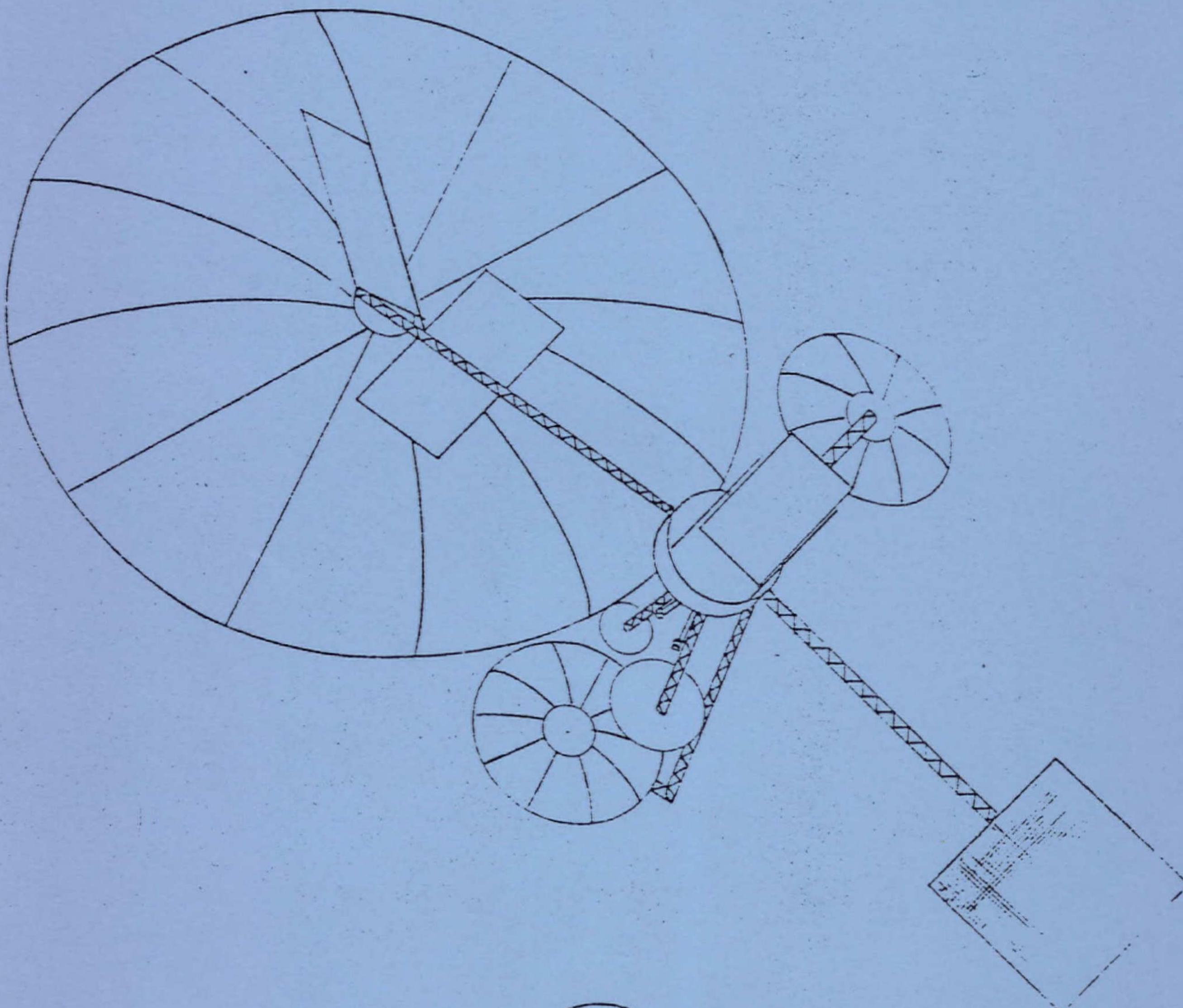
DOC-CR-SP-80-008

SPACE PLATFORMS

AN EVALUATION

EXECUTIVE SUMMARY



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DOC-CR-SP-80-008 (A)

DEPARTMENT OF COMMUNICATIONS - OTTAWA - CANADA

SPACE PROGRAM

TITLE: Study of the Potential Impact of Large Multifunctional Space Platforms on Canadian Satellite Systems

AUTHOR(S): David Tong

ISSUED BY CONTRACTOR AS REPORT NO: N/A

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STUDY OF THE POTENTIAL IMPACT OF LARGE MULTIFUNCTION SPACE PLATFORMS ON CANADIAN SATELLITE SYSTEMS

Prepared For: Department of Communications

DSS File No.: 15SV.36100-9-0836

DSS Serial No.: 0SV79-00060

July 1980

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1.0 INTRODUCTION

1.1 Background of Study

This report presents the results of a study performed by Canadian Astronautics Limited for the Department of Communications, under DSS Contract Number 15SV.36100-9-0836, to assess the potential impact of the large multifunction space platform (MSP) on Canadian satellite systems. The Statement of Work for the study is presented in Appendix A, and summarized in the Table on the next page.

In recent years there has been a growing international interest in the possibility of using large, hybrid spacecraft to carry large and/or multiple payloads in geosynchronous orbit. This interest has resulted in a number of detailed studies, particularly in the United States, aimed at determining the major technical and economic parameters and drivers of such systems. In addition to the studies, there have been a number of editorial articles published in the literature, presenting both positive and negative opinions concerning the replacement of the current families of single-payload satellites with fewer, larger spacecraft. The purpose of the present study is to review and evaluate the detailed work being done elsewhere, and to provide an assessment of the potential application of the large multifunction space platform to meeting Canadian needs. It is a long range planning study, designed to identify likely trends in the development of such systems, and determine whether they could be used to satisfy our requirements. The major technical, economic, and institutional factors which may influence a decision to choose multi-purpose or single purpose satellites are identified, and the advantages and disadvantages of this approach are discussed. Potential problems areas, and those requiring further study, are highlighted.

CANADIAN ASTRONAUTICS WAS UNDER CONTRACT TO:

- CARRY OUT A TECHNOLOGY FORECAST FOR BOTH MULTI-FUNCTION SPACE PLATFORMS (MSP'S) AND THEIR SUPPORTING TECHNOLOGIES

- DEFINE CANADIAN SATELLITE MISSION MODELS FOR THE 'RELEVANT' TIME FRAME

- DETERMINE THE APPLICABILITY OF MSP'S TO MEETING THE REQUIREMENTS OF CANADIAN MISSION MODEL

- CONSIDER TECHNICAL ASPECTS OF USING MSP'S TO MEET CANADIAN NEEDS

- CONSIDER ECONOMIC & INSTITUTIONAL ASPECTS OF USING MSP'S TO MEET CANADIAN NEEDS

- DISCUSS ADVANTAGES/DISADVANTAGES OF MSP'S WITH RESPECT TO CANADIAN USAGE, & IDENTIFY PROBLEM AREAS

THE STUDY IS PART OF A LONG RANGE PLANNING PROGRAM; ITS PURPOSE IS TO REVIEW AND EVALUATE THE WORK BEING DONE ELSEWHERE.

1.2 Report Format

Canadian Astronautics Limited has taken an overall systems approach in assessing the potential application of multifunction space platforms to Canadian satellite systems, and this is reflected in the report format.

Chapter 2 provides the required background information for the study. It contains a summary of the reasoning behind the early development of the MSP concept, followed by a description of what that concept was. This is then related to the specific Canadian concerns which the study addresses. Finally, the manner in which the overall study was conducted is described.

Chapter 3 presents the Canadian mission model derived during the study. The goals of the mission model survey, and the methodology used in conducting the survey are described, followed by presentation and discussion of the results. These are then compared to the results of similar U.S.-based studies in order to assess their accuracy, and finally a baseline mission model is defined in some detail.

The technology of MSP's is evaluated in Chapter 4, commencing with a description of the evolution of thought concerning the definition of what constitutes a multifunction space platform.

The technical impact of MSP's on satellite systems in general is discussed, and then the major technical concerns of Canadians are separately highlighted. Work being done to address the problem areas is described, with emphasis on the particular elements which are likely to be critical or pacing items in the development of the technology. Chapter 4 concludes with two strawman versions of MSP's, one carrying all the payloads defined in the mission model for the next generation of Canadian geostationary satellites, and the other a subset thereof. The technical constraints and tradeoffs performed during derivation of the spacecraft configurations are presented in detail.

The economics of multifunction space platforms are discussed in Chapter 5, commencing with a description of the pivotal role economy of scale has played in the development of the MSP concept, and the continuing concern being expressed about the true economic trade-offs between conventional satellite systems and MSP systems. The published economic studies, all of which have been conducted in the U.S., are evaluated next, and their results critically analyzed, with both purely domestic and international programs being considered. A rough order of magnitude cost estimate is made for both platform and individual satellite systems meeting the needs of the baseline mission model, and these are compared.

The institutional aspects are discussed in Chapter 6. This is one area which has apparently received relatively little attention, and yet will have a major impact on any decision to develop operational MSP systems. There are generic institutional problems which will have to be solved before the technology can be fully exploited anywhere, and in addition there are significant Canadian-specific institutional concerns which will further impact its application in this country. Both sets are described and analyzed in Chapter 6, and major areas requiring further study are highlighted.

The major conclusions of the report are summarized in Chapter 7, and the resultant recommendations are made in Chapter 8.

Background information, including a detailed bibliography of the literature surveyed, is presented in a series of Appendices.

The main body of the report (Chapters 2 to 8) is modular in format, with each two page spread consisting of a text (left hand page) accompanied by graphics (right hand page). It is intended that the graphics complement the text in one of three ways: illustrating the concepts discussed, highlighting major points, or presenting tabular or numerical results.

2.0 BACKGROUND OF THE MULTIFUNCTION SPACE PLATFORM & STUDY

2.1 Introduction

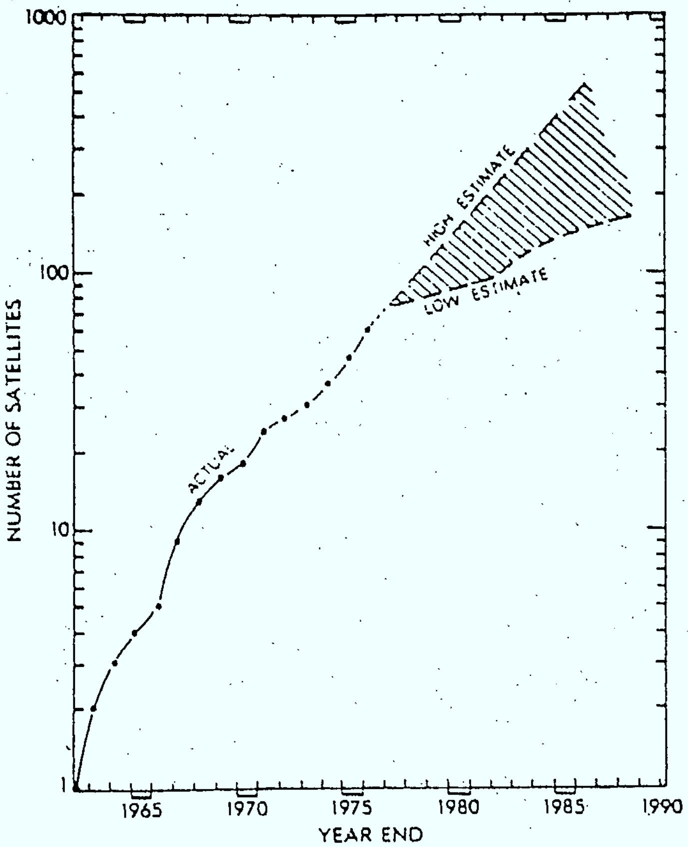
The launch of Syncom into geosynchronous orbit in 1963 marked the beginning of the era of practical satellite communications. In the past seventeen years there has been a proliferation of domestic, regional and international systems designed to capitalize on the high capacity and cost effectiveness of communications satellites. This has resulted in increasing congestion of both the geostationary orbit and the portions of the RF spectrum allocated to satellite services. In addition to the historical growth, recent market forecasts show even greater increases in demand for communications satellite traffic over the next twenty years.

Various methods are now being employed to improve the efficiency of orbit and spectrum utilization, and even newer, more advanced concepts must be developed for the future. The bandwidth available for satellite communications is limited, and must be reused by various means. At present, two means of frequency reuse are employed. The first is spatial reuse, in which satellites are spaced far enough apart on the geosynchronous arc to ensure that a ground station antenna pointed at one satellite doesn't pick up a strong enough signal from adjacent satellites to cause interference. This system has worked well up to now, but the growth in requirements is such that soon more satellites, and hence closer spacing, will be required. This is largely undesirable, because it forces narrowing of the ground station antenna patterns, which in turn forces users to buy larger, more expensive antennas. A means of overcoming this, and increasing the available spectrum capacity by a factor of two, is polarization isolation, in which the spectrum is reused by transmitting and receiving two sets of signals on cross-polarized beams. This system can be made to work well for fixed systems, but is less generally useful for mobile systems. In the latter case many of the ground terminals proposed are simple omnidirectional antennas which are unable to discriminate between opposite senses of circularly polarized signals. In addition, as in the case of physical separation of satellites around the orbit, even the limit of capacity using this technique will be reached in the near future.

The proliferation of small systems has also caused some concern about the ability to maintain the natural competitive advantages which satellite communications systems have had. Intelsat in particular has expressed concern that the form of growth experienced is actually inhibiting further improvements in the economies of scale which make satellite-based systems so attractive.

THE PROJECTED GROWTH OF SATELLITE SERVICE REQUIREMENTS STRAINS THE CAPACITY OF THE TWO MAIN LIMITED RESOURCES

O ORBIT SPACE



(ref [illegible])

O AVAILABLE SPECTRUM, E.G.

GHz
10.7 - 11.7

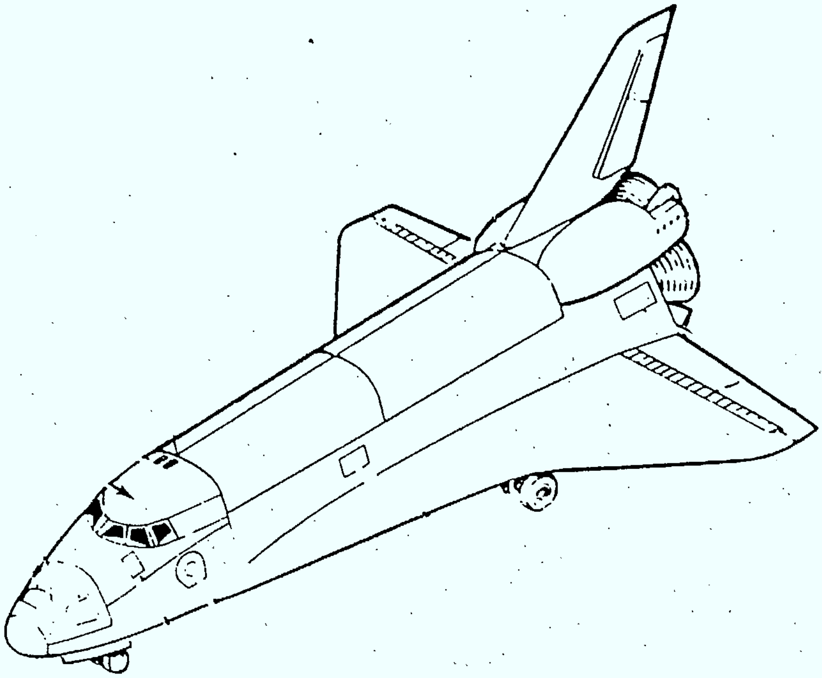
Allocation to Services		
Region 1	Region 2	Region 3
10.7 - 11.7 FIXED FIXED-SATELLITE (space-to-Earth) (Earth-to-space) 3784A MOBILE except aeronautical mobile	10.7 - 11.7 FIXED FIXED-SATELLITE (space-to-Earth) MOBILE except aeronautical mobile	

ADD 3784A In Region 1, the use of the band 10.7 - 11.7 GHz by the fixed-satellite service (Earth-to-space) is limited to feeder links for the broadcasting-satellite service.

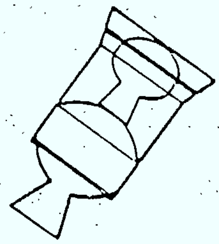
At the same time as the orbit and spectrum crowding starts to become severe, a new transportation system capable of placing very large satellites into geostationary orbit will become available.

By the mid to late 1980's, the U.S. Space Transportation System (STS), consisting of the Shuttle orbiter and a series of high energy upper stages, will provide the capability of routinely and economically delivering heavy (up to 6000-7000 kg per flight) payloads to geostationary orbit. The STS will also be able to provide a base for on-orbit construction, allowing even larger geostationary payloads to be delivered to Low Earth Orbit (LEO) in multiple flights, assembled there, and then transferred to geostationary orbit (GEO). A projected long term addition to the STS is a teleoperator system which would carry items from LEO to GEO and back again. When this becomes operational, on-orbit repair and refurbishment of suitably designed geostationary satellites will be possible.

THE 1980's AND BEYOND WILL SEE THE DEVELOPMENT AND EVOLUTION OF THE SPACE TRANSPORTATION SYSTEM



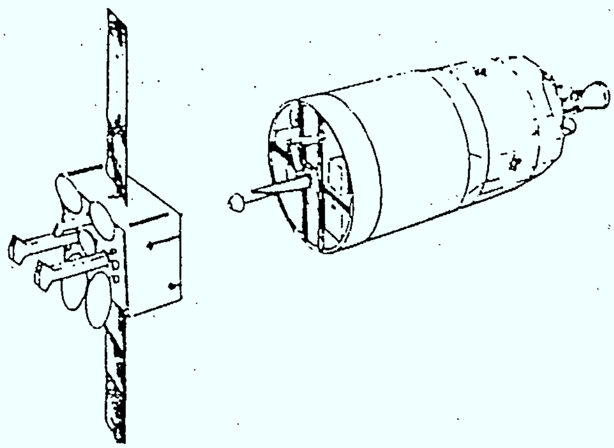
SHUTTLE ORBITER



IUS
OR
MODIFIED CENTAUR
OR
NEW UPPER STAGE

+

(LONG TERM)



ON ORBIT SERVICING

Starting in the mid 1970's, a few visionary engineers looked at these two developments, and proposed a solution to the orbit/spectrum crowding problem which would utilize the (anticipated then) soon-to-be available STS.

Their solution was the large geostationary communications platform (or multifunction space platform - MSP). It was conceived as a very large satellite designed to carry one or more large antennas (10's of meters in diameter) and multiple payloads. The large diameter antennas produce very narrow (1^{o} or less) spot beams. By suitably designing the feeds, an entire country, region or hemisphere could be covered by these spots, with either overlap or 'butting' of adjacent beams. Provided that sidelobe levels could be controlled to acceptably low values, any two non-adjacent beams could use the same transmission frequencies without interfering, thus conserving spectrum. The most common re-use plan proposed was one in which the available bandwidth was divided into three sub-bands, each of which was used by a third of the beams, as illustrated opposite. With this plan, coverage of a continent (say) by 100 small spot beams would allow over thirty reuses of the same frequencies.

An added advantage of this spot-beam concept was seen to be a higher EIRP obtainable with reasonable sized output stages, as a result of the higher antenna gain. This would permit the development of smaller, cheaper earth stations, and potentially expand the market greatly. Because there would be fewer satellites in orbit, they would be spaced farther apart, and hence not interfere with each other, despite the wider beams of the small ground stations. It was also prophesied that by interconnecting payloads on board the satellite, the quality of certain services would be improved and spectrum would be conserved by avoiding unnecessary double hops.

Economy of scale would be preserved by the use of shared housekeeping subsystems on the platform. Duplication of structure, thermal, and attitude control systems was one of the expenses of multiple satellite systems which would hopefully be avoided. It was also anticipated that the STS facilities would be more cost effectively used, by filling the entire payload bay and carrying less airborne support equipment per unit of actual payload.

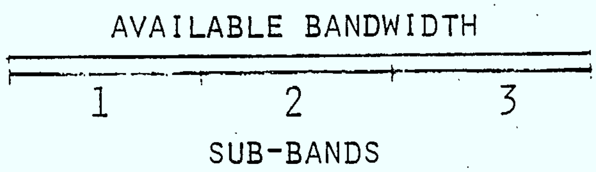
These economies were proposed to be also applied to non-communications missions (e.g. meteorological) which could share platform real estate with the primary payloads.

THE MULTIFUNCTION SPACE PLATFORM WAS PROPOSED TO:

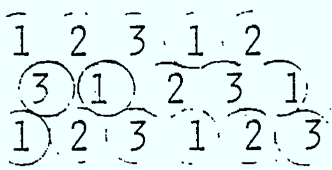
- O ALLEVIATE ORBIT & SPECTRUM CROWDING
  - O MULTIPLE SPOT BEAM ANTENNAS FOR FREQUENCY REUSE
  - O INTERCONNECTION OF SERVICE TO AVOID MULTIPLE HOPS
- O PROVIDE ADDITIONAL ECONOMY OF SCALE
  - O SHARED SUBSYSTEMS
  - O MORE COST EFFECTIVE USE OF STS
  - O SMALLER, LESS EXPENSIVE GROUND TERMINALS
- O PROVIDE PERFORMANCE IMPROVEMENTS
  - O INTERCONNECTIVITY
  - O EXPANSION OF TYPES OF SERVICE
  - O EXPANSION OF VOLUME OF SERVICE

MULTIPLE SPOT BEAMS ANTENNA PATTERNS WOULD PERMIT A LARGE INCREASE IN FREQUENCY REUSE:

- O AVAILABLE SPECTRUM SPLIT INTO THREE SUB-BANDS



- O COVERAGE AREA BLANKETED BY SPOT BEAMS, EACH USING ONE SUB-BAND



Canadian interest in MSP's is at present more of an academic, or long range planning nature than that of the U.S. organizations and Intelsat, since our foreseeable capacity requirements are relatively modest, and could be served by conventional satellite systems. There are, however, a number of reasons for studying MSP's at this time, and they are enumerated opposite.

WHY THE CANADIAN INTEREST IN MSP's AT THIS TIME?

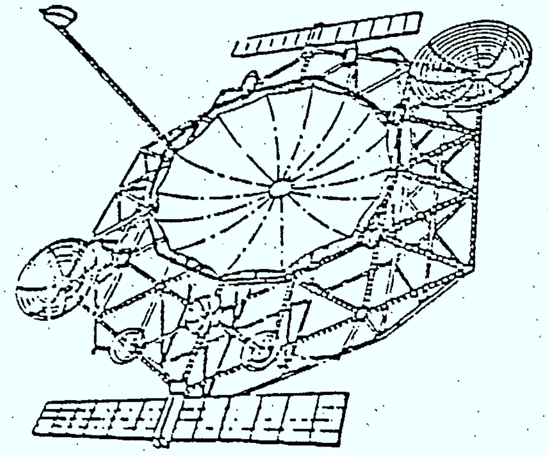
- O PREVIOUS STUDIES (TECHNICAL & INSTITUTIONAL) ADVOCATE THE DEVELOPMENT OF HEMISPHERIC COVERAGE (N. & S. AMERICA) MSP'S TO OBTAIN MAXIMUM BENEFIT OF ECONOMIES OF SCALE. THE OWNER/OPERATOR OF THE PLATFORM WOULD BE U.S. BASED OR AN INTERNATIONAL CONSORTIUM.
  - O THIS HAS A DIRECT & EXPLICIT EFFECT ON CANADIAN SATELLITE SYSTEM PLANNING. DO WE WISH TO PLACE OUR PAYLOADS ON AN INTERNATIONAL MSP, AND IF SO, UNDER WHAT CONDITIONS? HOW DO WE RESPOND TO OUTSIDE PLANNERS WHEN THEY APPROACH US?
- O IF THE PREDICTED ECONOMIES OF SCALE ARE REAL, THEY MAY ALSO APPLY TO A CANADIAN DOMESTIC MSP CARRYING ALL OUR FIXED, MOBILE, & TV BROADCAST SERVICES
  - O ARE THESE ECONOMIES REAL?
  - O DO THEY APPLY TO THE CANADIAN SCALE OF NEEDS?
  - O IF DOMESTIC MSP'S WERE USED TO CARRY CANADIAN PAYLOADS, WHAT WOULD THE EFFECTS BE ON THE CANADIAN SPACE COMMUNITY?
- O TELESAT HAVE DETERMINED THAT THE CURRENT DISTRIBUTION OF PAYLOADS ON MULTIPLE SATELLITES BEST SERVES THEIR NEEDS OF THE FORESEEABLE FUTURE. HOWEVER, UPCOMING INSTITUTIONAL DRIVERS, SUCH AS THE PLANNING CONFERENCES OF THE ITU (RARC: 1983 & WARC-SPACE: 1984/85), MAY REMOVE SOME OF THE FLEXIBILITY FROM THE SYSTEM ARCHITECTURE PLANNING FUNCTION
  - O IF WE END UP WITH RESTRICTIONS, HOW DO WE BEST REDEFINE THE OVERALL SYSTEM? WHAT ARE OUR OPTIONS?
- O SOME IDENTIFIED CANADIAN PAYLOADS, PARTICULARLY ADVANCED MOBILE COMMUNICATIONS, WILL REQUIRE A LARGE ANTENNA.
  - O WOULD IT BE DESIRABLE TO TAKE ADVANTAGE OF AN ALREADY LARGE SATELLITE & HYBRIDIZE IT?

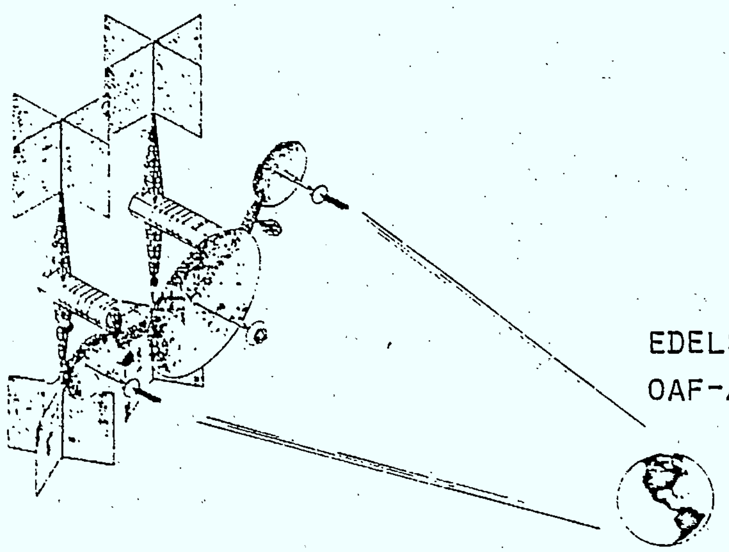
2.2 The Concept of the Multifunction Space Platform

The early concepts of the Multifunction Space Platform were on a grand scale --- very large satellites (6000 - 24000 kg, 20-280 kW primary power) carrying many and/or complex payload packages supported by common bus subsystems such as structure, electrical power, attitude and thermal control, stationkeeping, propulsion and TT&C. The payloads would serve many missions in areas of international and domestic fixed communications, mobile communications, navigation, search and rescue, meteorological service, and data collection. Very few (4 or 5) satellites would be required to serve all the global (non military) needs; they would be interconnected by RF or laser inter-satellite links.

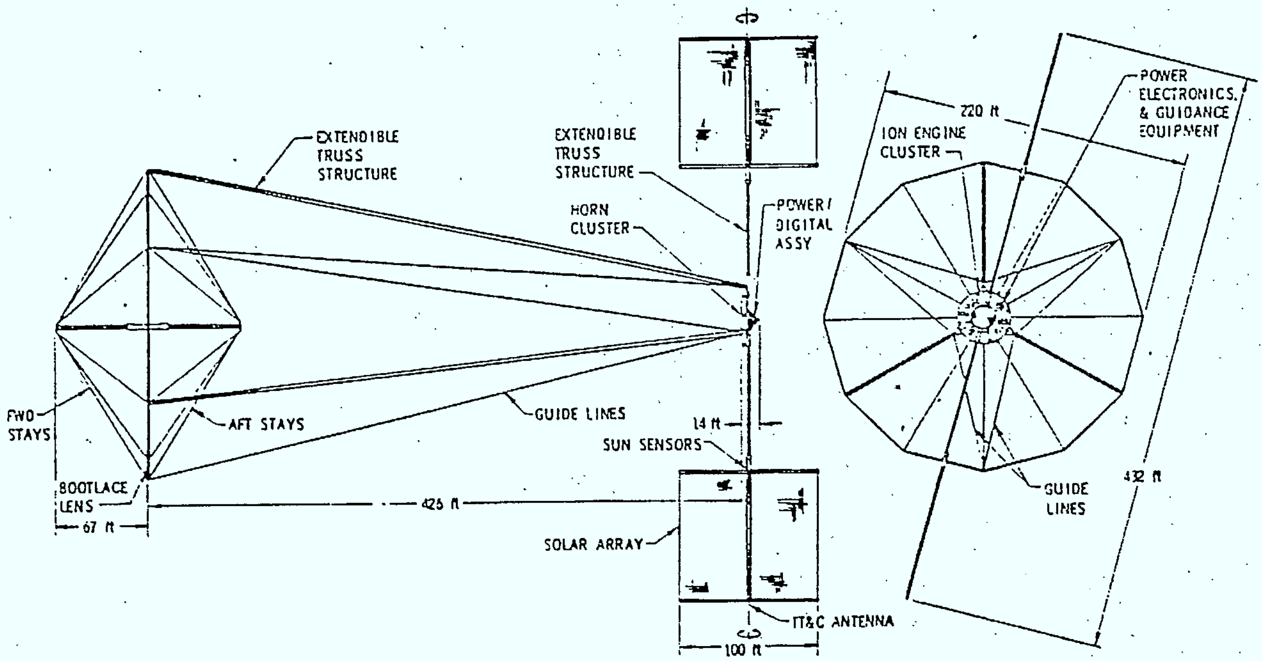
EARLY MSP CONCEPTS WERE TRULY ON A GRAND SCALE

FORDYCE, JAFFE & HAMILTON'S[8]
SWITCHBOARD IN THE SKY





EDELSON & MORGAN'S[3]
OAF-AMERICAS



BEKEY'S PERSONAL COMMUNICATIONS SATELLITE[15]

There were a number of common elements among all of the early MSP concepts. Many of them are generic characteristics of all multifunction space platforms; others are specific to the versions having the scope of an 'OAF' or 'Switchboard in the Sky'. Although this latter group represents only the end item in a long evolutionary growth process, it has come to be generally identified with all MSP's.

BASIC COMPONENTS OF THE EARLY MSP CONCEPTS WERE

- O SINGLE BUS - STRUCTURE, POWER, ATTITUDE CONTROL, THERMAL CONTROL, TT&C, PROPULSION SUBSYSTEMS
- O LARGE (TENS OF METERS) DIAMETER ANTENNAS FOR FREQUENCY REUSE
- O MULTIPLE PAYLOADS
- O ON-BOARD SWITCHING AMONG PAYLOADS
- O ASSEMBLY IN ORBIT (LEO OR GEO)
- O MODULARITY FOR
  - O PAYLOAD ADDITION
  - O REFURBISHMENT
- O LONG LIFETIME - 20 YEARS & UP

OTHER COMMON ELEMENTS NOT SPECIFIC TO THE PLATFORM ITSELF ARE:

- O OPERATIONAL LEO ASSEMBLY CAPABILITY & TOOLS
- O REUSABLE ORBIT TRANSFER VEHICLES (LOW THRUST)
- O MODULE INTERCHANGE MECHANISMS (MANNED OR ROBOTIC)

For purposes of the present study the MSP concept was made more general. While it is recognized that the large grandiose designs originally proposed may well represent the state of the art of operational communications satellites at some point in the future, they are unlikely to be realized in the 1990's, as originally predicted by the visionaries. The transition from present systems to those put forth in the early literature is more likely to be evolutionary than revolutionary.

Consequently, it was decided to study the potential impact of not only the "OAF/Switchboard" form of spacecraft on Canadian satellite systems, but also the various early forms of MSP, as they evolved. In order to allow us to do this, the definition of what constitutes an MSP was modified as shown opposite. The basic elements are in agreement with the revised definitions now being used by other workers in the field, and represent the characteristics which are unique to MSP's. Note that the definition is now based more on the capabilities and functions of the spacecraft systems, rather than their configurations.

REVISED CONCEPT OF AN MSP

- O CARRIES MULTIPLE PAYLOADS
  - O ECONOMY OF SCALE
  - O INTERCONNECTION POTENTIAL
- O INTERCONNECTS SERVICES AS REQUIRED
- O USES MULTI-BEAM ANTENNAS

2.3 Study Goals and Objectives

The objective of the study was to assess the likely impact of MSP technology on Canadian satellite systems, by evaluating the work being carried out elsewhere and applying the results to the Canadian context. Particular emphasis was to be placed on both the anticipated major concerns of the Canadian space community and those which were revealed by the study.

The community of interest was defined as broadly as possible. It consists of three main groups: planners and builders of satellite systems, operators of satellites and (potential satellite-based) communications networks, and end users of satellite services. These groups are not mutually exclusive; there is in fact a high degree of overlap.

The relationship between the needs at any particular time and the technology available to meet those needs will be a major determinant of whether MSP's can or should be considered for Canadian satellites. However, a matching of technical needs and capabilities only defines the relevance of the platform concept to the Canadian context. The impact of the technology must be analyzed from two additional points of view: the basic economic trade-offs must be performed and institutional concerns addressed.

Since this study is part of a long range planning program, its goal was not to solve the problems in detail, but rather to determine what the advantages and disadvantages of combining payloads on MSP's are, discover where potential problem areas lie, and define what needs to be done to solve them.

THE TOP LEVEL OBJECTIVE OF THE STUDY WAS TO:

- O ASSESS THE LIKELY IMPACT OF MSP TECHNOLOGY ON CANADIAN SYSTEMS BY
  - O EVALUATING WORK BEING DONE IN THE FIELD
  - O APPLYING IT TO THE CANADIAN CONTEXT
  - O WITH EMPHASIS ON MAJOR CANADIAN SPECIFIC CONCERNS

THE IMPACT ON

- O SYSTEM PLANNERS & OPERATORS
- O SPACECRAFT INDUSTRY
- O MAJOR GEOSYNCHRONOUS SATELLITE SERVICE USERS

WAS CONSIDERED FROM

- O TECHNICAL
- O FINANCIAL
- O INSTITUTIONAL

POINTS OF VIEW

The objectives of the study were met in the following manner.

The starting point was an evaluation of Canadian needs and major concerns about MSP's. A mission model was derived by means of a survey of Canadian satellite system planners, operators, and users; two different questionnaires were used, one for the planners and operators, and the other for major users. These were answered by various experts in their respective fields, and the results were used to determine the volume and nature of Canadian requirements for the various geosynchronous orbit satellite services (communications and others) over the next fifteen to twenty years (the longest period over which reasonable estimates could be made). At the same time as the quantitative market assessments were being made, the respondents were also asked to list their own technical, institutional, and economic concerns, with respect to both the concept of the MSP in general, and its specific applications to Canadian systems.

In parallel with the mission model survey, an assessment was made of the ongoing technical work related to the evolution of large multifunction spacecraft. The literature was surveyed, and major investigators were interviewed, in order to derive a 'technology model'. For each of the major spacecraft systems and support technologies, advances required to support platform development were identified, and estimates made of when these advances would be available. The elements studied were not only those specific to MSP's but also peripheral, but related, ones such as advanced orbit transfer vehicles (OTV's) and on-orbit construction techniques.

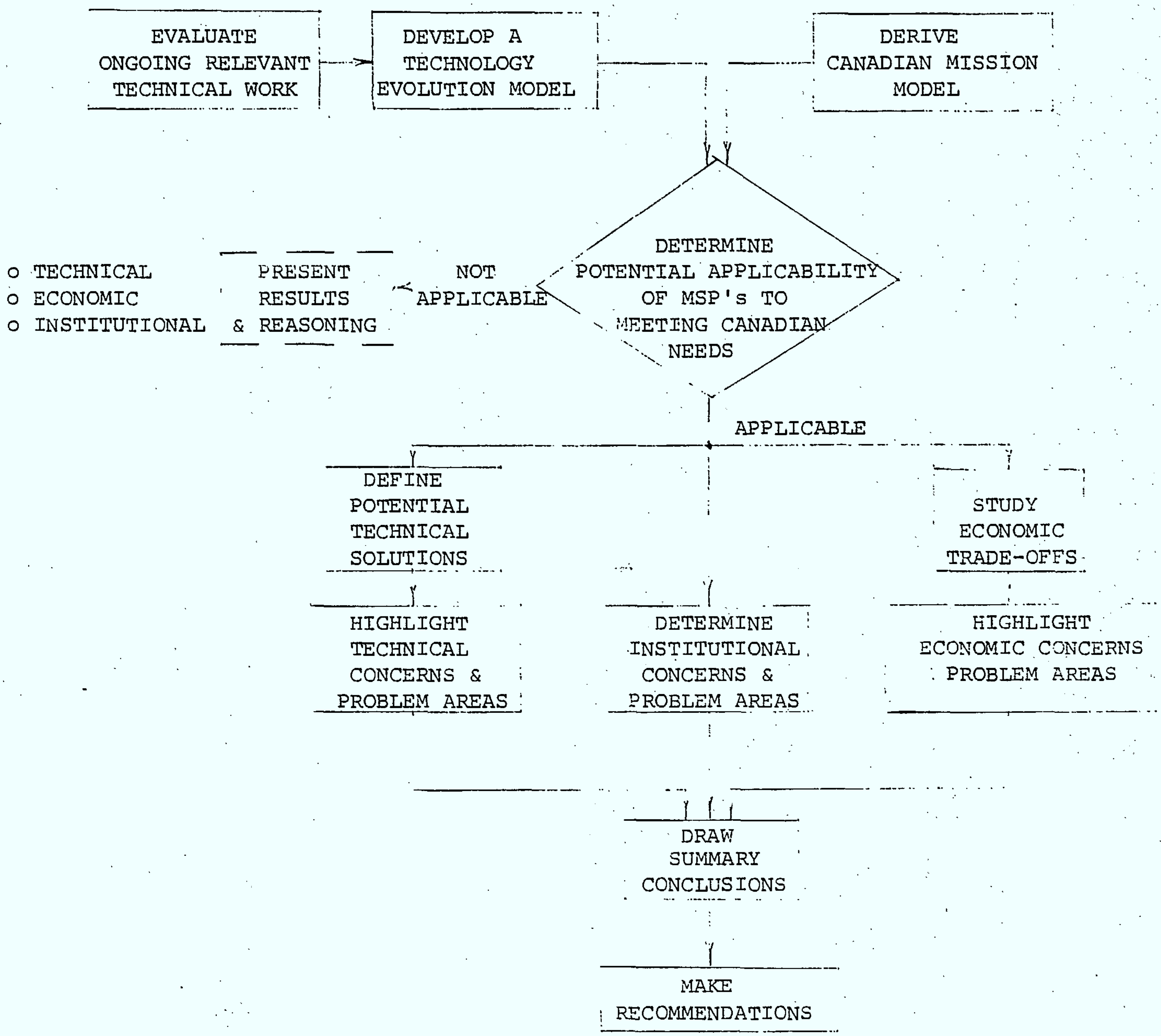
Once the mission model and large platform technology forecast had been completed, they were compared, and the following two questions addressed:

- Is there sufficient user need and payload compatibility at any point in the relevant timeframe to make the use of hybrid spacecraft practical?

- Will the multifunction platform technology of the period be capable of meeting these needs?

As will be seen, the answers to these questions were in the affirmative, so the technical means of meeting the requirements on a multifunction platform were investigated. This was done by developing two strawman spacecraft configurations. These configurations were not analyzed in any great detail, but were used in two ways. First, they provided a means of confirming that the available platform technology would be adequate, and it would be possible to place the payloads on one spacecraft.

THE MAJOR TASKS OF THE STUDY WERE:



The second use of the configuration derivation exercise was to learn first-hand what some of the major trade-offs and difficulties were likely to be in an actual MSP design, and to provide a base for comparative costing in the Canadian context.

All three aspects (technical, economic, and institutional) of the impact of platform technology on Canadian systems were evaluated once the potential applicability was established. The major concerns and drivers were determined for each category, and further work needed to resolve them determined. This was done not only for purely domestic platforms, but also international ones which might affect Canadian systems.

The findings were summarized, and recommendations then made.

3.0 CANADIAN SATELLITE MISSION MODELS

3.1 Introduction and Derivation of the Mission Model

3.1.1 Introduction

The starting point for a study of the potential impact of multifunction space platforms on Canadian satellite systems is by necessity a definition of user requirements, in the form of a mission model. All Canadian satellite systems to date have been applications oriented, and it is anticipated that this will continue in the future, with even scientific satellites continuing to stress 'applied' rather than 'pure' science. In addition, existing communications satellite systems are operational, and the proposed new systems (both communications and remote sensing) are planned to be proto-operational, transitioning smoothly into follow-on operational ones. Consequently, it has been assumed for purposes of this study that a Canadian multi-function space platform will not be developed for its own sake (as a potential export item), but only if it is determined a priori that it is the best technical, and most cost effective, means of meeting the Canadian operational systems' needs of the time.

A mission model survey was conducted in order to determine what the perceived Canadian needs will be as a function of time, and allow us to ascertain whether there is adequate commonality of timing and payload compatibility to make the use of multifunction space platforms practical and/or desirable.

The survey has been restricted to those missions which are in geosynchronous orbit. The time frame of interest is the next twenty years. A first generation experimental platform is being studied by NASA, with a target launch date of the late 1980's; operational systems are planned to follow almost immediately. This places the start date for the mission model at the mid 1980's. Forecasting uncertainties affect the latest date for which requirement estimates can be believed. It would be desirable to have a mission model extending beyond 2000; however, there is already much uncertainty in mission planners' predictions for 1995, so the model has been terminated at that date.

- THE CANADIAN SATELLITE MISSION MODEL IS:
    - A CANDIDATE SET OF MISSIONS (COMMUNICATIONS & OTHERS)
    - USING GEOSYNCHRONOUS ORBIT SATELLITES
    - MEETING CANADIAN NEEDS FROM THE LATE 1980's ONWARDS
- ITS PURPOSE IS TO DETERMINE WHAT NEEDS ARE FORECAST
    - AS A FUNCTION OF TIME
    - OVER THE NEXT 20 YEARS
- IT WILL BE USED TO
    - DETERMINE THE NUMBER & TYPES OF PAYLOADS ANTICIPATED
    - DETERMINE THE TIMING OF THE NEED FOR THE IDENTIFIED PAYLOADS
    - IN ORDER TO ASCERTAIN WHETHER ADEQUATE
        - COMMONALITY OF TIMING
        - PAYLOAD COMPATIBILITY

      EXIST IN ORDER TO CONTEMPLATE THE USE OF MSP'S TO MEET THE NEEDS

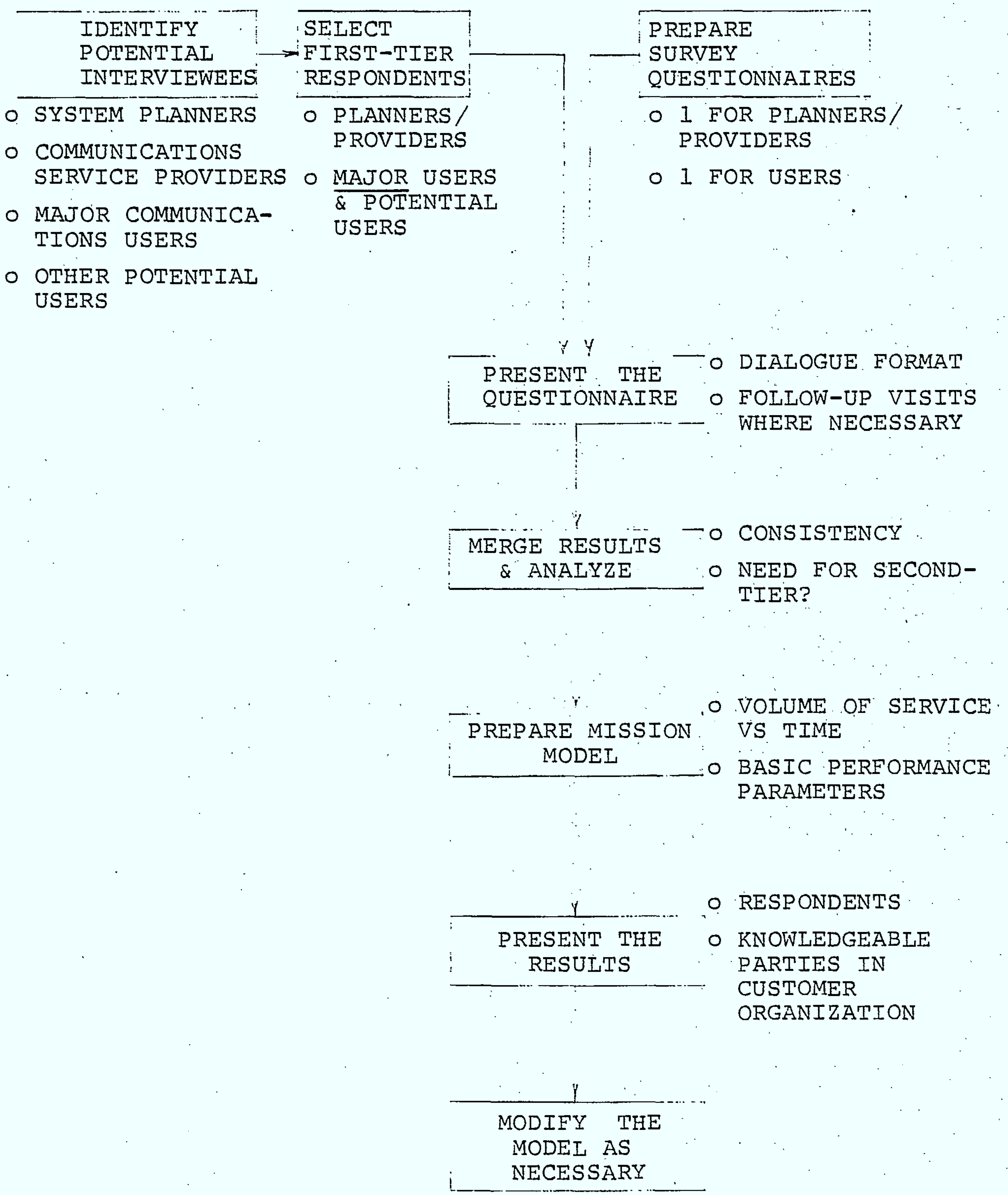
3.1.2 Derivation of the Mission Model

A survey of operators and possible users of satellite services was conducted in order to determine the potential Canadian missions for inclusion on a multifunction space platform. It represents one of a number of different methods which have been used to derive 'future' mission models for planning purposes, including user surveys(75), extrapolation of existing trends(73,74,76,77), and models based on demographic parameters(79). It would be beyond the scope of the present study to develop a detailed mission model by any of these methods; however, it was determined that the user survey would be the most efficient means of deriving a coarse model which would meet the needs of the study.

A survey was prepared which consisted of two questionnaires, one for each of two groups of respondents (see Appendix B). The first questionnaire was intended for common carriers, satellite system operators, and satellite system planners. Its aim was to determine the views of those people most directly involved in the provision of satellite services with respect to the envisaged nature and size of future requirements, as well as their specific feelings and concerns about meeting these requirements with multifunction space platforms. The second questionnaire was for potential users of geostationary satellite services. It was aimed primarily at determining the nature and level of the services which would have to be provided to the users, and hence was most concerned with the performance and institutional aspects of satellite service provision, and less concerned with the technical means of providing the service. Users were asked to consider all types of geosynchronous satellite services, not only communications.

At the same time as the questionnaires were being prepared, potential respondents were identified. These were knowledgeable individuals in both industry and government, representing a total of seventeen different organizations. Following discussions with the customer (DOC), they were grouped into two 'tiers'. The first tier consisted of known major users and all the planners, representing seven organizations in total. It was anticipated that they would be able to provide the necessary level of information for derivation of the mission model, and that it would only be necessary to interview selected individuals in the second tier if major inconsistencies or gaps were discovered in the first set of results.

Appointments were set up with each of the first-tier users to present the questionnaires, and hopefully receive many of the answers in a joint discussion session. All of the selected respondents were willing to participate, and many requested that other individuals in their organization be also given an opportunity to respond, either in a group session or individually. This was agreed to, and a complete list of the respondents is contained in Appendix D.



FLOW OF TASKS IN DERIVATION OF THE MISSION MODEL

In most cases the questionnaire was answered in the initial meeting, with follow-up sessions required to obtain more detailed information in only two instances. It was found that the dialogue format worked very well, as the respondents were able to ask clarifying questions, and present their views in both greater depth and breadth than would be expected from purely written replies.

Once the survey was completed the results were transferred to a common form and analyzed. It was found that there was remarkable consistency, both in projected level of service requirement and timing. Consequently, it was decided not to extend the survey to the second tier of respondents.

In addition to the basic service volume and timing predictions, the planners and users were also asked to provide estimates of the major performance parameters of the systems, such as operating frequencies, downlink/uplink satellite antenna patterns, and ground station figure of merit. These were obtained in order to determine the major spacecraft payload constraints, such as antenna configuration and output amplifier power.

It was determined that the most practical means of achieving the desired confidentiality of the inputs while maintaining the usefulness of the mission model would be to aggregate the results by frequency band, listing only the major parameters and uses of each payload without specifically identifying the relative fraction used by the individual services.

Keeping this constraint in mind, a baseline mission model was created from the results of the survey, and formally presented to a group consisting of the respondents and knowledgeable individuals within DOC. This provided an opportunity for additional feedback and a final revision of the model before it was used in other portions of the study.

In addition to the questions specifically directed at deriving the mission model, the survey contained a number of questions designed to obtain background information for the economic and institutional portions of the study. The respondents were asked to highlight their major technical and institutional concerns, and if possible present information likely to be useful in the cost trade-off analyses. It was found that the questionnaire had its desired catalytic effect, and much useful technical and institutional input was received. Unfortunately, little economic information was received.

GOALS OF THE MISSION MODEL SURVEY

- O DETERMINE BY TYPE OF SERVICE
  - O VOLUME REQUIREMENTS VS TIME
  - O FREQUENCY BANDS USED
  - O MAJOR PERFORMANCE PARAMETERS
- O DETERMINE USERS' TECHNICAL CONCERNS WRT MEETING THEIR NEEDS WITH MSP'S
- O DETERMINE USERS' INSTITUTIONAL CONCERNS
- O OBTAIN BACKGROUND INFORMATION FOR COST TRADE STUDIES

3.2 Mission Model Survey Results

3.2.1 Responses to the Questionnaire for System Planners and Service Providers

This questionnaire was answered in part or in total by six individuals from within three different organizations (Department of Communications, Telesat, TCTS). It was stressed to all of them that it was their personal estimates and opinions which were being solicited, and not official corporate or departmental positions. Despite this caveat, there was almost total agreement in both the quantitative answers related specifically to the mission model, and the qualitative responses and opinions given to the questions concerning technical, economic and institutional concerns. Consequently, it has been assumed that the survey results are a reasonable representation of the current state of Canadian communications satellite system planning.

All respondents addressed the 'Fixed', 'Broadcast', and 'Specialized' service portions of the questionnaire, but only the DOC people answered the 'Mobile' service portion. The others chose to skip this section since they did not feel that they had sufficient current relevant knowledge to provide meaningful answers.

In general, the results paint a very conservative picture of communications system growth, especially when compared to the recent, and continuing, explosive expansion of satellite services in the United States. Some of those interviewed expressed the belief that, even with current regulatory and contractual constraints, a marketing and pricing policy could be developed which would profitably fill all presently planned systems soon after launch. This optimism was not reflected in the quantitative projections provided by the planners, however. Not only is the growth of existing services predicted to be slow, but there was negligible support for the development of 'new' or specialized services on any significant scale. The two cases which stand out in this regard are full-motion videoconferencing and direct-to-user fixed voice/data communications, both of which are predicted to grow considerably in the next decade within the U.S., but neither of which is expected to grow significantly in Canada over the time frame under consideration.

The other area in which conservatism is evident is the response to the 'interconnection of service' question. One of the major advantages put forth for MSP's is their ability to switch among different payloads on board. This allows users to interconnect various services (e.g. fixed telephony and sea mobile) without the use of double hops, as required by present systems. It was generally acknowledged that it was plausible to consider on-board service interconnection, but that the requirements would be too low to justify the added cost and complexity.

A basic conclusion which can be drawn from these conservative growth predictions is that 6/4 GHz and 14/12 GHz systems will provide more than adequate bandwidth to meet the user requirements throughout the time frame of interest, so there is no requirement to develop a 30/20 GHZ system or go to multiple spot-beam frequency reuse antennas based solely on Canadian commercial communications

- ALL RESPONDENTS TO THE "SYSTEM PLANNER/SERVICE PROVIDER" QUESTIONNAIRE PROVIDED INPUTS TO THE 'FIXED', 'BROADCAST', & 'SPECIALIZED' SERVICE PORTIONS.

- THERE WAS BASIC AGREEMENT WITH RESPECT TO

  - VOLUME OF SERVICE REQUIRED AS A FUNCTION OF TIME
  - TIMING OF INTRODUCTION OF NEW SERVICES
  - FREQUENCIES TO BE USED BY EACH SERVICE
  - UPLINK & DOWNLINK SATELLITE ANTENNA PATTERNS
  - GROUND STATION PARAMETERS

- THE RESULTS PRESENT A VERY CONSERVATIVE OUTLOOK

  - PRESENT PLANS FOR TRUNKING SYSTEM GROWTH ARE BASED ON A TIMELY LAUNCH OF ANIK C. THERE WILL BE A REAL REQUIREMENT FOR ITS CAPACITY WHEN IT IS LAUNCHED. THIS REPRESENTS A QUANTUM JUMP IN TOTAL REQUIRED CAPACITY AT THAT TIME
  - THERE WILL BE A SIMILAR QUANTUM JUMP WHEN OPERATIONAL TV BROADCAST SERVICE IS INTRODUCED IN THE LATE 80'S
  - ONCE EITHER OF THESE SERVICES IS INTRODUCED THE GROWTH WILL BE LOW (~20% OVER 5 YRS)
  - THERE WILL BE NEGLIGIBLE INTRODUCTION OF 'NEW' SERVICES, INCLUDING TELECONFERENCING
  - THERE WILL BE NEGLIGIBLE GROWTH IN THE GROUND SEGMENT, WITH RELATIVELY FEW, LARGE TERMINALS CONTINUING TO DOMINATE
  - THERE IS NEGLIGIBLE REQUIREMENT FOR INTER-CONNECTION OF SERVICES (E.G. FIXED-MOBILE VOICE) ON THE PLATFORM
  - 6/4 AND 14/12 GHz SYSTEMS WILL PROVIDE ADEQUATE BANDWIDTH THROUGHOUT THE TIMEFRAME OF INTEREST

3.2.2 Responses to the Questionnaire for Users of Satellite Services

This questionnaire was answered by a total of eleven individuals within four government departments which were considered to be potential major users of satellite services other than those provided by the common carriers. The departments represented were: Department of National Defence, Ministry of Transport (Air Branch and Coast Guard), Energy Mines and Resources (CCRS), and Department of the Environment (AES). As in the case of the first questionnaire, it was stressed to all respondents that the views being presented were recognized as those of knowledgeable individuals in the field, and not official departmental policy.

All four of the departments presently use the common carriers for most of their communications (including the military for operational communications). They are happy with the service they are receiving, and prefer to treat the communications systems as black boxes. It makes no difference to them what method is used to carry the information, as long as all their performance requirements are met in the most economical manner.

In all but one case, several individuals from the user organization were present during the interview. This group format tended to stimulate discussion and free thinking, with the result that a large number of potential new payloads, or new uses of existing payloads, were identified. In each case an attempt was made to identify when these might be implemented, if at all. The result was a sorting into two categories: those to be included in the baseline mission model, and those to be excluded, since their probability of occurrence by 1995 was negligible. The result of this filtering exercise was to add a total of three channels to the fixed communications service requirements, and leave five other payloads out of the baseline. It was hoped that a number of non-communications (e.g. remote sensing) payloads would be identified at this stage; however, such was not the case. Most of the new payloads were communications oriented, with the result that the platform concept arising out of the survey is more a multifunction communications spacecraft, and less of a general purpose geosynchronous platform than was originally anticipated.

A basic conclusion which can be drawn from the results of the user survey is that the basic performance characteristics and requirements of the next two generations of Canadian geosynchronous satellites are known to, and will be driven by, the present service providers and planners. It is unlikely that an individual user will generate a new requirement large enough to significantly alter the system concept.

THE USERS INTERVIEWED:

- CONCENTRATED ON POTENTIAL COMMUNICATIONS APPLICATIONS
- WERE BASICALLY HAPPY WITH THE COMMUNICATIONS SERVICES PROVIDED BY THE COMMON CARRIERS
- WERE FREE-THINKING IN IDENTIFYING POTENTIAL ADDITIONAL OR GROWTH AREAS OF USAGE
- WERE CONSERVATIVE IN THEIR ESTIMATES OF WHEN (OR IF) THE IDENTIFIED POTENTIAL WOULD BE REALIZED

THE IDENTIFIED POTENTIAL SERVICE REQUIREMENTS BEYOND THOSE PROVIDED BY THE COMMON CARRIERS OR PLANNED MOBILE SERVICES ARE:

- 1 CHANNEL FOR REMOTE SENSING DATA BACKHAUL FROM THE ARCTIC
- 1 CHANNEL FOR DND ARCTIC COMMUNICATIONS
- 1 CHANNEL FOR REMOTE MONITORING OF WEST COAST RADAR STATIONS

ADDITIONAL 'LOWER PROBABILITY' PAYLOADS IDENTIFIED, BUT NOT INCLUDED IN THE BASELINE MISSION MODEL ARE:

- MILITARY FIXED COMMUNICATIONS AT 7/8 GHz
- 406 MHz CODED ELT SEARCH & RESCUE TRANSPONDER
- PROGRAMMABLE ATMOSPHERIC SOUNDER
- HIGH RESOLUTION SEVERE WEATHER MONITOR
- SPECIALIZED DATA RELAY FOR WEATHER MONITORING

3.2.3 Results of the Survey - By Type of Service

The next five charts show the quantitative results of the mission model survey. The first four present the basic parameters of each category of service (Fixed, Mobile, Broadcast and Specialized). In keeping with the request of some respondents that their predictions of required capacity as a function of time remain confidential no capacity requirements have been indicated for either the 'Fixed' or 'Broadcast' service. These are presented in aggregate form in the fifth chart, which lists the total 14/12 GHz and 6/4 GHz transponder requirements, without identifying the specific fraction allocated to each service. A range of capacity requirement predictions was received for all four services. In each case the maximum of the range was chosen for the baseline mission model, since this would place the greatest constraint on the platform configuration and power system, and hence result in the worst-case design exercise.

The first service considered is the Fixed Satellite Service. Note that the basic operating parameters of the system are not predicted to change greatly. It was stated by three respondents that the proliferation of small (≃ 2m diameter) earth terminals was desirable, but this was not forecast to happen by the planners.

FIXED SATELLITE SERVICE

- MAJOR SUBGROUPS
  - VOICE (TELEPHONY)
  - LOW SPEED DATA (E.G. TELEX, FAX)
  - HIGH SPEED DATA (>9600 BPS)
  - SPECIALIZED DATA NETS (E.G. WEATHER)
- DATES OF INTRODUCTION
  - ALL SUBGROUPS NOW EXIST VIA COMMON CARRIER
  - DIRECT TO USER IN MID-TO-LATE 1980'S
- FREQUENCY BANDS USED & SATELLITE ANTENNA PATTERNS
  - 6/4 GHz
    - ALL-CANADA COVERAGE IN A SINGLE BEAM FOR BOTH UPLINKS & DOWNLINKS
  - 14/12 GHz
    - 4 ZONE BEAMS (APPROX 2^o BY 3^o EACH) COVERING ALL CANADA FOR DOWNLINKS
    - SINGLE ALL-CANADA COVERAGE BEAM FOR UPLINK
- EARTH STATION CHARACTERISTICS
  - 6/4 GHz: 8-10M DIA FOR TRUNK SERVICE
    8M DIA FOR MEDIUM ROUTE
    4.5M DIA FOR THIN ROUTE
  - 14/12 GHz: 8M DIA FOR TRUNK SERVICE
    4.5M DIA FOR LIGHT TDMA
- EARTH STATION OWNERSHIP
  - EXPECTED TO BE DOMINATED BY TELESAT
  - DEVELOPMENT OF SPECIALIZED COMMON CARRIERS WITH THEIR OWN STATIONS MAY OCCUR NEAR END OF PERIOD

The Mobile Satellite Service is presented next.

It consists of three basic subsets: land, sea, and air mobile, all of which are presently available to some degree internationally. Military land and air mobile systems are operational, as are both civilian and military maritime mobile systems covering the three ocean basins. The services being addressed in the survey are specifically those provided to mobile stations on or over the Canadian land mass and coastal waters.

In parallel with the present MSP study, DOC are conducting separate studies aimed at defining various options for providing land-mobile satellite communications. One of the tasks in those studies is the definition of the communications architecture. At the time of writing no final architecture has been defined, but the options being considered differ from that in this report, which is based on an earlier study conducted by Canadian Astronautics Ltd for DOC [82] and the results of the user survey. This architecture has been retained because of the lack of firmness of any potential updates.

MOBILE SATELLITE SERVICE

- O MAJOR SUBGROUPS
  - O LAND (VOICE & LOW SPEED DATA) } MILITARY & CIVIL
  - O SEA (VOICE & LOW SPEED DATA) } MILITARY & CIVIL
  - O AIR (VOICE & LOW SPEED DATA) } MILITARY & CIVIL
- O DATES OF INTRODUCTION
  - O SEA - SMALL SCALE NOW VIA MARISAT
  - O LAND - LATE 1980'S - BOTH MILITARY & CIVIL
  - O AIR - MID 1990'S AT EARLIEST FOR MILITARY
    - UNLIKELY BEFORE 2000 FOR CIVIL
- O FREQUENCY BANDS USED & SATELLITE ANTENNA PATTERNS
  - O 240-400 MHz (MILITARY LAND & SEA, POSSIBLY AIR)
    - O ALL CANADA & COASTAL ZONES IN A SINGLE BEAM
      - POSSIBLY GLOBAL (VISIBLE DISC)
  - O 806-890 MHz (CIVIL LAND, POSSIBLY AIR)
    - O 24 OF 1^{o} SPOT BEAMS COVERING CANADA
  - O L-BAND (CIVIL SEA, POSSIBLY AIR)
    - O ALL CANADA & COASTAL ZONES IN A SINGLE BEAM
- O VOLUME OF SERVICE, TIME PHASED (TOTAL BANDWIDTH REQUIREMENT)

	1985	1990	1995
O LOW UHF	4 MHz	NO GROWTH	
O HIGH UHF	4 MHz	6 MHz	15 MHz
O L-BAND	500 KHz	GROWTH TO 1 MHz	

- O EARTH STATION CHARACTERISTICS
  - O LOW UHF : TRACKING HELIX/YAGI OR OMNI, VARIOUS G/T
  - O HIGH UHF: OMNI, -25 DB/K
  - O L-BAND : TRACKING DISH, -4 DB/K
- O EARTH STATION OWNERSHIP
  - O BOTH USERS & SPECIALIZED COMMON CARRIERS FOR CIVIL
  - O MILITARY OWNS ITS OWN COMPLETE SYSTEM

The Broadcasting Service is the third presented.

This service encompasses all forms of broadcasting related satellite transmissions, both radio and TV, from network trunking of programs through community antenna (including pay-TV) and direct-to-home systems.

Satellite fed cable systems, many of which carry pay TV, have proliferated in recent years in the United States, but a different regulatory climate has prevented a similar growth in Canada. Most respondents stressed this, and prefaced their answers related to CATV, direct-to-home, and pay-TV with the caveat that the development of these subsystems would be strongly dependent on the outcome of the ongoing CRTC hearings.

Direct broadcast of radio signals is predicted to be carried along with the direct TV signals. UHF direct-to-receiver radio broadcasting is a long range likelihood, but not expected to develop within the timeframe of the survey.

BROADCASTING SERVICE

- O MAJOR SUBGROUPS
  - O NETWORK TRUNKING (RADIO & TV)
  - O CATV FEEDS
    - O PAY TV (SUBSET OF CATV)
  - O EDUCATIONAL TV
  - O DIRECT TO RECEIVER (RADIO & TV)
- O DATES OF INTRODUCTION
  - O NETWORK TRUNKING - NOW
  - O CATV FEEDS - NOW
    - O PAY TV: DEPENDENT ON CRTC
  - O EDUCATIONAL TV: 1983-85
  - O DIRECT TO RECEIVER (OPERATIONAL) - LATE 1980'S
- O FREQUENCY BANDS USED & SATELLITE ANTENNA PATTERNS
  - O 6/4 GHz (NETWORK TRUNKING & CATV)
    - O 4 ZONE BEAMS (2^o X 3^o) FOR DOWNLINKS
    - O ALL CANADA FOR UPLINKS
  - O 14/12 GHz (NETWORK TRUNKING, DIRECT BROADCAST, & EDUC)
    - O 4 ZONE BEAMS (2^o X 3^o) FOR DOWNLINKS
    - O ALL CANADA FOR UPLINKS
- O EARTH STATION CHARACTERISTICS
  - O 6/4 GHz : 8-10M DIA FOR TRANSMIT & NETWORK RECEIVE
4.5M DIA FOR CATV RECEIVE ONLY
  - O 14/12 GHz: 8-10M DIA FOR TRANSMIT
4.5M DIA FOR NETWORK RECEIVE
1.2-2.5M DIA FOR ETV & DIRECT BROADCAST RECEIVE ONLY
- O EARTH STATION OWNERSHIP
  - O TELESAT FOR UPLINKS
  - O USERS (INCLUDING NETWORKS) FOR DOWNLINKS

Specialized Services

This category contains many relatively small volume subgroups, and one potential system driver: full motion video teleconferencing.

Projections of the turn of the century capacity requirements for teleconferencing range from near zero, to an order of magnitude greater than all other fixed communications systems combined. The high predictions are based on an extrapolation of current business travel levels, and the assumption that fuel prices will drive the cost of travel high enough that a significant fraction (5-10%) will be replaced by video teleconferences. Estimates of the typical duration and number of conferences are then made in order to derive the required satellite capacity. Those making low estimates argue that user acceptance of a teleconference instead of a face to face meeting is presently negligible, and likely to remain so, no matter what the cost incentives. Those questioned during the survey fall into the latter category of 'low growth' predictors, so very little teleconferencing capacity has been included in the mission model.

The remainder of the subgroups were predicted to start at low levels with the introduction of Anik C, and remain at low levels.

SPECIALIZED SERVICES

- O MAJOR SUBGROUPS IDENTIFIED BY THOSE SURVEYED
  - O VIDEO TELECONFERENCING
  - O ELECTRONIC FUNDS TRANSFER
  - O ELECTRONIC MAIL
  - O REMOTE PRINTING

- O DATES OF INTRODUCTION
  - O VIDEO TELECONFERENCING - CAPABILITY NOW EXISTS USING STANDBY FACILITIES, BUT NOT BEING EXPLOITED
  - O ELECTRONIC FUNDS TRANSFER - NOW VIA COMMON CARRIERS
  - O ELECTRONIC MAIL - AT LOW LEVEL WITH ANIK C
  - O REMOTE PRINTING - 1981

- O FREQUENCY BANDS USED & SATELLITE ANTENNA PATTERNS
  - O 14/12 GHz IN LONG RUN FOR ALL
    - O 4 ZONE BEAMS (2^{0} X 3^{0}) COVERING ALL CANADA

- O EARTH STATION CHARACTERISTICS
  - O EXISTING 8-10M DIA STATIONS IN COMMON CARRIER SYSTEMS FOR MOST
  - O SOME 4.5 & 6M DIA STUDIO-BASED ANTENNAS FOR TELECONFERENCING

- O EARTH STATION OWNERSHIP
  - O TELESAT

The final chart presents the SHF capacity requirements in aggregate form. They contain all the identified Fixed, Broadcasting and Teleconferencing requirements, and the three 'additional' payloads identified by users.

SHF TRANSPONDER REQUIREMENTS

O BASIC ASSUMPTIONS:

- o 6/4 GHz
  - O EACH TRANSPONDER HAS A BANDWIDTH OF 36 MHz
  - O SERVICES PROVIDED ARE:
    - O FIXED COMMUNICATIONS (TELEPHONY & DATA)
    - O BROADCAST DISTRIBUTION (NETWORK FEEDS)
    - O REMOTE SENSING & MILITARY DATA BACKHAUL FROM THE NORTH
- o 14/12 GHz
  - O EACH TRANSPONDER HAS A BANDWIDTH OF 54 MHz
  - O SERVICES PROVIDED ARE:
    - O FIXED COMMUNICATIONS (TELEPHONY & DATA)
    - O DIRECT BROADCAST & VIDEO TELECONFERENCING
    - O REMOTE SITE RADAR MONITOR BACKHAUL
  - O ONE TRANSPONDER CARRIES TWO DIRECT TV BROADCAST CHANNELS
- O TRANSPONDER REQUIREMENTS, TIME PHASED

	1985	1990	1995
o 6/4 GHz	15	19	24
o 14/12 GHz	9	20	25

3.2.4 Results of the Mission Model Survey - Summary

The basic objectives of the mission model survey were achieved: Canadian geosynchronous orbit payload requirements were defined over the period of interest, and their operating parameters were obtained in sufficient detail to determine whether they could feasibly be accommodated on a domestic multifunction space platform.

The total payload requirements are modest, with only 49 operational SHF channels and a total L-band/UHF bandwidth of 20 MHz being predicted for 1995. The total coverage areas for all services are similar, so that a common orbit slot could be used without compromising any payload's needs. In addition, the currently planned time frame for introduction of the mobile and broadcast services matches that for the next generation of Telesat spacecraft. Consequently, it would appear to be feasible to meet the system requirements identified in the mission model survey with a single multifunction space platform launched in 1987-89, and sized for the 1995 requirements. It would be an 8-year lifetime satellite. This concept will be examined further in sections 3.4 and 4.4.

IN CONCLUSION:

- O THE TOTAL PAYLOAD REQUIREMENTS OF THE MISSION MODEL ARE MODEST, ESPECIALLY WHEN COMPARED TO MISSION MODELS IN OTHER SPACE PLATFORM STUDIES

- O BASIC MISSION TIMING COMPATIBILITY EXISTS
  - O NEXT FAMILY OF ANIK'S: LATE 1980'S, BOTH 14/12 & 6/4 GHz
  - O MOBILE SYSTEM IMPLEMENTATION DATE: LATE 1980'S
  - O OPERATIONAL DIRECT BROADCAST IMPLEMENTATION DATE: MID TO LATE 1980'S

- O AN EARLY GENERATION PLATFORM COULD BE USED TO CARRY SOME OR ALL OF THE PAYLOADS AT THAT TIME

  AND/OR

  THE REPLACEMENT SYSTEMS (MID 1990'S) COULD BE PLACED ON A LARGER, SECOND GENERATION MSP

- O ANTICIPATED REQUIREMENTS ARE:

	1985	1990	1995
LOW UHF	4 MHZ	4 MHZ	4 MHZ
HIGH UHF	4 MHZ	6 MHZ	15 MHZ
L-BAND	500 KHZ	----→	1 MHZ
C-BAND	15 CH	19 CH	24 CH
KU-BAND	9 CH	20 CH	25 CH

3.3 Comparison of the Mission Model Survey Results with other Models

3.3.1 Introduction

In the past two years NASA have funded a number of studies to evaluate the market demand for fixed communications service via satellite [73-77], and other studies which contain similar market demand derivations as subtasks [29,79]. These have been aimed at determining when either 30/20 GHz systems, or multiple spot-beam frequency re-use antennas (on platforms), will be required to meet total capacity demands which exceed the capabilities of 'conventional' C- and Ku-band satellite systems. Because it is the point-to-point communications services which are predicted to dominate the capacity requirements within the U.S., they are the ones which have been studied in most detail.

One of the studies [29] explicitly includes a Canadian component, but the remainder are restricted to the U.S. market. It is nevertheless useful to analyze the study methods and results, not only as a guide to the reasonableness of the present mission model, but also as an indicator of the range of estimates which can be obtained from even detailed studies.

The other payloads identified in the Canadian mission model survey (mobile and direct broadcast) have been included in most lists of candidate payloads for MSP's. However, since their requirements are not the primary ones which will drive the development of platform-based systems, they were not analyzed in nearly the same depth as the point-to-point services.

One of the studies [79] specifically excluded broadcast services from the candidate payload list. The argument used was that the communications architecture (multiple spot beams) of platforms is not well adapted to video distribution, which requires wide area dissemination of common signals. For this reason, it was expected that small specialized satellites would be used for most TV distribution (other than specialized local programming and network trunking). This apparent incompatibility does not exist in Canada. On the contrary, the downlink antenna patterns for Ku-band telephony service defined in the mission model survey (4 regional beams) match those desired for broadcast, and the traffic levels identified are low enough that smaller beams will not be required for spectrum conservation through additional frequency re-use.

- NASA HAVE FUNDED A NUMBER OF STUDIES CONTAINING MISSION MODELS TO DERIVE:
    - TRANSPONDER REQUIREMENTS FOR 'FIXED' SERVICES (POINT TO POINT)
    - OVER THE NEXT TWENTY YEARS
    - FOR BOTH MULTIFUNCTION PLATFORM & 30/20 GHz PLANNING PURPOSES
- THE MAJOR STUDIES WERE CONDUCTED BY
    - SPACE PLATFORMS
        - COMSAT
        - FUTURE SYSTEMS INCORPORATED
        - AEROSPACE CORPORATION
        - GENERAL DYNAMICS/CONVAIR
    - 30/20 GHz
        - WESTERN UNION
        - ITT
- MOBILE AND BROADCAST PAYLOADS
    - INCLUDED IN MOST MSP CANDIDATE PAYLOAD LISTS
    - NOT STUDIED IN SAME DEPTH AS POINT TO POINT

3.3.2 Individual Market Studies

Future Systems Incorporated (FSI)

FSI have produced a number of satellite service requirement forecasts based on demographic and economic indicators and service use correlation factors. One such forecast is contained in a cost trade study they performed in 1979 for NASA[79], and their work has also been heavily relied upon by the Aerospace Corporation[71] and General Dynamics/Convair[29] in the conduct of their geostationary platform studies.

The FSI study provides a forecast of U.S. point-to-point telephony and data traffic. Video services were excluded on the grounds that they would not be carried on MSP's. The two sets of traffic estimates were obtained by separate means.

The telephony traffic model was developed using correlation factors derived from historical data, and subsequently applied to forecasts of future population and GNP. FSI have found that GNP per telephone is a factor which is nearly uniform for all countries at similar levels of economic development. This factor was coupled with another known one, the ratio of long distance calls per telephone, to derive the ratio of long distance calls per unit GNP. This correlation factor was applied to estimates of future population and GNP per capita to predict the volume of long distance telephone traffic. This was then converted to the number of trunks required using statistics on average call duration and number of channels per trunk. The 'capture fraction', or portion of this total service which would be carried by satellite, was estimated from a comparison of the economic break-even point (distance) between terrestial and satellite transmission, and the distribution of long distance calls versus distance. The final conversion was to the number of 'equivalent 36 MHz transponders' required to handle the traffic, based on a capacity of 1000 half circuits per transponder.

Because data transmission is a new service for which the above method cannot be applied, market forecasts must be used. FSI chose to base their estimates on an SBS market survey described in a 1976 FCC filing. For purposes of digital data transmission, an equivalent 36 MHz transponder was assumed to be capable of handling 64 Mbps.

Four sets of traffic predictions are shown opposite: the FSI study numbers, and those in the two other reports which relied heavily on FSI data. Note that one set explicitly includes a Canadian model.

The fourth set of data is labelled 'FSI-Update'. This represents the results of a recent (March 80) FSI study[30] which has reworked the estimates based on more recent information. The study results are stated to be contingent on the development of high capacity advanced satellites of the type described in the report (387 equivalent 36 MHz transponders, 4440 kg, 11 kW). The study report has been recently received, and not yet analyzed in detail.

- FSI ESTIMATED, FOR UNITED STATES DOMESTIC COMMUNICATIONS
  - TELEPHONY TRAFFIC USING DEMOGRAPHIC & ECONOMIC FACTORS
  - DATA TRAFFIC USING AN SBS MARKET SURVEY
- THEIR STUDY EXCLUDED VIDEO TRAFFIC FROM CONSIDERATION
- RESULTS BASED ON THEIR METHODS ARE:*

YEAR	1980	1985	1990	1995	2000
FSI STUDY (REF. 79)	108	298	465	665	890
FSI UPDATE (REF. 30)	73	313	734	1128	
AEROSPACE CORP'N STUDY (REF. 71)			643 (55 VID)	900 (75 VID)	1260 (105 VID)
GEN. DYNAMICS STUDY (REF. 29)			455	574	688
- CANADIAN			47	59	71

- BOTH AEROSPACE & GENERAL DYNAMICS STUDIES INCLUDE VIDEO DISTRIBUTION
- CAPTURE FRACTIONS: FSI - 8% OF TELEPHONY OVER 500 MI
  AEROSPACE - 10% OF TOTAL CIRCUITS
  G-D/C - UNDEFINED
- *CAPACITY DEFINED IN TERMS OF 'EQUIVALENT 36 MHz TRANSPONDER'
  - 1000 HALF CIRCUITS (VOICE)

  OR
  - 64 MBPS (DATA)

  OR
  - 2 CHANNELS (VIDEO)
- BOTH ORIGINAL FSI STUDY & AEROSPACE PREDICT 7% GROWTH IN 1990'S, G-D/C PREDICTS 4%

COMSAT Laboratories

COMSAT Labs performed a Geostationary Platforms Mission and Payload Requirement Study for NASA in 1979[75]. Its main objectives were to identify time-phased missions and payloads for potential accommodation on geostationary platforms, and to identify the engineering requirements placed on the platform housekeeping elements by selected payloads.

The study was aimed more at determining the technical parameters of the potential MSP payloads than the actual capacity requirements. The parameters were obtained from a detailed user survey, which contained one question related to capacity. The respondents were asked to estimate what portion of the total communications marketplace would be served by satellites in 1984. The results of approximately 25 questionnaires were consolidated, and a 'most probable' estimate derived for each service. These were then extrapolated to 1989. It was the intent that the actual transponder requirements be established by applying the capture fractions thus arrived at to the total communications markets being estimated as part of the 30/20 GHz studies[73,74,76,77].

The 'capture fractions' are higher than those estimated by FSI.

COMSAT LABS

- O USED A 'CARD SELECTION' FORM OF USER SURVEY TO
  - O RANK MISSIONS IN ORDER OF "IMPORTANCE"
  - O ESTIMATE WHEN NEW SERVICES WOULD BE INTRODUCED
  - O DETERMINE MAJOR TECHNICAL PARAMETERS
  - O ESTIMATE THE MARKET SHARE ('CAPTURE FRACTION')
- O THE ESTIMATED CAPTURE FRACTIONS ARE:

	1984	1989
O TELEPHONY	20%	25%
O NETWORK TV & CATV	90%	97%
O HIGH SPEED DATA & EFT	10%	35%
O OTHER DATA (INC. TELECONF)	35%	55%

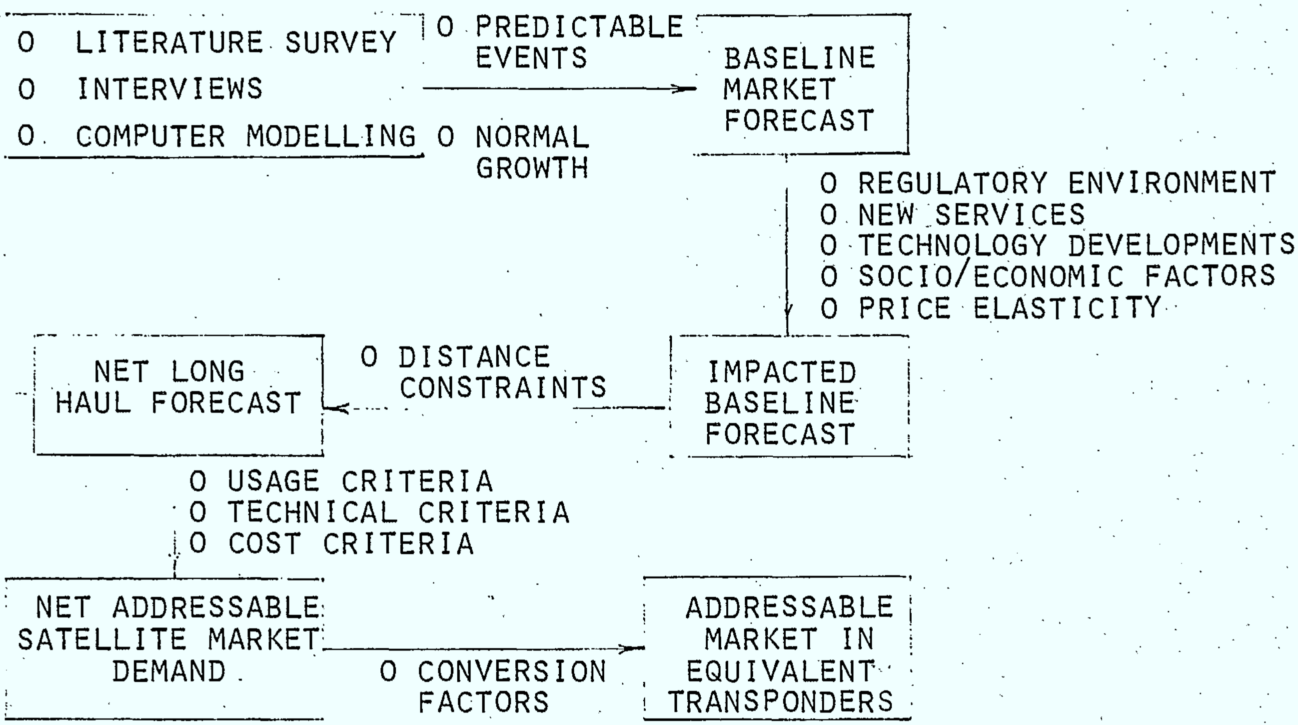
Western Union

Western Union[73,76] was one of two contractors who developed satellite fixed communications system service demand assessments for NASA in 1978-79. The study was aimed at determining the need for 30/20 GHz services, but its basic mission model is equally applicable to an MSP service demand study.

The model was derived in a bottom-up fashion. A detailed literature survey was used to develop a data base of both current communications requirement levels and market trends/forecasts. The inital results were discussed with government, university and industrial (communications and market research industries) experts, and suitably modified. A set of market forecasts were then developed using computer modelling, with "high", "low", and "expected" scenarios being produced. The 'expected' case, which was based on lower risk, predictable events and 'normal' levels of growth was used as the baseline forecast. This forecast was then further modified by the application of market determinant and cross impact factors to yield what was defined as the "impacted baseline forecast". The application of distance-related constraints to this model produced the net long haul traffic forecast.

This forecast was converted to a "net addressable satellite market demand" by applying three sets of criteria (user/usage characteristics, technical considerations, terrestial/satellite cost crossover) to arrive at potential (= "addressable") capture fractions. These were converted from the basic communications units (e.g. half-circuits for voice) to number of transponders by assuming a transponder bandwidth of 36 MHz for 1980, and 50 MHz for 1990 and 2000. This assumption takes into account both the introduction of wider bandwidth transponders at Ku and Ka band, and (implicitly) the introduction of improved bandwidth utilization techniques.

THE WESTERN UNION STUDY FLOW WAS:



THE RESULTANT 'ADDRESSABLE MARKET' TRANSPONDER REQUIREMENTS AND CAPTURE FRACTIONS ARE:

	1980	1990	2000
VOICE	346 (16%)	630 (18%)	1862 (21%)
DATA	6 (43%)	42 (46%)	201 (53%)
VIDEO	72 (45%)	157 (62%)	258 (72%)
TOTAL	424	829	2321

International Telephone and Telegraph (ITT)

ITT [74,77] was the other contractor providing 30/20 GHz market assessments for NASA, and they also developed their model from the bottom up, in a method very similar to that used by Western Union.

The study commenced with a data base developed from a literature survey and series of interviews. For the mature services, correlating demographic and economic trends were used to project telecommunications traffic levels, which were then adjusted for the impact of regulatory trends. Traffic models for new or rapidly changing services were developed using studies, and estimates of such factors as business document flow, travel replacement, and the substitution of electronic means for hard copy in data filing and transmittal. All projections were in user oriented units. Distance factors were then applied to produce a long distance traffic model.

At this point all traffic projections were converted to common units (terabits/yr), to allow easier comparison, and in recognition of the fact that most transmission would be digital in the time frame of interest. Because capacity must be provided for the maximum expected loading, estimates were made of the relevant peak/average ratios. A series of technical and economic analyses were performed to arrive at satellite capture fraction estimates. The results were presented in terms of 'digital equivalent transponders', a unit which was derived to account for improved modulation and access techniques. The assumed capture fractions for the various services are similar to those of Western Union. However, the net transponder requirements are significantly less, even when converted to common throughputs. The ITT data projections are much higher than WU's, but this is more than made up for by a relatively low (in comparison) telephony requirement.

ITT ASSUMED DIGITAL TRANSPONDER THROUGHPUTS OF

- o 42 MBPS IN 1980 (CONSERVATIVE)
- o 72 MBPS IN 1990
- o 108 MBPS IN 2000

THE TRANSPONDER REQUIREMENTS AND CAPTURE FRACTIONS ARE:

	1980	1990	2000
VOICE	21 (2)	225 (15)	475 (25)
DATA	5 (1)	355 (50)	438 (60)
VIDEO	35 (50)	110 (60)	210 (60)
TOTAL	61	690	1124
EQUIV TO WU (WU VALUE)		558 (829)	1364 (2321)

- o CONVERTED USING WU THROUGHPUT = 89 MBPS IN 1990 & 2000

3.3.3 Relationship of the U.S. Models to the Canadian Mission Model

Because of the strong similarity between the Canadian and U.S. economies and lifestyles, it would appear reasonable to assume that the two sets of communications markets would also be similar if suitably scaled according to population. Canadian business communications are less well developed than those in the U.S., largely because of the difference in scale, but the lower population density would conceivably partially compensate, putting more of the traffic on satellites. A similar compensatory situation exists in the video field, where the CATV feeder service has grown rapidly in the U.S., but not in Canada, primarily because of differences in regulatory and institutional aspects. The compensating factor in this case is the heavier Canadian use of satellites for network trunking. Consequently, it is assumed that potential Canadian transponder requirements are roughly 10% of those in the U.S. This is consistent with the General Dynamics' model.

The comparative values for all the referenced models are listed opposite. The totals contain telephony, data and video distribution services, but no direct broadcast. All results have been converted to a common basis of 'equivalent 36 MHz transponders'.

The Canadian planners' and users' estimates are below even the G-D/C model values, which are themselves the lowest of the U.S. sets of estimates. This implies that the Canadian mission model derived during the study is relatively conservative, and there is room for significant expansion beyond that foreseen.

The range of predictions among the U.S. studies is noteworthy. The three 'primary' references (most detailed stand-alone studies) are the Western Union, ITT and FSI reports, which show a range of 250% to 350% between the low and high estimates. Even the two concurrent studies based on the same statement of work (WU and ITT) show a 50-70% variation. This serves to highlight the difficulty in projecting traffic requirements even ten years ahead of time, a factor which must be taken into consideration in satellite system design: there must be enough built in flexibility to accommodate growth and/or changes in demand which arise during the system's lifetime.

COMPARATIVE SURVEY RESULTS

STUDY \ YEAR	1980	1985	1990	1995	2000
WU	424		1151		3224
ITT	61		776		1897
FSI (NO VIDEO)	108	298	465	665	890
FSI-UPDATE	73	313	734	1128	
AEROSPACE			643	900	1260
G-D/C			455	574	688
G-D/C (CAN)			47	59	71
CAL STUDY		29	37	50	

- PRESENT (CAL) STUDY VALUES INCLUDE 3.5 TRANSPONDERS FOR POTENTIAL ADDITIONAL SERVICES IDENTIFIED BY USERS, BUT EXCLUDE TVBS FOR CONSISTENCY WITH OTHER SURVEY RESULTS.

3.4 Baseline Mission Model for Configuration Studies

A specific set of payload configurations meeting the requirements of the mission model were defined, and used to produce two strawman versions of potential Canadian MSP's.

The purpose of doing this was twofold. Basic mission timing compatibility had already been determined, but not the technical feasibility of combining all the payloads on one platform. This feasibility could only be ascertained by defining the payload configurations and support requirements, and matching them to the capabilities of the technology expected to be available at the time. In addition, it was felt that the actual exercise of defining some strawman configurations would yield valuable insight into the types of problems likely to be encountered, and trade-offs which would have to be made, during an actual platform design.

The payloads were sized to meet the 1995 requirements of the mission model, since there were no substantive estimates of the requirements beyond that time. Preliminary link calculations were performed to define the RF power requirements. It was assumed that the spacecraft would be launched in the late 1980's and would have an 8-year design life. It was also assumed that the platform would be fully deployed and checked out in low Earth orbit before being boosted to geosynchronous altitude by a low thrust OTV (Centaur derivative - 4700 Kg capability).

The next five charts show the basic parameters for each payload. Preliminary link calculations are presented in Appendix C.

BASELINE MISSION MODEL:

O WHAT

- O CANDIDATE SET OF PAYLOADS
- O MEETING IDENTIFIED TRAFFIC REQUIREMENTS OF 1995

O WHY

- O DETERMINE BASIC TECHNICAL <u>FEASIBILITY</u> OF A CANADIAN MSP

  W.R.T. O MASS
  O POWER
  O ORBIT SLOT REQUIREMENT

  CONTRAINTS

- O DEVELOP STRAWMAN CONFIGURATIONS
  - O CONFIRM FEASIBILITY
  - O HIGHLIGHT DESIGN CONSTRAINTS, TRADE-OFFS

The low UHF payload provides land and sea mobile service to the military. The antenna pattern selected was one of two options presented; the other was full coverage of the visible portion of the Earth. The choice of limited coverage over global was based on a desire to include the more constraining of the two configurations, not the one considered most likely.

240-400 MHz BAND PAYLOAD PARAMETERS

- O CAPACITY
  - O 4 MHz TOTAL BANDWIDTH
  - O SCPC/DAMA OPERATION
- O COVERAGE
  - O ALL CANADA & COASTAL ZONES
  - O SINGLE BEAM
  - O 18M DIAMETER, DEPLOYABLE MESH ANTENNA
- O OUTPUT STAGES
  - O FULLY REDUNDANT SOLID STATE AMPLIFIER
  - O 0.5 W PER LINK, UP TO 50 IN PARALLEL
- O MASS & POWER ESTIMATES
  - O 30 KG REPEATER
  - O 90 KG ANTENNA (REFLECTOR & FEEDS)
  - O 100 WATTS DC POWER TO PAYLOAD

The high UHF payload provides civilian land mobile service. The payload configuration is based on the survey results, and does not reflect the configuration studies being conducted by DOC in mid 1980.

806-890 MHz BAND PAYLOAD PARAMETERS

- CAPACITY
  - 15 MHz TOTAL BANDWIDTH
  - SCPC/DAMA OPERATION
- COVERAGE
  - ALL CANADA
  - 24 OF 1^{o} SPOT BEAMS
  - 26 M DIAMETER, OFFSET FED MESH PARABOLA
- OUTPUT STAGES
  - FULLY REDUNDANT SOLID STATE AMPLIFIER
  - 6.5 W MAXIMUM PER AMPLIFIER, 1 AMPLIFIER/BEAM
- MASS & POWER ESTIMATES
  - 225 KG REPEATER
  - 250 KG ANTENNA (REFLECTOR AND FEEDS)
  - 400 WATTS DC POWER TO PAYLOAD

The L-band payload is interoperable with the INMARSAT system. The Canadian landmass is also covered to allow for the possible development of aeronautical mobile service.

L-BAND PAYLOAD PARAMETERS

- O CAPACITY
  - O 1 MHz TOTAL BANDWIDTH
  - O SCPC/DAMA OPERATION

- O COVERAGE
  - O ALL CANADA & COASTAL WATERS
  - O SINGLE BEAM
  - O 7 M DIAMETER, DEPLOYABLE MESH PARABOLA

- O OUTPUT STAGES
  - O FULLY REDUNDANT SOLID STATE AMPLIFIER
  - O 1 WATT PER CHANNEL, UP TO 50 IN PARALLEL

- O MASS & POWER ESTIMATES
  - O 55 KG REPEATER
  - O 45 KG ANTENNA (REFLECTOR & FEEDS)
  - O 200 WATTS DC POWER TO PAYLOAD

The C-band payload provides the point-to-point services defined earlier plus the central station backhaul for the mobile services.

6/4 GHz PAYLOAD PARAMETERS

- CAPACITY
  - 24 CHANNELS TOTAL
  - EACH CHANNEL 36 MHz USABLE BANDWIDTH
  - MIXED OPERATION (TDMA, FM/FDM/FDMA)
- COVERAGE
  - REGIONAL BEAMS FOR VIDEO: 4 OF 2^{o} X 3^{o}
  - ALL CANADA FOR TELEPHONY/DATA
  - 3 M DIAMETER, OFFSET FED PRECISION PARABOLA
- OUTPUT STAGES
  - TWTA
  - 30 TUBES FOR 24 CHANNELS, RING REDUNDANCY
  - 5 WATTS PER TUBE, ALL 24 OPERABLE EOL
- MASS & POWER ESTIMATES
  - 115 KG REPEATER
  - 40 KG ANTENNA (REFLECTOR & FEEDS)
  - 360 WATTS DC POWER TO PAYLOAD

The performance parameters of the Ku-band system provide significant margins for the fixed services. The direct broadcast performance is adequate for the 1.5-1.8 m diameter TVRO antenna systems predicted to be the standard by those surveyed. However, the EIRP is lower than the currently discussed 54 dBW EOC, and will not support a TVBS system using 80 cm - 1.2 m earth stations.

14/12 GHz PAYLOAD PARAMETERS

- O CAPACITY
  - O 25 CHANNELS TOTAL
  - O EACH CHANNEL 54 MHz USABLE BANDWIDTH
  - O MIXED OPERATION (TDMA, FM/FDM/FDMA)
- O COVERAGE
  - O ALL CANADA, MADE UP OF 4 REGIONAL BEAMS
  - O 2 M DIAMETER, OFFSET FED PRECISION PARABOLA
- O OUTPUT STAGES
  - O TWTA
  - O 30 TUBES FOR 25 CHANNELS, RING REDUNDANCY
  - O 50 WATTS PER TUBE, ALL 25 OPERABLE EOL
- O MASS & POWER ESTIMATES
  - O 240 KG REPEATER
  - O 30 KG ANTENNA (REFLECTOR & FEEDS)
  - O 3125 WATTS DC POWER TO PAYLOAD

The basic payload parameters are combined in this chart. It is seen that the mass and power requirements are modest compared to those in early studies of large geostationary platforms (approximately 6000-10000 KG, 10's of kW). Estimates were made of the deck mounting area required for each payload, and north-south facing heat rejection area requirements.

SUMMARY OF CANDIDATE PAYLOADS

O PAYLOAD PARAMETERS

PAYLOAD	ANTENNA DIA (M)	MASS (KG) ANTENNA DISH	ANTENNA FEEDS	REPEATER	TOTAL
LOW UHF	18	80	10	30	120
HIGH UHF	26	150	100	225	475
L-BAND	7	25	20	55	100
C-BAND	3	25	15	115	155
KU-BAND	2	15	15	240	270
					1120 KG

O SUPPORT REQUIREMENTS CONSIDERATIONS

PAYLOAD	POWER (W) DC IN	RF OUT	AREA (M^2) MOUNTING	HEAT REJ'N
LOW UHF	100	25	.2	.4
HIGH UHF	400	155	.7	1.3
L-BAND	200	50	.2	.8
C-BAND	360	120	5.	1.3
KU-BAND	3125	1250	6.	10.
TOTAL	4185	1600	12.1	13.8

4.0 TECHNOLOGY OF MULTIFUNCTION SPACE PLATFORMS

4.1 Introduction

The development of the multifunction space platform concept can be traced to a series of study efforts undertaken by NASA in the early 1970's to define desirable directions for the space program during the last quarter of the century.

One of those studies was conducted by the Aerospace Corporation, and the results were publicly presented in mid 1976 (2). The goal of the study was to determine areas in which industrial exploitation of space could occur in the period 1980-2000. The guidelines were to assume that weekly launches, on-orbit maintenance and continuous manned operation would become routine. The concepts were presented purely as potential applications requiring only reasonable extrapolation of existing technology, and operation based on known principles. It was intended that the publication of the concepts would stimulate further innovation and technical and economic discussions.

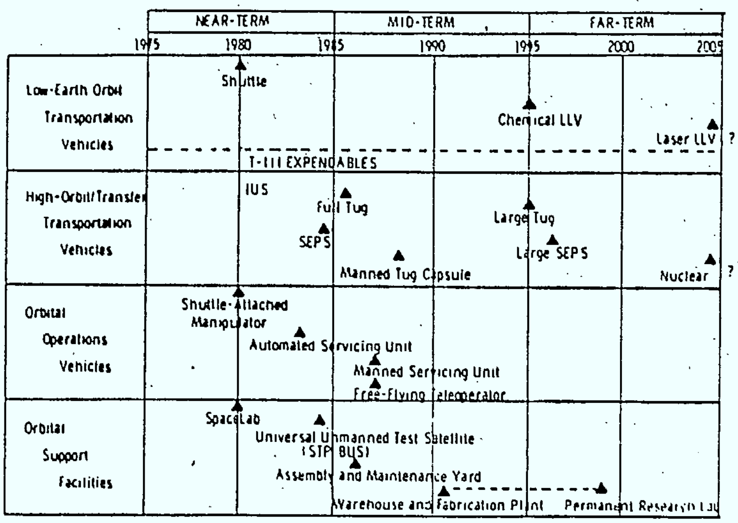
Satellite communications was one of the fields studied. The technology limitations which had restricted early communications satellites to being purely simple repeaters were foreseen to disappear in the near future, and with them the concept of a complex earth segment and simple space segment. 'Technology inversion' was advocated, with large, powerful, and complex satellites being used to interconnect very many tiny, extremely low power terminals on the ground. It was predicted that such a system would not only expand the capabilities of the overall communications system in terms of volume and type of service offered, but would do so at lower cost than present systems, because of the large number of significantly cheaper user terminals. A number of potential uses of such a system were presented, including personal communications (portable terminals), electronic mail, data collection, and data retrieval (Telidon-type systems).

THE MULTIFUNCTION SPACE PLATFORM CONCEPT WAS DEVELOPED IN EARLY 70's NASA STUDIES

- O TO DEFINE SPACE SYSTEM CONCEPTS WITH <u>POTENTIAL</u> UTILITY IN 1980-2000
- O TO EXTRACT FROM THE CONCEPTS LIKELY NEEDS FOR
  - O TRANSPORTATION
  - O OPERATIONAL FACILITIES
  - O SUPPORT BASES

THE TECHNOLOGY INVOLVED WAS

- O A REASONABLE EXTRAPOLATION OF THAT EXISTING AT THE TIME
- O BASED ON KNOWN PRINCIPLES
- O ANTICIPATED TO EVOLVE RELATIVELY QUICKLY[2]



COMPLEX, POWERFUL COMMUNICATIONS SATELLITES WERE IDENTIFIED AS ONE SUCH CONCEPT. THE MAJOR NEW ELEMENTS W.R.T. CURRENT SYSTEMS WOULD BE:

- O TECHNOLOGY INVERSION
- O EXPANSION OF SERVICE
- O INTERCONNECTION OF SERVICES

One year after publication of the NASA study results, the Orbital Antenna Farm (OAF) concept was presented[(3)]. This particular version was developed at Comsat Labs, and is usually thought of as the original multifunction space platform.

A system comprising five OAF's was projected to be capable of meeting most of the global communications needs as early as the 1990's. One spacecraft in the constellation, the 'OAF Americas' was studied in more detail, in order to estimate the number and configurations of the payloads, and the types of support services required. This satellite was to carry payloads capable of serving 17 communications missions, to have a beginning of life mass of 6500 kg, to require 20,000 watts from its solar panels and to have a battery capacity of 18,000 watt-hours. The OAF Americas satellite would be linked to other large OAFs using inter-satellite links at frequencies too high to be useful for satellite to earth links.

TECHNOLOGY LEVELS REQUIRED FOR OAF's

- COMMUNICATIONS
  - LARGE, MULTIBEAM FREQUENCY REUSE ANTENNAS
  - ON-BOARD
    - DEMODULATION
    - BASEBAND SWITCHING
    - BIT REGENERATION
    - ERROR CORRECTION CODING

- PLATFORM
  - LARGE, LIGHTWEIGHT STRUCTURES
  - LOW COEFFICIENT OF THERMAL EXPANSION MATERIALS
  - THERMAL CONTROL SYSTEMS CAPABLE OF HANDLING A WIDE RANGE OF DISSIPATIONS
  - CENTRALIZED POWER MANAGEMENT SYSTEM
  - ACS CAPABLE OF MAINTAINING PLATFORM POINTING TO 0.1^{o}
  - HIGH CAPACITY, ADAPTIVE TELEMETRY & COMMAND
  - ON-BOARD COMPUTERS: CENTRAL MINI & DISTRIBUTED MICROS

- AUXILIARY SYSTEMS
  - ON-ORBIT SERVICING - 'DESIRABLE'
    - MODULARITY
    - SPACE TUG/TELEOPERATOR
  - ON-ORBIT CONSTRUCTION TECHNIQUES
  - HEAVY-LIFT OTV'S

- TECHNOLOGY PREDICTED TO EXIST BY 1990'S
  - ADVANCED PROPULSION & POWER SYSTEMS
  - HIGH-ENERGY-DENSITY FUEL CELLS
  - FLYWHEEL ENERGY STORAGE
  - ELECTRIC PROPULSION
  - WELL DEVELOPED ON-BOARD DATA PROCESSING

Even though the early proponents of MSP's predicted that they could be operational as early as the 1990's, they did recognize that many technical problems would have to be overcome for this to happen. The major areas in which development was required were recognized by even the visionaries. In addition, a number of other authors[3,14,9] have pointed out further technical challenges to the concept, as well as some basic disadvantages relative to individual satellite systems.

The technical challenges can and will be met as the need arises, although the evolution of MSP technology will likely be much slower than originally forecast. The generic problems are some of the parameters which must be weighed against the advantages already stated for platforms when performing the detailed trade-off studies before committing to a specific system. Their existence does not preclude the development of the technology, but will strongly influence where, when and how it is applied.

SOME OF THE MAJOR IDENTIFIED TECHNICAL PROBLEMS RELATED TO LARGE MULTIFUNCTION PLATFORMS ARE:

'GENERIC' PROBLEMS

- O A COMPROMISE ORBIT SLOT MUST BE CHOSEN VS OPTIMIZING EACH SATELLITE'S LOCATION IN 'CONVENTIONAL' SYSTEMS
- O THE REQUIREMENTS OF THE INDIVIDUAL PAYLOADS ON BOARD MAY DIFFER IN THE FOLLOWING CATEGORIES
    - O ORBIT SPACING
    - O STATIONKEEPING
    - O ATTITUDE CONTROL
    - O LIFETIME
    - O GROWTH CAPABILITY
- O VULNERABILITY OF MANY PAYLOADS TO FAILURE OF THE BUS

TECHNICAL CHALLENGES

- O DEVELOPMENT OF LARGE MULTIBEAM FREQUENCY REUSE ANTENNAS
- O DEVELOPMENT OF FAST, HIGH CAPACITY SWITCHES
- O PROTECTION AGAINST RFI/EMI
- O DEVELOPMENT OF SOPHISTICATED & FLEXIBLE TELEMETRY AND COMMAND SYSTEMS
- O DEVELOPMENT OF IMPROVED ATTITUDE CONTROL SYSTEMS
- O DEVELOPMENT OF IMPROVED POWER MANAGEMENT SYSTEMS
- O DEVELOPMENT OF THERMAL CONTROL SYSTEMS CAPABLE OF HANDLING LARGE & VARIABLE LOADS
- O DEVELOPMENT OF HIGHER PERFORMANCE (LARGER CAPACITY, LOW THRUST) OTV'S
- O DEVELOPMENT OF COST EFFECTIVE LIFETIME EXTENDERS (IMPROVED RELIABILITY AND/OR SERVICING)

Some of the areas in which significant technology evolution is required before operational large MSP's enter service are already well understood.

TECHNOLOGY EVOLUTION REQUIRED FOR LARGE MSP's

o	STRUCTURES	- MSP WILL REQUIRE THE DEVELOPMENT OF VERY LARGE DIAMETER, LARGE F/D RATIO ANTENNAS AND THEIR SUPPORT SYSTEMS. IN ADDITION MORE DEVELOPMENT IS REQUIRED FOR LARGE, LIGHTWEIGHT STRUCTURES FOR THE BUS.
o	ASSEMBLY/ SERVICING	- MODULARIZATION TECHNIQUES ARE REQUIRED, INCLUDING TECHNIQUES FOR REPLACEMENT OF FAILED MODULES AND FOR ADDITION OF NEW MODULES. TECHNIQUES FOR IN ORBIT FABRICATION OR STRUCTURE ERECTION ARE ALSO REQUIRED.
o	COMMUNICATIONS TECHNOLOGY	- HIGH RELIABILITY SOLID STATE TRANSMITTERS SHOULD BE DEVELOPED. MUCH WORK REMAINS TO BE DONE CONCERNING ON BOARD REGENERATION, SATELLITE SWITCHING AND SPECTRUM EFFICIENT MODULATION SCHEMES. THE PROBLEM OF RF INTERFERENCE BETWEEN MISSION PAYLOADS MUST BE ADDRESSED. PROBLEMS OF HIGH VOLUME, NARROW BEAM INTERSATELLITE LINKS (MSP TO MSP) MUST BE SOLVED.
o	ATTITUDE CONTROL	- PROBLEMS IN ORIENTING VERY LARGE, SOMEWHAT FLEXIBLE STRUCTURES SUBJECT TO THERMAL DISTORTIONS MUST BE ATTACKED. SCHEMES FOR EFFICIENTLY HANDLING THE DIVERSITY OF POINTING REQUIREMENTS MUST BE DEVELOPED.
o	ANTENNAS/FEEDS	- VERY LARGE DIAMETER, LARGE F/D RATIO ANTENNAS MUST BE DEVELOPED. TECHNOLOGY MUST BE DEVELOPED FOR MULTIBEAM ANTENNAS AND SHAPED BEAM ANTENNAS WITH LOW SIDE LOBES AND GOOD CROSS POLARIZATION CHARACTERISTICS OFF AXIS.

TECHNOLOGY EVOLUTION REQUIRED FOR LARGE MSP's (CONTINUED)

- POWER - VERY LARGE (20 KW) POWER SYSTEMS MUST BE DEVELOPED.

- THERMAL - MUST DEVELOP NEW TECHNIQUES FOR THERMAL BALANCE AND HEAT REJECTION. MINIMIZE THERMAL DISTORTION OF STRUCTURE TO A GREATER EXTENT THAN EVER BEFORE (AMPLIFYING EFFECT OF LARGE STRUCTURE).

- PROPULSION - DEVELOP HIGHER RELIABILITY OR REPLACEABLE RCS THRUSTER SYSTEMS.
  DEVELOP HIGHER EFFICIENCY RCS SYSTEMS E.G. BI-PROPELLANT.
  DEVELOP NEW, LARGE, LOW THRUST ORBIT TRANSFER VEHICLES

- DATA MANAGEMENT AND CONTROLS - DEVELOP SHARED HOUSEKEEPING SYSTEM.

The present status of the various technologies indicates that there are many areas which are still at an early stage of evolution towards MSP-level capability.

TECHNOLOGY EVOLUTION - PRESENT STATUS

o	STRUCTURES	- MUCH EFFORT ALREADY UNDERWAY BUT COMPARABLE TECHNOLOGY WILL NOT BE SPACE TESTED FOR A FEW YEARS AT LEAST
o	ASSEMBLY/ SERVICING	- BASIC STUDIES ONLY, SPACE SHUTTLE OPERATIONS SHOULD SOON PROVIDE PRACTICAL RESULTS
o	COMMUNICATIONS TECHNOLOGY	- MOSTLY STUDIES AND EXPERIMENTS, SOME RF INTERFERENCE EXPERIENCE ON FLTSATCOM, ATS-6 AND MARISAT, SOME INTERSATELLITE LINK EXPERIENCE (K_a BAND) ON LES 8 & 9.
o	ATTITUDE CONTROL	- NEW AREA, MUCH DEVELOPMENT WORK REMAINS
o	ANTENNAS/FEEDS	- MUCH EFFORT UNDER WAY, ATS-6 HAD FAIRLY LARGE ANTENNA, BUT MSP WOULD REQUIRE SIGNIFICANTLY LARGER ANTENNAS, MULTI-BEAM TECHNOLOGY IS JUST NOW EMERGING.
o	POWER	- MUCH EXPERIENCE GAINED ALREADY FROM CTS & SKYLAB.
o	THERMAL	- NEW AREA, SHARED THERMAL CONTROL NOT LIKELY POSSIBLE.
o	PROPULSION	- BIPROPELLANT TECHNOLOGY HAS BEEN TESTED AND WILL BE USED ON SHUTTLE. NEW LARGE UPPER STAGE WILL LIKELY BE BASED ON CENTAUR.
o	DATA MANAGEMENT AND CONTROL	- NEW STUDIES REQUIRED, ON BOARD COMPUTERS HAVE FLOWN AND COULD BE BASIS OF THE SYSTEM.

The problems to be overcome, both institutional and technical, before a satellite on such a grand scale as the OAF can become a reality, are not all likely to be satisfactorily solved by the early 1990's. Furthermore, even the most optimistic of the visionaries who believe that the MSP is inevitable recognize that some experimental packages may have to be orbited first in the search for solutions to some of the difficult technical problems to be overcome.

The current thinking[29] is that MSP's themselves are an evolutionary concept. The original C-band satellites had hemispherical coverage patterns, and were later followed by satellites having a narrower regional coverage beam such as the shaped Canadian coverage beam on Anik A. The trend now is towards still narrower spot beams to permit frequency reuse, and towards multi-band satellites such as ANIK-B, Marisat, FLTSATCOM, TDRSS and Intelsat V. Another technique for increasing capacity which has been used at C and Ku band is orthogonal polarization. Some of these satellites, notably Intelsat V, also have some interconnectivity.

These satellites may be considered as the first steps in the evolution of MSPs. Basically the attributes of an MSP are a variety of payloads, common bus functions and interconnectivity, resulting in economies of scale, bandwidth efficiency and new and improved services resulting from the connectivity. The OAF Americas concept is actually the final step foreseen in this evolutionary process.

In parallel with the more general acceptance of the evolutionary nature of the MSP concept, there has been a broadening of the definition of what constitutes a multifunction platform. It is now defined more in terms of its three basic attributes: multiple payloads, connectivity and central subsystem support. Size is not an essential characteristic, nor is the sharing of a single platform structure by all payloads in the system.

It is this latter fact which represents the greatest change in thinking. Clusters of current technology satellites have been proposed[19] to perform the same functions as single platforms, trading off potential economies of scale for the low development cost and low risk resulting from the use of current technology. Until recently, clusters and platforms were seen as different systems competing for a single market share, and this is still true to a degree if one restricts the cluster concept to that originally proposed. However, the most recent study conducted for NASA[29] has considered clusters of both single and multiple payload spacecraft within the definition of MSP's, and in fact has found that clusters of smaller platforms may well be preferable to a single large platform from both cost and operational points of view.

MORE RECENT CONCEPTS OF AN MSP

- AN EVOLUTIONARY CONCEPT -

	COVERAGE	POLARIZATION	FREQUENCIES	INTER-CONNECTIVITY
EARLY COMMUNICATIONS SATELLITES	HEMISPHERICAL	SINGLE	C-BAND	NONE
↓	↓ REGIONAL	↓	↓	↓
	↓ SPOT/MULTIBEAM		C + KU BAND	LIMITED
MSPs	↓ NARROW SPOT/MULTIBEAM	DUAL	↓ MULTIBAND	↓ COMPLETE

- A BROADER DEFINITION OF WHAT IT MAY LOOK LIKE -

FOUR POSSIBILITIES ARE:

- O A SINGLE PLATFORM LAUNCHED INITIALLY, MULTIPLE PAYLOADS ADDED AS NEEDED
- O PLATFORM MODULES
  - O LAUNCHED OVER A PERIOD OF TIME
  - O EACH CARRIES PAYLOAD & SOME SUPPORT SYSTEMS
  - O DOCKED DEPENDENT MODULES
    - O EACH IS DEPENDENT ON THE POWER, TT&C, AND THERMAL CONTROL SYSTEM OF THE FIRST MODULE LAUNCHED
- O PLATFORM MODULES
  - O LAUNCHED OVER A PERIOD OF TIME
  - O EACH CARRIES PAYLOAD & FULL SUPPORT SYSTEMS
  - O DOCKED INDEPENDENT MODULES
    - O PAYLOADS INTERCONNECTED
    - O NO PLATFORM SUBSYSTEM SHARING
- O PLATFORM MODULES
  - O LAUNCHED OVER A PERIOD OF TIME
  - O EACH CARRIES PAYLOAD & FULL SUPPORT SYSTEMS
  - O FLY IN FORMATION (CLUSTER)
    - O PAYLOADS INTERCONNECTED BY MICROWAVE LINKS

The current view of MSPs as being an evolutionary process has the advantage of allowing an examination of competing technologies and their merits before committing to a large project with many problems yet unresolved.

Single mission satellites deployed as at present can be designed to more closely match the mission requirements without the compromises likely to be generated by MSPs, and do not present the same institutional problems. Demand assignment, orthogonal polarization and increased bandwidth efficiency from improved modulation techniques could greatly increase capacity. Multibeam spacecraft antennas could further increase capacity; however, large earth station antennas would still be necessary for side lobe minimization and non interference from other satellites. Clusters of single mission satellites connected by inter-satellite links and precisely stationkept could provide some of the performance advantages of the MSPs, while reducing the problems of in orbit maintenance or replacement. The clusters would not, however, have the economies of scale resulting from shared bus functions and more efficient space transportation system utilization, but would be able to use existing technology and STS elements.

In addition, non satellite communications techniques (e.g. improved cable systems, guided millimeter waves and fibre optics) may steal some of the projected capacity required from satellite based systems. Fibre optics installations are now being installed, by AT&T and AGT amongst others, in regular commercial service over links up to 50 km. It is now expected that a transcontinental or transatlantic cable could be operating in 1990.

COMPETING TECHNOLOGIES

SINGLE MISSION SATELLITES

- AVOIDS TECHNICAL COMPROMISES
- AVOIDS INSTITUTIONAL PROBLEMS
- HAS FURTHER CAPABILITIES FOR CAPACITY INCREASE
- LARGE EARTH STATIONS STILL REQUIRED
- DOES NOT PROVIDE MSP ECONOMIES OF SCALE

SATELLITE CLUSTERS (SINGLE PAYLOAD PER SATELLITE)

- PROVIDE MSP PERFORMANCE
- DO NOT PROVIDE MSP ECONOMIES OF SCALE
- CAN USE EXISTING TECHNOLOGIES

LAND BASED SYSTEMS

- CABLES, GUIDED MILLIMETER WAVES, FIBRE OPTICS
- FIBRE OPTICS ARE NOW AT THE "TAKE OFF" PHASE

4.2 Technical Impact of MSPs on Satellite Systems

4.2.1 Introduction

The development of multi-function space platforms will require the development of new satellite system technology.

As compared with single mission satellites, MSPs are larger, heavier and require more power. Thermal dissipation, telemetry and command are distributed on MSPs and centralized on single satellites. MSPs will tend to have larger antennas and more complex feed systems for multibeam frequency reuse. The MSP structure, being larger, will also tend to be more flexible and more subject to thermal bending. MSPs will have to be designed to have a longer life than single mission satellites and to be more reliable to avoid catastrophic failures. MSPs will tend to have more complex on board processing to enable the connectivity between mission payloads.

The following sections describe the current status and predicted evolution of the various technologies. NASA currently hope to launch an experimental platform in 1987 or 88, to test various platform technologies. Some of the particular subsystem requirements likely to be proven on that mission have been identified.

MSPs vs SINGLE MISSION SATELLITES

	MSPs	SINGLE MISSION
o SIZE o MASS o THERMAL DISSIPATION o ANTENNAS o STRUCTURAL FLEXIBILITY o RELIABILITY	LARGER	SMALLER
o THERMAL DISSIPATION o TELEMETRY o COMMAND	DISTRIBUTED	CENTRALIZED
o ANTENNA/ FEED SYSTEM o SIGNAL PROCESSING	MORE COMPLEX	SIMPLER
o LIFETIME	LONGER	SHORTER

4.2.2 Structure

Structures of the scale of the OAF Americas require new technology development, some of which may not be available until the year 2000. The evolutionary growth of MSPs will be paced by the development of structures and materials technology.

New analytical tools are required for prediction of strctural behaviour at 0g, at low orbit transfer vehicle thrust levels ($\leq 0.2g$), under 0g assembly/deployment loads, stationkeeping and attitude control maneuver loads and (for advanced MSPs) docking loads and impacts during servicing. MSP structures will, generally speaking, be too weak to withstand testing in a 1g environment.

New structural designs (e.g. foam in place) will be required to produce very lightweight structures, with very high packaging density to decrease the number of Shuttle flights required.

New joining technology is desirable to produce structures with fewer joints and quick joins. The structure must minimize thermal distortion.

Geometrically, shadowing of the solar arrays must be prevented, thrusters allowed to act through the C of M while firing in an east-west or north-south direction, and solar torques must be minimized.

The structure should permit modularity for advanced MSP design to allow platform buildup and replacement of modules.

STRUCTURE TECHNOLOGY

ANALYTICAL TOOLS

- STRUCTURAL INTEGRITY IN ORBIT
- LARGE STRUCTURE DYNAMICS
- AVOID 1G TESTING
- AVAILABLE/VERIFIED BY NASA EXPT ≈ 1990

NEW STRUCTURAL DESIGNS

- LIGHTWEIGHT STRUCTURES
- HIGH PACKAGING DENSITIES
- EVOLUTIONARY - RESULTS STARTING TO SHOW NOW, SHOULD BE WELL DEVELOPED ≈ 2000

NEW JOINING TECHNOLOGY

- FEWER JOINTS
- QUICK JOINS (E.G. LATCHING)
- SOLAR OR ELECTRIC JOINT FUSING
- EVOLUTIONARY - 1987-2000

THERMAL DISTORTION CONTROL

- LOW CTE MATERIALS
- THERMAL INSULATION
- SURFACE TREATMENT
- MUCH OF THIS TECHNOLOGY IS AVAILABLE NOW, NEW LOW CTE MATERIAL WILL HAVE BEEN TESTED BY NASA BY 1990

MODULARITY

- PERMITS PLATFORM BUILD UP
- PERMITS EQUIPMENT REPLACEMENT
- CURRENT MMS TECHNOLOGY, EVOLVING - NASA TESTING ON EARLY MSP BY 1990

4.2.3 Materials

New materials will be required to build the lightweight structures required by MSPs. The transition from aluminum structures to fibreglass and honeycomb structures plus graphite composite components has already begun. Current graphite composites have cut weight in half for some components, but at greatly increased cost. Further materials development will be required to reduce the weight by another factor of two while reducing the cost below conventional (aluminum) components, and to extend the range of components which can be built with these composites. In particular, the use of non-isotropic materials for the large momentum wheels required for large MSPs could result in considerable weight savings.

In addition to minimizing weight, new materials should have lower coefficients of thermal expansion to reduce structural deformation, which is not only more severe for these large satellites, but more critical because of the tight pointing requirements of the narrow spot beams.

Finally, more work needs to be done to determine the effects of long duration exposure of materials to radiation. Structures should be sufficiently radiation resistant to allow a 30 year useful lifetime in order to make the large platforms truly cost effective.

MATERIALS TECHNOLOGY

- WEIGHT & COST TRADE-OFFS

TYPE	RELATIVE WEIGHT	RELATIVE COST	AVAILABILITY
ALUMINUM	1	1	NOW
GRAPHITE COMPOSITES	0.5	5	NOW/SOON
ADVANCED COMPOSITES (CERAMICS?)	0.25	0.5	≃ YEAR 2000

- TWO OTHER CRITICAL TECHNOLOGIES ARE
  - LOW CTE MATL
    - FIRST NASA TEST 1987
    - EVOLUTION TO CONTINUE TO AT LEAST 2000

- RADIATION RESISTANCE
  - MORE R&D REQUIRED
  - GROUND BASED - ACCELERATED EXPOSURE
  - SPACE BASED - ACCELERATED BY PLACING FACILITY IN ORBIT WITH SEVERE RADIATION ENVIRONMENT

4.2.4 In Orbit Assembly/Deployment

Current technology for deployment in space is now well developed, but assembly techniques (erectable structures and space fabricated trusses) have not yet been tested in space to any significant extent. Techniques of assembly must be developed which do not involve heavy loading of the existing structure, in order to minimize structural weight.

Present concepts are to assemble or deploy the spacecraft in low earth orbit (LEO) where it may be checked out by astronauts prior to raising it to GEO.

DEPLOYMENT/ASSEMBLY TECHNOLOGY

ANTENNAS

- 10M DIAMETER DEPLOYABLE ANTENNA - SPACE PROVEN NOW
- STS LARGE DEPLOYABLE ANTENNA TEST BED - 1988
- FREE FLYING LARGE DEPLOYABLE ANTENNA - 1991
- ERECTABLE ANTENNA - 1992

STRUCTURE/TRUSSES

- DEPLOYABLE BOOMS - NOW
- DEPLOYABLE TRUSSES - 1987 NASA PLATFORM
- ERECTABLE STRUCTURES - 1992
- SPACE FABRICATED TRUSSES/STRUCTURES - 1997

STS BASED CONSTRUCTION EXERIMENTS - 1985-1991

MAJOR CONSTRUCTION PROJECTS - 1993-1997

4.2.5 Communications Technology - Spacecraft & Links

Considerable new communications technology must be developed to permit the evolution of MSPs. Much of this new technology, however, is also applicable to single mission satellites and clusters.

Among the technologies most important to MSPs is on board satellite switching, payload control and signal processing.

These are applicable to both single platform and cluster forms of MSP. The variable distances among the various elements of the cluster will place additional constraints on the design for this version, because of the variability of transit times.

ON BOARD SWITCHING/PROCESSING TECHNOLOGY

- RF SWITCHING	-	16 x 16 SWITCHES AVAILABLE 1978, NEEDS MUCH WORK TO DECREASE WEIGHT AND COST AND TO INCREASE CAPACITY.
	-	GETS RID OF SOME DOWNLINKS AND UPLINKS, INCREASES FLEXIBILITY.
- BIT STREAM PROCESSOR	-	RF TO IF, DEMOD THE DIGITAL BIT STREAM, SWITCH AND MODULATE ANOTHER CARRIER ON A SYMBOL-BY-SYMBOL BASIS
	-	NEEDS MUCH WORK, AVAILABLE 1985-1990
	-	CAN BE USED TO SUPPRESS UPLINK NOISE
- FULL BASEBAND PROCESSOR	-	RF, DEMOD, DECODE, SWITCH, RE-ENCODE AND REMOD
	-	MUCH DEVELOPMENT WORK REQUIRED, AVAILABLE 1990-1995
	-	CAN ROUTE MESSAGES OR OTHERWISE PROCESS THE SIGNAL
- ON-BOARD REGENERATION	-	STUDIES AND LABORATORY EXPERIMENT
	-	AVAILABLE ≃ 1990
- SSTDMA	-	INHERENT SYSTEM ADVANTAGES AND GROWTH POTENTIAL
	-	LESS COMPLEX SPACECRAFT AND HIGHER TERMINAL COSTS RELATIVE TO FDMA
	-	SBS IS NOW PUTTING CONSIDERABLE EFFORT INTO REDUCING TERMINAL COSTS
	-	TECHNOLOGY IS AVAILABLE 1985-1990
	-	PROBABILITY OF PROBLEM SOLUTION IS LIKELY BETTER THAN FOR SATELLITE SWITCHING
- ON-BOARD PAYLOAD CONTROL (RECONFIGURATION)	-	DYNAMICALLY REALLOCATES RESOURCES TO MAXIMIZE SYSTEM EFFICIENCY
	-	NEW DEVELOPMENT REQUIRED, SOME APPLICATION ON INTELSAT V AVAILABLE 1985-1990
	-	INCLUDES USE OF VARIABLE POWER DIVIDERS AND VARIABLE PHASE SHIFTERS

Other technologies very important for the evolution of MSPs are RFI/EMI alleviation techniques, intersatellite links and lower cost earth station baseband and RF electronics.

RFI/EMI PROBLEMS

- GENERATED BY PROXIMITY OF PAYLOADS
- CAN BE SOLVED WITH ENOUGH SPACE AND FILTERING
- PROBLEMS HAVE ALREADY BEEN ADDRESSED (E.G. FLTSATCOM AND MARISAT)

INTERSATELLITE LINKS

- WILL USE HIGHER FREQUENCIES, HAVE TIGHT POINTING REQUIREMENTS
- TECHNOLOGY DEMONSTRATED IN 1976 ON LES 8&9 AT KA BAND
- NEW TECHNOLOGY DEVELOPMENT REQUIRED FOR HIGHER FREQUENCIES (≈ 55 GHZ) AND LASER LINKS, AVAILABLE 1990-1995

LOWER COST EARTH STATIONS

- MSPS WILL OPERATE WITH SMALLER EARTH STATIONS, BUT COST REDUCTION IS BECOMING LIMITED BY EARTH STATION ELECTRONICS
- RAPID EVOLUTION/REDUCED COSTS IN ELECTRONICS FIELD LIKELY TO ENABLE OVERALL LOWER COST EARTH STATIONS BY 1985-1990
- TRANSITION TO DIGITAL SWITCHING IN GENERAL HAS BEGUN - ALL NEW EXCHANGES IN THE 1990'S LIKELY TO BE DIGITAL AND SOFTWARE WILL DOMINATE THIS GENERATION
- A COMPLETE LOW NOISE MICROWAVE RECEIVER IC MADE OF GAAS HAS BEEN DESIGNED BY ROCKWELL MICROELECTRONICS - COULD BE MOUNTED DIRECTLY IN ANTENNA FEED BRINGING SATELLITE TRANSMISSIONS DIRECTLY INTO HOMES - AVAILABLE 1985.

Other satellite communications technologies will also prove very useful in the evolution of the MSP concept, for example: modulation/coding techniques, new power output devices, and higher frequency bands.

MODULATION/CODING TECHNIQUES

- WILL GREATLY INCREASE CAPACITY
- DELTA MODULATION - NOW
- LINEAR PREDICTIVE CODING - 1980-1985
- HIGH BIT RATE MODEMS - 1985-1990
- NEW INTERFERENCE RESISTANT MODULATION TECHNIQUES - STILL IN STUDY/EXPERIMENT PHASE - NEEDS MORE WORK
- FORWARD ERROR CORRECTION - NOW
- ADVANCED ERROR CORRECTING TECHNIQUES - STILL IN STUDY/EXPERIMENT PHASE - NEEDS MORE WORK

NEW POWER OUTPUT DEVICES

- NEW TWT'S
  - 12 GHz TWT'S, 100-300W RANGE - AVAILABLE 1981-1982
  - X-BAND TWT'S, 260W - 1981-82 FLIGHT MODEL
    480W - 1980-81 ENGINEERING MODEL
    800W - 1980 BREADBOARD STAGE
- SOLID STATE POWER AMPLIFIERS (SSPA'S)
  - CAN SUBSTITUTE FOR TWTA'S
  - REDUCES SIZE AND WEIGHT
  - INCREASES LINEARITY
  - REDUCES AM-PM CONVERSION
  - REDUCES DEGRADATION IN LINK MARGIN (DUE TO INTERMOD AND CROSSTALK)
  - INCREASED LIFETIME
  - LOW POWER DEVICES AVAILABLE NOW

HIGHER FREQUENCY BANDS

- 1100 MHz AVAILABLE AT C-BAND AND 1 GHz KU-BAND BUT 2500 MHz AVAILABLE AT KA BAND
- EFFECTS OF ATTENTUATION AND DEPOLARIZATION STILL NOT WELL KNOWN AT KA BAND. SOME FEEL ORTHOGONAL POLARIZATION TECHNIQUE NOT POSSIBLE - MORE RESEARCH NEEDED
- SIGNAL FADE MONITORING TECHNIQUES SHOULD BE DEVELOPED ALONG WITH EARTH STATION UPLINK POWER CONTROL
- ADAPTIVE POLARIZATION CORRECTION TECHNIQUES SHOULD BE DEVELOPED - MAY SOLVE ORTHOGONAL POLARIZATION ISOLATION PROBLEM

4.2.6 Attitude Control

The development of new attitude control technology is critical for the operation of MSPs. The MSPs will tend to be very large flexible satellites with potential for significant thermal bending and solar radiation torque problems. In addition to flexibility problems, large MSPs could be subject to accelerations larger than now experienced by most present day satellites.

ATTITUDE CONTROL PROBLEMS OF LARGE MSPs

- LARGER STRUCTURE, SOLAR ARRAYS, ANTENNAS RESULT IN LOWER RESONANT FREQUENCIES
- INCREASED ACCELERATIONS DUE TO:
  - WORN CMGs
  - PUMPS, VALVES, ROTATING JOINTS
  - NON IDEAL SLEW CHARACTERISTICS
  - TURBULENT COOLANT FLOW
  - RENDEZVOUS/DOCKING LOADS
- MUST GUARANTEE A LARGE SEPARATION BETWEEN THE MODAL FREQUENCIES AND THE BANDWIDTH OF THE CONTROL SYSTEM. CURRENT TECHNOLOGY SOLUTIONS ARE:
  - STIFFENING THE STRUCTURE - MASS BECOMES TOO LARGE
  - DECREASING THE BANDWIDTH - POINTING ERRORS BECOME TOO LARGE, SYSTEM TOO SLUGGISH
- NEW TECHNOLOGIES REQUIRED FOR CONTROL OF THE VIBRATORY RESPONSES OF STRUCTURAL MODES
  - AUGMENTATION OF STRUCTURAL DAMPING - NEEDS STUDY AND EXPERIMENT
  - GLOBAL ABSORPTION OF ENERGY BY MONITORING AND COUNTERACTING VIBRATION AT SEVERAL POINTS ON THE MSP - NEW TECHNOLOGY, COULD BE TESTED ON NASA PLATFORM IN 1987 AND BE AVAILABLE IN EARLY 1990's
  - ULTIMATELY "OBSERVER CONCEPT" AND ADAPTIVE MODAL CONTROL, AVAILABLE ≃ 1995
- THERMAL DISTORTIONS
  - CAN BE REDUCED BY LOW CTE MATERIALS ≃1987-1990
- SOLAR TORQUE
  - CAN BE REDUCED BY USE OF SOLAR SAILS - COULD BE DEMONSTRATED ON NASA 1987 MISSION & AVAILABLE 1990.

    SMALL VERSIONS EXIST (TDRSS, INSAT).

In addition to flexibility effects, an MSP carries a multitude of payloads with a wide range of pointing requirements. Designing the platform to handle the tightest requirement would be very expensive, so compromise solutions must be developed.

POINTING CONTROL

- 0.3° CONTROL FOR LARGE PLATFORMS LIKELY TO BE POSSIBLE WITH PRESENT TECHNOLOGY
- 0.1° CONTROL ACHIEVABLE WITH LOW CTE MATERIAL, AVAILABLE 1987-1990
- TIGHTER PLATFORM CONTROL POSSIBLE BUT WOULD REQUIRE EXCESSIVE STRUCTURE AND MOMENTUM WHEEL MASS
- COMPROMISE COULD BE TO CONTROL THE PLATFORM TO 0.1° TO 0.3° AND CONTROL ANTENNAS AND/OR FEEDS OF INDIVIDUAL PAYLOADS TO REQUIRED ACCURACY
    - CONTROL USING GIMBALLED FEEDS AND 3-BEAM MONOPULSE RF SENSORS, VERY ACCURATE, TECHNOLOGY COULD BE DEMONSTRATED BY NASA 1987 MISSION
    - CONTROL USING MAGNETICALLY SUSPENDED VERNIERS AND STELLAR POSITIONS, EXTREMELY ACCURATE (<< 1 ARC SEC), COULD BE DEMONSTRATED BY NASA 87 MISSION
    - POINTING TO 0.05° RMS WITH A COMBINATION OF MOMENTUM WHEELS AND ARTICULATED FEEDS OR ELECTRONIC BEAM STEERING SHOULD BE DEMONSTRATED BY NASA 1987 MISSION.
- ALTERNATE COMPROMISE IS TO CONTROL PLATFORM FAIRLY TIGHTLY (SAY 0.1°) AND ADD EXTRA RF OUTPUT POWER FOR MISSIONS IDEALLY REQUIRING TIGHTER (SAY 0.05°) POINTING TOLERANCE
- ATTITUDE CONTROL MUST BE MAINTAINED DURING MODULE SERVICING/REPLACEMENT - VERY SEVERE REQUIREMENT - THIS IS AN AREA WHICH SHOULD BE IDENTIFIED AS REQUIRING MORE STUDY/EXPERIMENT/DEMONSTRATION.

4.2.7 Antennas/Feeds

The development of very large multibeam antennas is a key technology in making the MSP viable, since increasing the performance of a single space segment antenna decreases the demands on tens, hundreds or even thousands of earth stations, and permits large increases in frequency reuse. Multibeam reflector antenna technology is just emerging, but has already found use in such satellites as ATS-6 and ANIK-B. Surface errors are very critical ($\simeq \lambda/10$ for the highest frequency) presenting considerable challenges for designers of very large antennas.

ANTENNA TYPES

- AVAILABLE NOW
  - SINGLE HORNS - GLOBAL COVERAGE AT MICROWAVE FREQUENCIES
  - ARRAYS OF HELICES, YAGIS AND DIPOLES FOR LOWER FREQUENCIES
  - REFLECTORS - OFFSET FED CASSEGRAINS PREFERRED
- FUTURE (1995) AVAILABILITY
  - MICROWAVE LENS - REQUIRE NEW LIGHTWEIGHT DIELECTRIC MATERIALS WITH INCREASED BW
    - HAVE GOOD SIDELOBE CHARACTERISTICS
  - PHASED ARRAYS - STRIPLINE AND SOLID STATE TECHNOLOGIES
  - REFLECTORS WITH IMPROVED SURFACE TOLERANCES AND INCREASED FEED EFFICIENCIES.

REFLECTOR ANTENNAS

- FAVOURED CURRENT TECHNOLOGY FOR MULTIBEAM ANTENNAS
- CENTRE-FED CASSEGRAIN HAS GOOD CROSS-POLARIZATION CHARACTERISTICS AT LARGE OFF AXIS ANGLES BUT POOR SIDELOBE CONTROL DUE TO APERTURE BLOCKAGES
- OFFSET-FED CASSEGRAIN HAS GOOD SIDELOBE CONTROL
- OFFSET-FED PARABOLA HAS LARGE DISTANCE TO FEED PLANE MAKING IT IMPRACTICAL FOR LARGE ANTENNAS
- LARGE SURFACE ERRORS DUE TO FABRICATION, GEOMETRIC APPROXIMATION AND THERMAL DISTORTION
- SMALL SURFACE ERRORS DUE TO GRAVITY GRADIENT FORCE, SOLAR RADIATION PRESSURE AND ATTITUDE/ORBIT CONTROL FORCES
- NEEDS FURTHER DEVELOPMENT OF MESH DEPLOYABLE CONCEPTS FOR LARGE ANTENNAS
- NEEDS AN ANALYTICAL CAPABILITY DEVELOPED FOR CHARACTERIZING THE ON-ORBIT RF PERFORMANCE (ESPECIALLY SIDE LOBES AND WIDE SCAN ANGLE CROSS-POLARIZATION). COULD BE AVAILABLE 1990.
- NEEDS CAPABILITY FOR AUTOMATED MEASUREMENT AND CONTROL OF REFLECTOR SURFACES ON ORBIT. COULD BE AVAILABLE 1990.
- CURRENT TYPES: LMSC WRAP-RIB (ALUMINUM OR GRAPHITE EPOXY RIBS), HARRIS RADIAL RIB (TDRSS TYPE), HARRIS MAYPOLE
- AVAILABLE ≃ 1990: MARTIN MARIETTA ORBITAL ASSEMBLY, GENERAL DYNAMICS ERECTABLE TRUSS, GRUMMAN SPACE FED PHASED ARRAY

Alternate antenna types are lenses and phased arrays, both of which have excellent interference nulling characteristics. For the next 10-15 years however, reflector antennas are likely to be favoured over both the lens and the phased array.

LENS ANTENNAS

- WAVEGUIDE TYPE: LIGHT, BUT LOW (≈ 5%) FRACTIONAL BANDWIDTH
- DIELECTRIC: HEAVY, BUT BROADBAND. SHOWS PROMISE IN THE FUTURE SINCE LIGHTER WEIGHT DIELECTRICS ARE BEING DEVELOPED.
- TEM: MEDIUM WEIGHT, MEDIUM BANDWIDTH
- CAN ALL BE USED VERY EFFECTIVELY TO NULL OUT INTERFERENCE SOURCES

PHASED ARRAYS

- TOO BIG AND INEFFICIENT FOR MOST PRESENT USES
- MAY BECOME MORE VIABLE IN THE FUTURE FOR MORE COMPLEX SATELLITE SYSTEMS
- HAS VERY GOOD INTERFERENCE NULLING CAPABILITY

4.2.8 Power

MSPs, because of the relatively larger number of missions they carry, will tend to require considerably more power than current satellites, requiring some new technology development.

For the foreseeable future, solar arrays will provide the power for the great majority of earth orbiting missions although RTGs are now available.

POWER SOURCES

SOLAR ARRAYS

- POWER REQUIREMENTS COULD BE UP TO ABOUT 20 KW BY 1995
- LARGER SOLAR ARRAYS HAVE LOWER RESONANT FREQUENCIES CAUSING ATTITUDE CONTROL PROBLEMS FOR WHICH TECHNOLOGICAL SOLUTION MAY NOT COME TILL 1990'S
- DESIGNS COULD BE BASED ON "NASA POWER MODULE" AND SOLAR ELECTRIC PROPULSION ARRAY TECHNOLOGY
- CURRENTLY AVAILABLE CELLS - TEXTURED (K7) CELL SCHEDULED FOR 1980 LAUNCH ON SBS
- WEIGHT SAVINGS CAN BE HAD WITH NASA-JPL 2 MIL THICK CELLS - 300-500 W/KG COVERED - NOW IN LABORATORY STAGE. ALTERNATELY, ALSO IN THE LABORATORY STAGE ARE GAALAS MULTIGAP CELLS. MUCH DEVELOPMENT WORK IS STILL NEEDED FOR BOTH TYPES TO DEVELOP TECHNIQUES FOR ROUTINE MANUFACTURE, COVERING, MOUNTING AND INTERCONNECTING. AVAILABLE: 1990 AT EARLIEST

ALTERNATE POWER SOURCES

- RADIOISOTOPE THERMAL GENERATORS (RTGS) - FLOWN ON LES 8&9, RADIATION HARDENED 500-5000 WATTS, AVAILABLE NOW, BUT NOT EXPECTED TO GENERALLY REPLACE SOLAR CELLS IN THE FORESEEABLE FUTURE FOR EARTH ORBITING MISSIONS.

Power storage technology advances will permit further decreases in MSP bus weight. For the near future, NiCd and $Ni-H_2$ batteries will be used, likely giving way to NaS batteries or fuel cells in the 1990's.

POWER STORAGE

BATTERIES

- NiCd BATTERIES ARE CURRENT STANDARD, 2 TO 20 W-HRS/KG HAS HIGHEST CREDIBILITY FOR MISSIONS FROM 1980-1985
- NiH_2 BATTERIES NEAR OPERATIONAL, 30 TO 50 W-HRS/KG, BUT REQUIRES MORE VOLUME THAN NiCd
- HAS HIGHEST CREDIBILITY FOR MISSIONS FROM 1985-1989
- NaS BATTERIES, ABOUT 500 W-HRS/KG, AVAILABLE IN LATE 1990's.

FUEL CELLS

- H_2-O_2 FUEL CELL, 50-57% EFFICIENCY, NOT CREDIBLE FOR MISSIONS PRIOR TO 1985, LESS CREDIBLE THAN NiH_2 BATTERY IN 1985
- REGENERATIVE FUEL CELLS, ≈100 W-HRS/KG, PROMISING TECHNOLOGY FOR LATE 1990's

OTHERS

- FLYWHEELS - PROMISING FOR 1990's BUT PROBLEMS WITH INERTIAL DISTURBANCES
- Ag-H_2 ELECTROCHEMICAL, NON-AQUEOUS LITHIUM COUPLES, STATUS UNCERTAIN

In addition to the energy source and energy storage technology developments which the MSPs can take advantage of, the MSP will drive power technology development in that the distributed nature of the power consumers will require a different power system architecture.

POWER GENERAL

- 2 BUS SYSTEM - MOST PROBABLE & AVAILABLE BY 1985
  - HIGH VOLTAGE (≃ 200V) FOR MAJOR LOADS (COMMUNICATIONS PAYLOADS) INTO DISTRIBUTED REGULATORS. THE HIGH VOLTAGE WILL MINIMIZE POWER HARNESS LOSSES AND REDUCE HARNESS WEIGHT
  - LOW VOLTAGE (28V) FOR SPACECRAFT SUPPORT SYSTEMS, OFF A CENTRAL REGULATOR

- AC BUS SYSTEM - POSSIBLE

- LIFETIME
  - 10 YEAR LIFETIME IS POSSIBLE WITH CURRENT TECHNOLOGY
  - 15-20 YEARS WOULD REQUIRE MUCH MORE DEVELOPMENT WORK, ESPECIALLY IN THE ENERGY STORAGE AREA. ALTERNATIVE IS IN-ORBIT REPLACEMENT.

4.2.9 Thermal

Thermal design of MSPs will result in some considerable challenges and may be a departure to the shared housekeeping function concept.

THERMAL

- RADIATORS
  - CENTRAL - REQUIRES LOTS OF "PLUMBING", OFFERS GOOD THERMAL FREEDOM
  - DISTRIBUTED - LITTLE PLUMBING BUT COMPLICATES THERMAL INDEPENDENCE, AT LEAST IN A COMPACT PLATFORM DESIGN

- HIGH TEMPERATURE DIFFERENCES ON ALL BUT NORTH AND SOUTH SURFACES, REQUIRES COVERING WITH SUPER INSULATION

- THERMAL DESIGN OF MSP'S COULD BE MADE MORE COMPLEX DUE TO DIURNAL LOAD VARIATIONS OF SOME MISSIONS (E.G. EDUCATIONAL TV)

- NEW TECHNOLOGY REQUIREMENTS
  - ADVANCED MATERIALS - AVAILABLE 1985-1995
  - COMPLEX ACTIVE CONTROL SYSTEMS - AVAILABLE 1985-1990

4.2.10 Propulsion

The large mass of MSPs will tend to drive designers towards finding increasingly efficient on board propulsion systems.

ON BOARD PROPULSION

- HYDRAZINE
  - CURRENT STANDARD, ISP = 220 S TYPICALLY, LOW THRUST - BEST FOR ATTITUDE CONTROL AND STATIONKEEPING UNTIL 1985-1990
- ELECTRICALLY HEATED HYDRAZINE
  - ISP UP TO 300 S, LOW THRUST FOR ATTITUDE CONTROL AND STATIONKEEPING, NOT LIKELY BEFORE 1985
- BIPROPELLANT (NITROGEN TETROXIDE AND MONOMETHYL HYDRAZINE)
  - ISP = 310 S TYPICALLY, HIGH OR LOW THRUST, COULD BE USED AS AN AKM IN ADDITION TO ATTITUDE CONTROL AND STATIONKEEPING. CURRENT TECHNOLOGY USED ON THE SPACE SHUTTLE, BUT SOME RESISTANCE BY NASA TO CARRYING A S/C CONTAINING BIPROPELLANTS. THRUSTER PULSES ARE CRISP. FUEL SLOSHING IS MORE OF A PROBLEM IF THRUSTERS ARE USED AS AN AKM.
- SOLIDS
  - ISP = 290 S TYPICALLY, HIGH THRUST, CAN BE USED AS AN AKM BUT NOT FOR ATTITUDE CONTROL OR STATIONKEEPING. CURRENT TECHNOLOGY.
- ELECTRIC PROPULSION
  - ISP = 2250 S TYPICALLY, VERY LOW THRUST, BUT COULD BE USED FOR ORBIT RAISING IF A LONG TRIP TIME THROUGH THE RADIATION BELTS WERE PERMISSIBLE. CONSUMES HIGH POWER. HAS ONLY SLIGHT MASS ADVANTAGE OVER HYDRAZINE ASSUMING A 5 YEAR REPLENISHMENT CYCLE AND 0.5^{o} STATIONKEEPING. POSSIBLY VIABLE FOR VERY ACCURATE STATIONKEEPING IF USED WITH NiH_2 BATTERIES RATHER THAN EXTRA SOLAR PANELS.

4.2.11 Data Management/Controls

A new technology, centralized system for data management, and spacecraft monitoring and control, can reduce costs because of sharing among missions. Such a powerful system would have great advantages in overcoming problems of attitude control and thermal control of large structures such as the MSP has.

APPLICATIONS OF CENTRALIZED DATA MANAGEMENT/CONTROL

- ATTITUDE CONTROL, INCLUDING USE OF "SMART" SENSORS, ADAPTIVE ANTENNA POINTING, CONTROL OF VIBRATION MODES
- THERMAL CONTROL, INCLUDING ACTIVE CONTROL OF THERMAL BENDING
- POWER - RECONDITIONING
- COMMUNICATIONS SYSTEM CONFIGURATION OPTIMIZATION
- COMMUNICATIONS SIGNAL PROCESSING, ERROR CORRECTION
- TELEMETRY, INCLUDING ADAPTIVE DATA COLLECTION
- AUTOMATED STATIONKEEPING (ESPECIALLY IMPORTANT FOR CLUSTERS).

THESE TECHNOLOGIES ARE LIKELY TO BE FEASIBLE IN THE EARLY 1990'S AND COULD BE TESTED ON THE NASA 1987 MISSION.

4.2.12 Orbit Transfer Vehicles

The MSPs will be assembled/deployed in LEO and then boosted to GEO on a space shuttle upper stage. They will initially use the IUS or a modified Centaur upper stage, but will likely help to drive the development of a new, low thrust orbit transfer vehicle. The dates given are the earliest projected dates at which the OTV's will be available, assuming that the programs are funded and proceed relatively smoothly.

ORBIT TRANSFER VEHICLE

REQUIREMENTS

- LARGE CAPACITY ≈ 2000+ KG
- LOW THRUST IS DESIRABLE TO DECREASE LOADS ON DEPLOYED STRUCTURE/ANTENNAS. (MINIMIZE THRUST/WEIGHT-AT-BURNOUT, T/W = MAXIMUM EQUIVALENT G-LOADING)

CANDIDATES

- APPROVED PROGRAMS
  - IUS - 2273 KG INTO GEO
    - T/W = 2.0 - UNDESIRABLE
    - AVAILABLE 1981
- UNAPPROVED PROGRAMS
  - IOTV (MODIFIED CENTAUR WITH RL-10 ENGINE AT IDLE)
    - 4763 KG INTO GEO
    - T/W = 0.19
    - AVAILABLE 1984 EARLIEST
  - ILS (INTERIM LARGE SCALE)
    - 16500 KG INTO GEO
    - T/W = 0.05
    - AVAILABLE 1988 EARLIEST
  - ALS (ADVANCED LARGE SCALE)
    - 24000 KG INTO GEO
    - T/W = 0.05
    - AVAILABLE 1990 EARLIEST
  - 2 STAGE AIRBREATHER BOOSTER
    - UNDEFINED - LARGE CAPABILITY
  - ELECTRIC PROPULSION
    - TOO SLOW THROUGH RADIATION BELTS
  - BIPROPELLANTS
    - POSSIBLE, BUT FUEL SLOSH PROBLEMS
    - VERY FLEXIBLE SYSTEM, LOW T/W

4.2.13 On-Orbit Maintenance/Retrofit/Reliability

The ultimate goal of the MSP evolutionary process is to have a platform in orbit in which only those elements which have failed, become obsolete or are consumed, are replaced. In addition, it is desirable to have a platform which can grow in size by adding new payloads periodically. This aspect of the MSPs will require a great deal of new technology which is applicable only to MSPs. In addition, at this very early stage of MSP development, studies must be performed to see if this evolutionary trend is justified - i.e. it must be established that, for example, it is more cost effective to replace a failed piece of equipment than to build in increased reliability.

The inherent modularity and ease of replacement is one area in which the cluster concept excels over the common bus.

MAINTENANCE/RETROFIT

- ON ORBIT SERVICING - SOME NASA STUDIES HAVE BEEN PERFORMED BUT MORE WORK IS REQUIRED HERE. THE TECHNOLOGY IS NOT LIKELY TO BE AVAILABLE UNTIL THE EARLY 1990'S. TYPICAL PROBLEMS TO BE SOLVED ARE TRANSPORTATION AND ATTITUDE CONTROL.

- NASA 1987 PLATFORM SHOULD IDEALLY DEMONSTRATE PLATFORM SERVICING & MODULARITY CONCEPT, PLATFORM DOCKING, AND PAYLOAD ADDITION.

RELIABILITY

- STUDIES ARE REQUIRED TO ESTABLISH THE RELIABILITY & ECONOMIC ADVANTAGES, IF ANY, OF THE IN-ORBIT SERVICING CONCEPT OVER THE BUILT IN RELIABILITY APPROACH.

The summary table on the opposite page shows that the technology could be available in most subsystems to launch a significantly improved MSP as early as the late 1980's. However, this would likely require the platform to be the demonstration article for many of those new generation technologies, as they are unlikely to have been flown, even on individual satellites, earlier. Certain other technologies are unlikely to be available until well into the 1990's; some of these are critical elements, and will pace the overall evolution of platforms.

The dates shown are the earliest expected; it is probable that both technical problems and funding priorities will delay many developments.

SUMMARY OF ANTICIPATED TECHNOLOGICAL ADVANCES

SUBSYSTEM/TECHNOLOGY	ELEMENT	AVAILABILITY DATE
STRUCTURE	NEW ANALYTICAL TOOLS	NOT TESTED ON ORBIT TIL 1990's
	NEW DESIGNS	CONTINUOUS EVOLUTION
	JOINING TECH	1987-2000: EVOLUTION
*	MODULAR	MAY BE TESTED BY 1990
MATERIALS	ULTRA LOW CTE	1990
ASSEMBLY TECHNIQUES	DEPLOYABLE - LARGE ANT & STRUCT	1987-1990
*	ERECTABLE	1992 ONWARDS
*	OPERATIONAL	1993-97
*COMMUNICATIONS	LARGE SWITCHES	1985-95 EVOLUTION
	ISL (EHF OR LASER)	1990's
	IMPROVED MODULATION	NOW - 1985
*ATTITUDE CONTROL	FLEX MODE CONTROL	1987-1990
	OBSERVERS	1995
*ANTENNAS	MULTI-BEAM REFLECTORS	1987
	LENSES	1990's
POWER	ULTRA-THIN SOLAR CELLS	1990
	RTG'S - OPERATIONAL	LATE 90's
	$Ni-H_2$ BATTERIES	1985-90
	FUEL CELLS	1990's
THERMAL	ADVANCED MATERIALS	1985
	ACTIVE CONTROL	1985
PROPULSION	MINOR IMPROVEMENT (BI-PROP OR AUGMENTED N_2H_4)	1985
	ELECTRIC	MID 1990's
*DATA MANAGEMENT	NEW FLEXIBLE SYSTEMS	1987-92
*OTV	CENTAUR	COULD BE AVAILABLE - 1984
*	ADVANCED	1990's
*MAINTENANCE	TELEOPERATOR	1990's
*	MANNED OPERATION	1990's

*THESE ARE CENTRAL, CRITICAL ITEMS FOR DEVELOPMENT OF LARGE MSP'S. MOST ARE STRONGLY DEPENDENT ON FINANCING.

4.3 Major Technical Concerns of Canadians

As part of the mission model survey, the users, operators and planners were asked to express their major technical concerns about meeting their requirements with MSP's instead of individual satellites. Since the survey was conducted early in the study, the recent evolution of thought concerning the definition of what constitutes an MSP was not understood at the time, so the questions were asked and answered with the prejudice that they referred to spacecraft similar to an OAF. Subsequent opportunities were presented at the formal mission model presentation and during informal discussions to revise any answers based on the updated concept. No significant changes of opinion were received.

The users had no major concerns at all relative to how the service was provided. All stated that they wished to have all their performance requirements met in the most cost effective way, and were unconcerned what the spacecraft looked like as long as it met the requirements. They did, however, express a strong desire to be involved in the early planning, to ensure compliance with their needs.

Some of the planners and operators, on the other hand, expressed strong preferences for individual satellites over platforms, for reasons to be discussed later. Most of the technical drivers behind this choice apply to the single bus platform concept only, and would be of lesser significance if a cluster were employed instead. However, two of the concerns (shown separately, opposite) are equally applicable to all forms of MSP. Some of the technical concerns were selected from a 'shopping list' contained in the survey questionnaire; others were added by the respondents.

One interesting set of responses was that to the question concerning on-orbit servicing/replacement. Only one respondent defined his willingness to place a payload on a platform in terms of meeting a reliability/availability goal, no matter how it was met; two others stated that on-orbit servicing would be a prerequisite for placing their service on a platform, and the fourth respondent expressed the view that it would never be a cost effective, feasible means of obtaining high reliability.

The technical aspects of meeting Canadian needs by participating in an international MSP program were not seen as differing significantly from a purely Canadian one, despite the fact that there were major institutional differences.

MAJOR TECHNICAL CONCERNS IDENTIFIED BY CANADIANS

- O MOST WERE RELEVANT TO THE SINGLE BUS CONCEPT ('OAF')
  - O RFI/EMI AMONG PAYLOADS
  - O SINGLE POINT FAILURES: ONE BUS & MANY PAYLOADS
  - O DIFFERENT & POSSIBLY INCOMPATIBLE ATTITUDE CONTROL REQUIREMENTS OF DIFFERENT PAYLOADS
  - O LACK OF FLEXIBILITY OF LAUNCH PERIOD
    - O ALL PAYLOADS MUST BE READY AT SAME TIME
    - O MORE DIFFICULT TO EXPAND SYSTEMS AS REQUIRED
  - O DIFFERENT PAYLOADS HAVE DIFFERENT FAILURE RATES & DESIGN LIFETIMES

- O TWO WERE RELEVANT TO ALL FORMS, INCLUDING CLUSTERS
  - O DIFFERENT PAYLOADS (E.G. C-BAND, KU-BAND, VARIOUS MOBILE SERVICES) HAVE DIFFERENT ORBIT SPACING REQUIREMENTS
    - O PLACING THEM ALL IN ONE ORBIT SLOT REMOVES MUCH OF THE FLEXIBILITY IN PLANNING THE OVERALL SYSTEM, & DETERMINATION WHERE OTHER PLATFORMS SHOULD GO
  - O DIFFERENT PAYLOADS HAVE DIFFERENT STATIONKEEPING REQUIREMENTS
    - O USE OF A PLATFORM FORCES THEM ALL TO ACCEPT THE MOST RIGID, THUS WASTING FUEL

- O MODULARITY, ABILITY TO REPLACE & EXPAND PAYLOAD CAPABILITY, IS NECESSARY IN THE LONG RUN

Most of the major Canadian concerns are identical to those expressed elsewhere, and their solution will occur as part of the normal evolution of platform technology. Whether they in actuality get applied to Canadian systems will depend on institutional and cost factors as much as technical ones.

This is most evident in the case of the orbit spacing concern. It is acknowledged that there are strong valid technical reasons for retaining the current system flexibility provided by the use of multiple orbit slots and single band satellites. However, there are at present significant outside factors of a combined technical/institutional nature which may remove some of the independence and freedom of Canadian users to maintain their preferred slots, and means must be developed to continue to provide the current level of service should that occur.

- MOST CANADIAN CONCERNS ARE A SUBSET OF 'GENERIC' ONES, & WILL BE ANSWERED AS THE TECHNOLOGY EVOLVES

- THE NOTABLE EXCEPTION IS THE ORBIT SPACING/SYSTEM ARCHITECTURE FLEXIBILITY WHICH IT IS DESIRED TO RETAIN
  - OUTSIDE FACTORS WHICH MAY AFFECT OUR CAPABILITY TO RETAIN THIS FLEXIBILITY ARE:
    - U.S. CAPACITY REQUIREMENTS ARE GROWING RAPIDLY & THE SLOTS ARE DESIRABLE
      - 'GREATER NEED' MAY BE USED AS AN ARGUMENT TO HAVE THEM RE-ALLOCATED
    - TWO MAJOR ITU PLANNING CONFERENCES WHICH MAY REMOVE MUCH GLOBAL FLEXIBILITY IN ORBIT UTILIZATION PLANNING ARE UPCOMING
      - 1983: RARC: OSTENSIBLY TO PLAN THE SATELLITE BROADCASTING SERVICE IN REGION 2, AS WAS DONE IN REGION 1 & 3 IN 1977
      - 1984: WARC-SPACE: TO GUARANTEE IN PRACTICE FOR ALL COUNTRIES EQUITABLE ACCESS TO THE GEOSTATIONARY-SATELLITE ORBIT AND THE FREQUENCY BANDS ALLOCATED TO SPACE SERVICES - NOMINALLY TO PLAN THE SERVICES

- SHOULD CANADA END UP WITH A RESTRICTED NUMBER OF ORBIT SLOTS AS A RESULT OF A COMBINATION OF THE ABOVE, WE MUST HAVE AN UNDERSTANDING OF THE OPTIONS AVAILABLE FOR PROVISION OF SERVICE

4.4 Technological Feasibility of MSP's to Meeting Canadian Needs

As discussed in Chapter 3, two strawman versions of Canadian multifunction space platforms were developed in order to confirm the feasibility of meeting the domestic requirements on a single platform, and as an exercise in determining some of the actual considerations which arise when designing a platform.

The first configuration carries all five identified payloads; the second carries the two civilian mobile payloads and the C-band fixed payload, which provides the central station backhaul for the mobiles. These payloads are also anticipated to be the most likely ones to be interconnected, if any are.

The development of these strawman configurations has shown that it is feasible to carry all or some of the Canadian payloads sized to meet the 1995 requirements on a single spacecraft utilizing technology expected to be available for launch in 1987.

Certain assumptions were made in deriving the configurations, and a set of trade-offs had to be made as a result. These are enumerated opposite.

STRAWMAN CONFIGURATIONS:

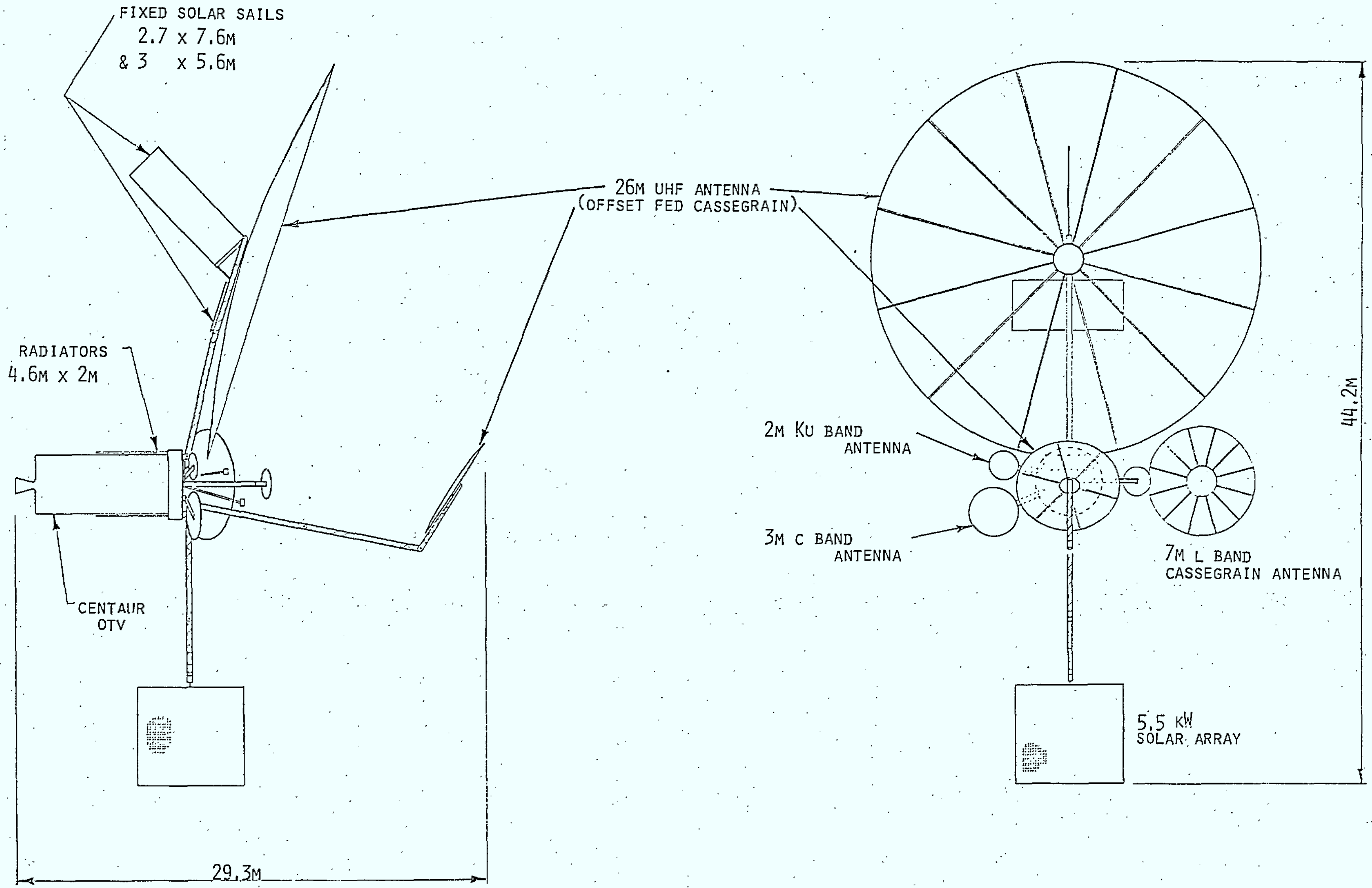
- O BASELINE ASSUMPTIONS
  - O OFFSET FED ANTENNAS ARE PREFERABLE FOR SIDELOBE CONTROL
  - O LOSSY WAVEGUIDE & COAX RUNS SHOULD BE MINIMIZED
  - O THE SPACECRAFT WOULD BE DEPLOYED & CHECKED OUT IN LEO
  - O THE CENTAUR WOULD BE THE ONLY 'ADVANCED' OTV AVAILABLE
- O CONFIGURATION TRADE-OFFS
  - O OFFSET FED (FOCAL POINT FEED) OR OFFSET FED CASSEGRAIN ANTENNAS DEPLOYED ON BOOMS WITH FEEDS NEAR BODY WHERE OUTPUT HPA'S ARE MOUNTED
  - O THE TWO UHF ANTENNAS SHARE COMMON REFLECTORS
    - \- POTENTIAL RISK OF PIM
  - O OTHER REPEATERS & ANTENNAS SPACED APART TO AVOID RFI AMONG PAYLOADS
    - O UHF & L-BAND PAYLOADS MOUNTED AT BASE OF FEEDS (HELICAL FEEDS FOR UHF, HORNS FOR L-BAND)
    - O C & KU-BAND PAYLOADS MOUNTED TO NORTH & SOUTH PLATFORMS WHICH SERVE AS THERMAL RADIATORS. HEAT PIPES DISTRIBUTE THE LOAD
  - O $F/D < 1$ REQUIRED FOR UHF FEEDS TO AVOID DEPLOYMENT & STILL FIT INTO CARGO BAY
  - O SOLAR SAILS REQUIRED TO MINIMIZE TORQUES AND ALLOW REASONABLE SIZE MOMENTUM WHEELS
  - O FOLDED BOOMS FOR APPENDAGES, RATHER THAN EXTENDIBLE ONES
    - O STIFFER DEPLOYED CONFIGURATION
    - O EASIER TO MOUNT MULTIPLE ELEMENTS ON A SINGLE BOOM (E.G. ANTENNA REFLECTOR & SOLAR SAILS)

None of the aspects of the two strawman spacecraft require technology breakthroughs; however development of current technology is required. This development is expected to occur regardless of whether there is a Canadian MSP or not.

DEVELOPMENT STATUS

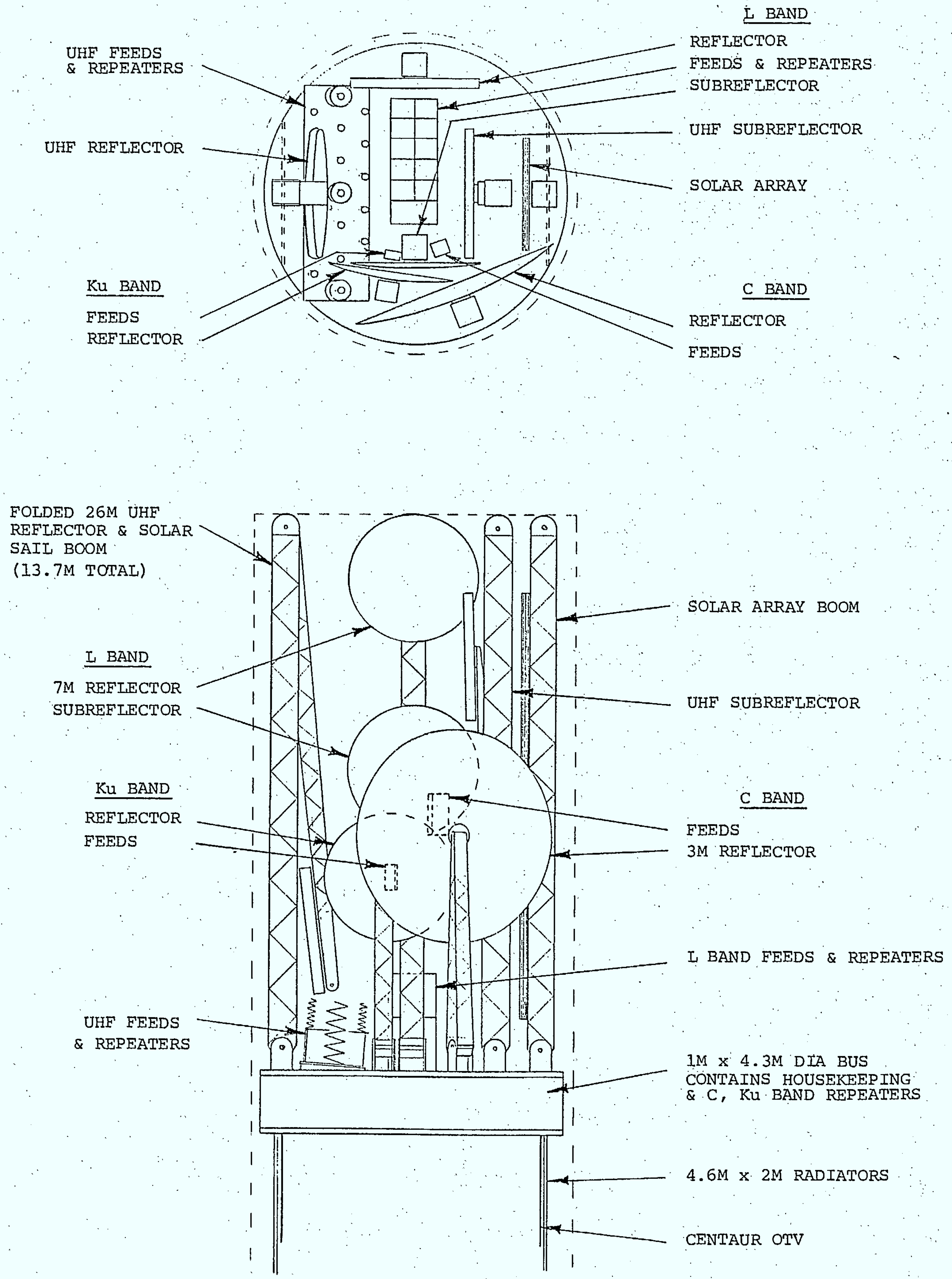
ITEM	DEVELOPMENT REQUIRED FOR CANADIAN PLATFORM	DEVELOPMENT STATUS
OTV	LOW THRUST OTV	CURRENT CENTAUR HAS CAPABILITY TO BE USED AS OTV. IUS COULD ALSO BE USED
DEPLOYABLE ANTENNA REFLECTORS	NORMAL ENGINEERING MODEL AND QUALIFICATION DEVELOPMENT	REFLECTORS SIMILAR IN SIZE TO THOSE SHOWN HAVE BEEN FLOWN OR ARE TO BE USED ON CURRENTLY PLANNED MISSIONS
BOOMS	HINGED BOOMS REQUIRE QUALIFICATION LEVEL DEVELOPMENT AND DEPLOYMENT TESTING	BOOMS SHOWN ARE GENERICALLY SIMILAR TO BOOMS WHICH HAVE BEEN USED ON PAST PROGRAMS AND ARE INHERENTLY SIMPLER THAN TELESCOPING OR DEPLOYING BOOMS
SOLAR REFLECTORS	DESIGN OF SURFACES FOR LONG LIFE REQUIRES DEVELOPMENT	SIMILAR TYPE SOLAR SAILS HAVE BEEN FLOWN
SOLAR ARRAYS	ARRAYS IN THE 1.5 TO 6 kW RANGE WILL REQUIRE NORMAL QUALIFICATION AND DEVELOPMENT	SOLAR ARRAYS IN THIS POWER RANGE HAVE BEEN OR ARE TO BE FLOWN IN PLANNED MISSIONS. NASA IS PLANNING A 25 kW STS DEMONSTRATION
CONTROL SYSTEMS FOR LARGE FLEXIBLE S/C	PRELIMINARY ANALYSIS SHOWS THAT THE OVERALL MODES CAN BE KEPT ABOVE .05 Hz. CONSEQUENTLY THERE SHOULD BE MINIMAL PROBLEMS WITH THE CONTROL SYSTEM. CTS TECHNOLOGY APPEARS APPLICABLE. LONGER LIFE IS REQUIRED FOR UNITS	CURRENT S/C PROGRAMS (E.G. INTELSAT 6) WILL DEVELOP ACS TECHNOLOGY IMPROVEMENTS
HIGH VOLTAGE BUS SYSTEMS	40 AND 100-200V COMPONENTS MAY REQUIRE DEVELOPMENT	CURRENT S/C PROGRAMS ARE STARTING TO LOOK AT THIS AREA
THERMAL CONTROL	SYSTEMS FOR 5 kW LEVEL SPACECRAFT REQUIRES DEVELOPMENT	CTS OR ATS-6 TECHNOLOGY MAY BE APPLICABLE
MAINTENANCE OF BORESIGHT	EFFECTS OF THERMAL DISTORTIONS OF LONG BOOMS MUST BE MINIMIZED BY EITHER ACTIVE THERMAL CONTROL, ANTENNA ELECTRICAL OR MECHANICAL STEERING, OR VERY GOOD PASSIVE THERMAL DESIGN	DEVELOPMENT IS JUST BEGINNING IN THIS TECHNOLOGY
POWER TRANSFER JOINTS FOR 5kW LEVELS	DEVELOPMENT REQUIRED	DEVELOPMENT IS GOING ON NOW
REACTION CONTROL SYSTEM	NORMAL ENGINEERING MODEL AND QUALIFICATION DEVELOPMENT	CURRENT TECHNOLOGY - HYDRAZINE

The figure shows the 5-payload MSP, after all appendages have been erected, at LEO with the OTV still attached. The acceleration level for the OTV is 0.19 g's.



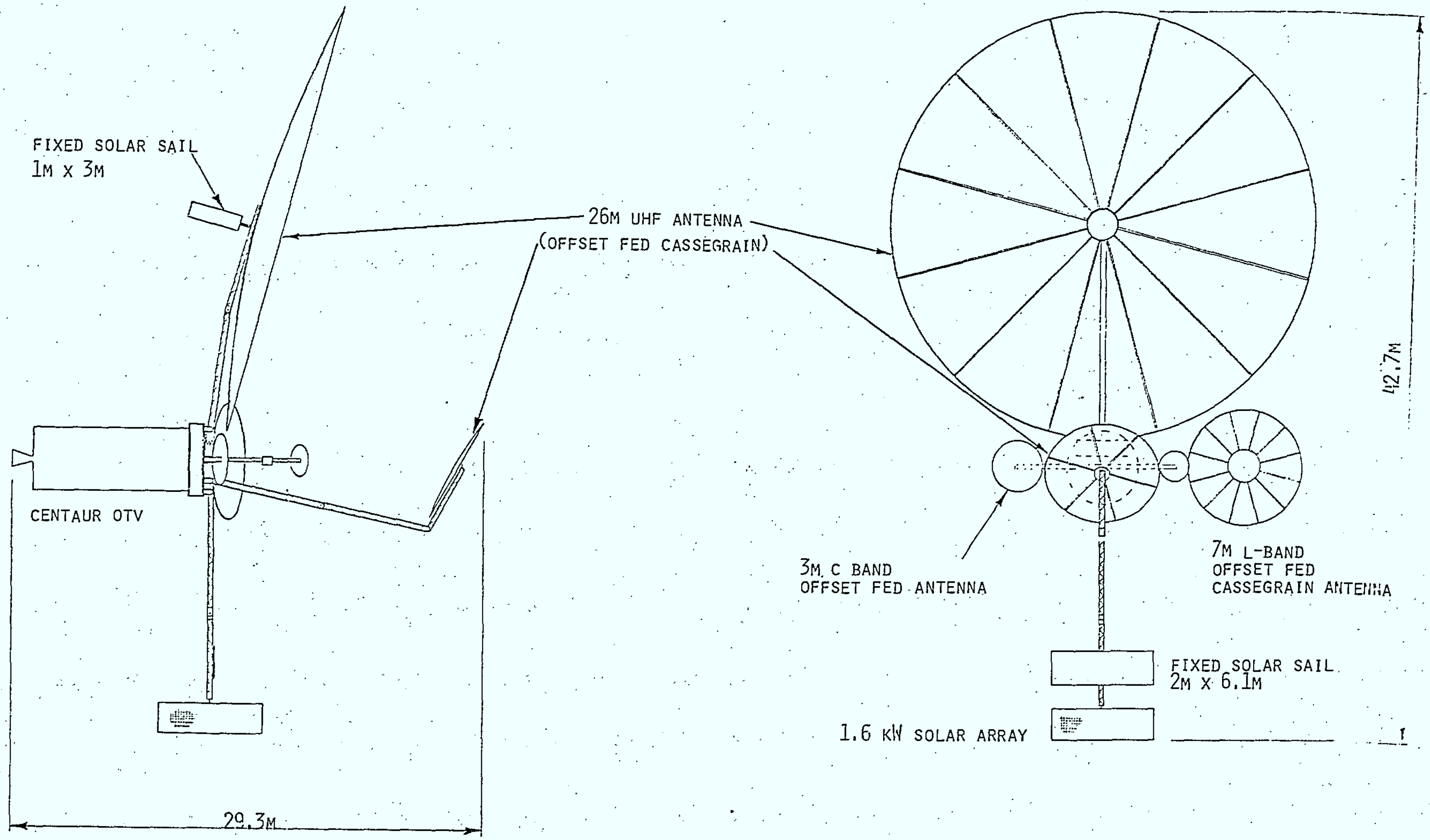
5 PAYLOAD STRAWMAN MULTIFUNCTION PLATFORM ON ORBIT CONFIGURATION

The figure shows that the larger MSP will fit in the 4.6m dia cargo bay envelope. The entire STS is utilized.



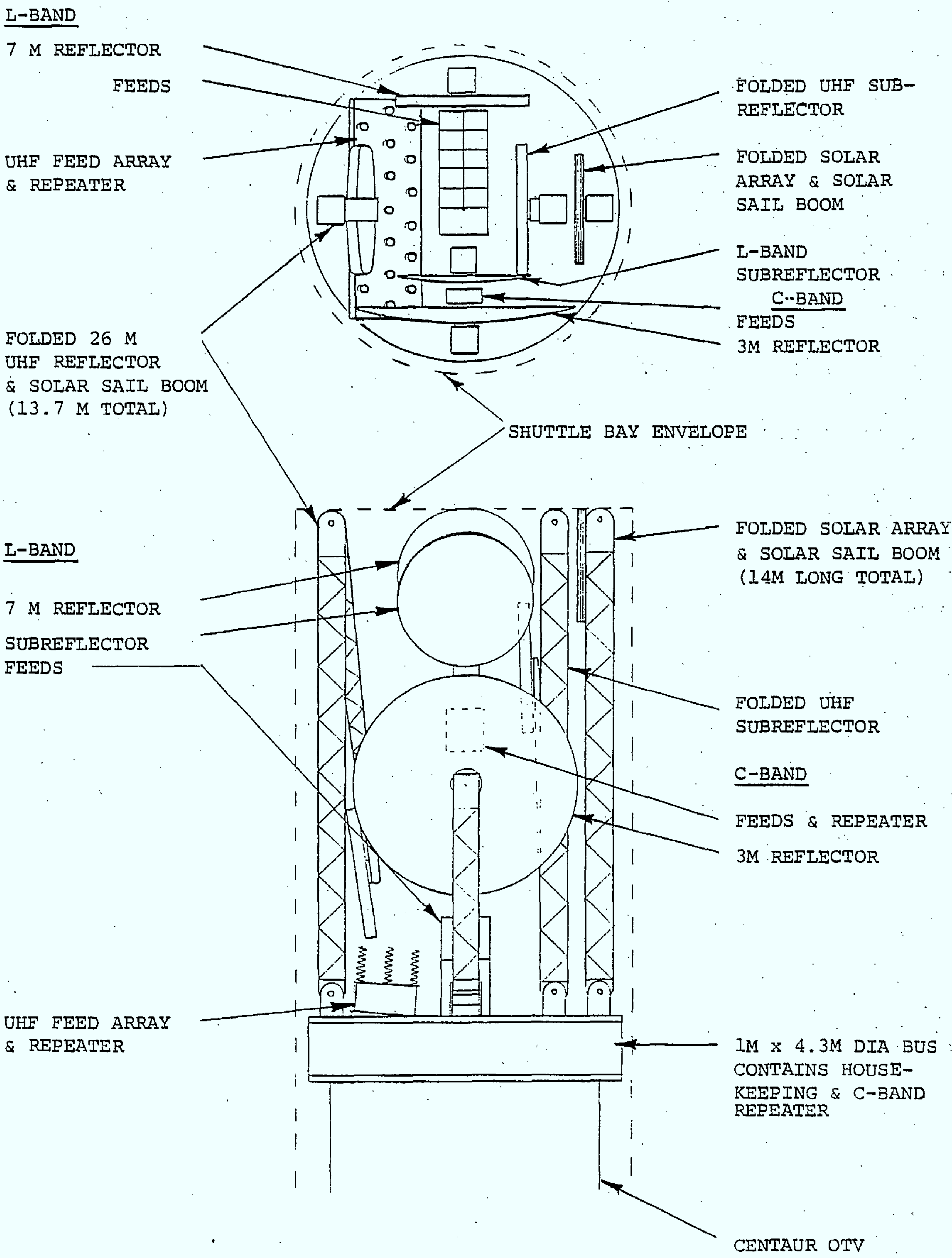
5 PAYLOAD MULTIFUNCTION PLATFORM STOWED CONFIGURATION

The configuration of the 3 payload MSP is very similar to the 5 payload version. The power requirements are greatly diminished and the mass is also lower. The mass is such that an IUS could be considered (2721 kg at GEO upgraded version) and the appendages could be deployed at GEO. Alternatively, the booms could be deployed at LEO and the elements could be made strong enough to withstand the 2.3g IUS acceleration.



3 PAYLOAD STRAWMAN MULTIFUNCTION PLATFORM ON-ORBIT CONFIGURATION

The figure again shows that by utilizing the entire cargo bay, the smaller MSP with hinged booms, can be easily stowed.



3-PAYLOAD MULTIFUNCTION PLATFORM-STOWED CONFIGURATION

The table indicates that the overall payload mass and power requirements for the large configuration are 1236 kg and 4185 W (EOL). Points to note are:

- The Ku-Band subsystem demands the major portion of the power.
- The dual use of the 26 m reflector for high and low UHF is baselined.
- The use of an LMSC type deployable mesh reflector is assumed for the 26 m reflector and the 7 m reflectors.

PAYLOAD MASS AND POWER SUMMARY

5 PAYLOAD SPACECRAFT CONFIGURATION

	MASS (KG)	DC POWER (W)
HIGH UHF ANTENNA (806-890 MHz):		
26M DIA REFLECTOR	150	
13M REFLECTOR BOOM	30	
7M DIA CASSEGRAIN SUBREFLECTOR	25	
5M & 15M SUBREFLECTOR BOOMS	20	
3 x 5.6M & 2.7 x 7.6M SOLAR SAILS	10	
FEED HORN ASSEMBLY (24 HORNS)	100	
TRANSPONDER	225	400
	560	
L-BAND ANTENNA ASSY:		
7M DIA REFLECTOR	25	
SUBREFLECTOR	10	
BOOMS	10	
FEED HORN ASSEMBLY (10 HORNS)	20	
TRANSPONDER	55	200
	120	
C-BAND ANTENNA ASSY:		
3M DIA REFLECTOR	25	
BOOMS	8	
FEED HORN ASSY	15	
TRANSPONDER	115	360
	163	
KU BAND ANTENNA ASSY:		
2M DIA REFLECTOR	15	
FEEDS	15	
BOOMS	8	
TRANSPONDER	240	3125
	278	
LOW UHF (240-400 MHz) ANTENNA ASSY:		
REFLECTOR: RE-USE 26M REFLECTOR	-	
HELICAL FEED HORN ASSEMBLY	10	
TRANSPONDER	30	100
	40	
TOTAL PAYLOAD	1161	4185
PAYLOAD WIRE HARNESS	50	
PAYLOAD INTEGRATION HARDWARE	25	
	1236	4185

The table indicates overall values of 913 kg and 960 W for the mass and power demand of the payloads on the smaller MSP. The configuration is similar to the 5 payload system, except the Ku band subsystem and the low UHF subsystems are deleted.

PAYLOAD MASS AND POWER SUMMARY

3 PAYLOAD SPACECRAFT CONFIGURATION

	MASS	DC POWER
HIGH UHF ANTENNA ASSY	555	400
L-BAND ASSEMBLY	120	200
C-BAND ASSEMBLY	163	360
WIRE HARNESS	50	
INTERFACE HARDWARE	25	
PAYLOAD SUMMARY:	913 KG	960W

The following sections present the preliminary considerations and calculations that were performed for the individual spacecraft subsystems. Detailed analyses were not performed; these are only 'back of the envelope' level calculations to confirm feasibility of the concept.

PRELIMINARY CONSIDERATIONS REQUIRED TO CONFIRM FEASIBILITY

- O TOTAL POWER DEMAND, INCLUDING HOUSEKEEPING
- O MASS PROPERTIES - PROPER C OF M LOCATION
- O SOLAR ARRAY SIZING
- O BATTERY SIZING
- O THERMAL CONTROL - MOUNTING AREA
  - REJECTION AREA (N-S FACING)
- O ATTITUDE CONTROL - NET DISTURBANCE TORQUE MINIMIZATION
  - MOMENTUM WHEEL SIZING
- O ON BOARD PROPULSION - FUEL BUDGET
- O STRUCTURE - STRENGTH
  - STIFFNESS
  - THERMAL STABILITY

The bus DC power demand levels are:

5 P/L bus	500 W
3 P/L bus	435 W

not including power demands for battery charging.

The table shows that there is approximately a 1000 kg BOL mass difference between the two configurations, 3333 kg vs 2323 kg, due to:

a) the increased payload mass itself plus

b) the increased bus mass to support the higher power demand and

c) the increased hydrazine required.

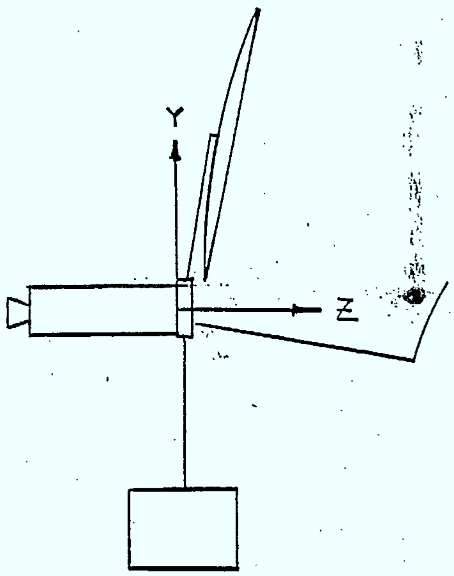
The mass of the expended OTV is not included. (If the expended OTV, estimated at 3500 kg were to remain attached at GEO, the overall BOL wet masses would be 7469 kg and 6856 kg for the 5 P/L and 3 P/L configurations respectively. Consequently the baseline design is that the OTV is jettisoned and a solar pressure sail is erected in its place.)

SPACECRAFT BUS MASS AND POWER DEMAND SUMMARY

	3 P/L S/C		5 P/L S/C	
	MASS	POWER DEMAND	MASS	POWER
PAYLOAD SUMMARY	913 KG	960W	1236 KG	4185 W
SOLAR ARRAY	45	10	152	25
BATTERIES AND BMU (@ 100% ECLIPSE)	145	25	467	25
POWER SUBSYSTEM	150	50	150	60
TT&C	30	50	30	50
OBC	30	25	40	30
ACS	100	75	110	80
SECONDARY PROPULSION (DRY)	100	75	110	80
STRUCTURE	200	-	210	-
THERMAL	50	100	75	125
BUS WIRE HARNESS	40	25	40	25
INTERFACE HARDWARE & BALANCE MASS	40	-	40	-
INTERFACE TO OTV	30	-	30	-
BUS SUMMARY (DRY)	960 KG	435 W	1454 KG	500 W
S/C SUMMARY (DRY)	1873 KG	1395	2690 KG	4685
HYDRAZINE FOR 8 YEAR MISSION	450	-	643	-
S/C SUMMARY BOL	2323 KG	1395 W	3333 KG	4685 W

The 3 payload and 5 payload configurations, with and without the expended OTV attached to the S/C at GEO, have overall system properties shown on the opposite page. For the 3 payload S/C a nominal mass of 450 kg of hydrazine was included and for the 5 payload S/C a mass of 590 kg was used. These fuel masses, for the baseline case of a detached OTV, correspond to BOL for the 3 P/L configuration and ≈ 1/2 year after launch for the 5 P/L configuration. The resultant overall center of mass is 1.12 m and 0.93 m forward of the separation plane, compared to a desired pitch axis distance of 1 m forward. As fuel is depleted the C of M will move forward. At this stage of analysis, the results show the general feasibility of designing an MSP and maintaining the C of M within the spacecraft body. This would be accomplished by slight geometric changes to the configurations shown, and possibly adding an aft balance mass.

INERTIA PROPERTIES OF THE TWO CONFIGURATIONS



PROPERTIES IN UNITS OF: KG, METERS & KG-M²	3 P/L S/C W/ EXPENDED OTV	3 P/L S/C @ BOL	5 P/L S/C W/ EXPENDED OTV	5 P/L S/C @ BOL + 1/2 YEAR
MASS	5823	2323	6770	3270
$\bar{X}$	.04	.09	.02	.04
$\bar{Y}$	.30	.80	.03	.07
$\bar{Z}$	-2.37	1.12	-1.98	.93
I_{xx}	153E3	105E3	185E3	131E3
I_{yy}	109E3	62E3	117E3	64E3
I_{zz}	89E3	88E3	115E3	115E3
P_{xy}	-67	-170	174	169
P_{yz}	15E3	9E3	11E3	10.6E3
P_{xz}	1021	276	678	311

The basic solar array requirements, based on the use of textured (K-7) cells are:

- Tracking Type Solar Arrays required
- Either fold-out panels or deployable substrate array designs can be used
- EOL capabilities needed, considering 85% overall power subsystem conversion efficiency, are:

  3 P/L S/C = 1.6 kW

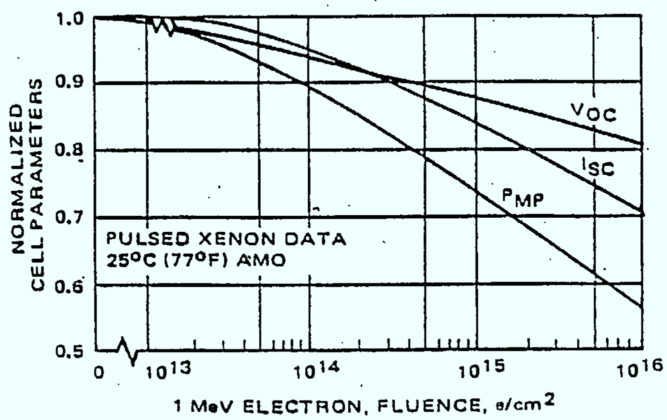
  5 P/L S/C = 5.5 kW

- For nominal 8 year lifetime platforms, BOL solar array capability will therefore be: ≈

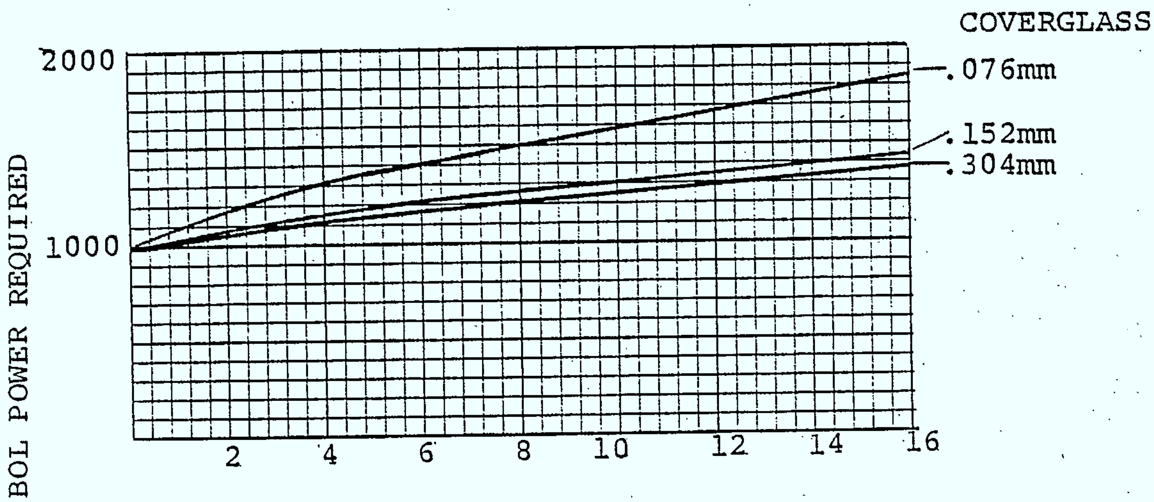
  3 P/L S/C = 2.1 kW

  5 P/L S/C = 7.2 kW

- Solar array mass, including tracking and deployment hardware, using current technology is estimated at 45 and 152 kg.



NORMALIZED K-7 CELL CHARACTERISTICS
AS FUNCTION OF 1 MEV ELECTRON RADIATION



SPACECRAFT LIFETIME (YEARS)

BOL SOLAR ARRAY PMAX REQUIREMENTS
TO OBTAIN 1 KW EOL, AS A FUNCTION
OF LIFETIME AT GEO

(ASSUMING PARTIAL BACKSHIELDING DUE TO SUBSTRATE AND FUSED SILICA COVERGLASS. UV DARKENING EFFECTS NOT INCLUDED)

The battery designs are based on the use of nickel-cadmium cells and an advanced high reliability battery management system, using the platform's central computer.

BATTERY REQUIREMENTS

O ASSUMPTIONS:
- O NI-CD CELLS
- O HIGH RELIABILITY BATTERY MANAGEMENT SYSTEM
- O 90% CONDITIONING EFFICIENCY
- O 60% DOD.

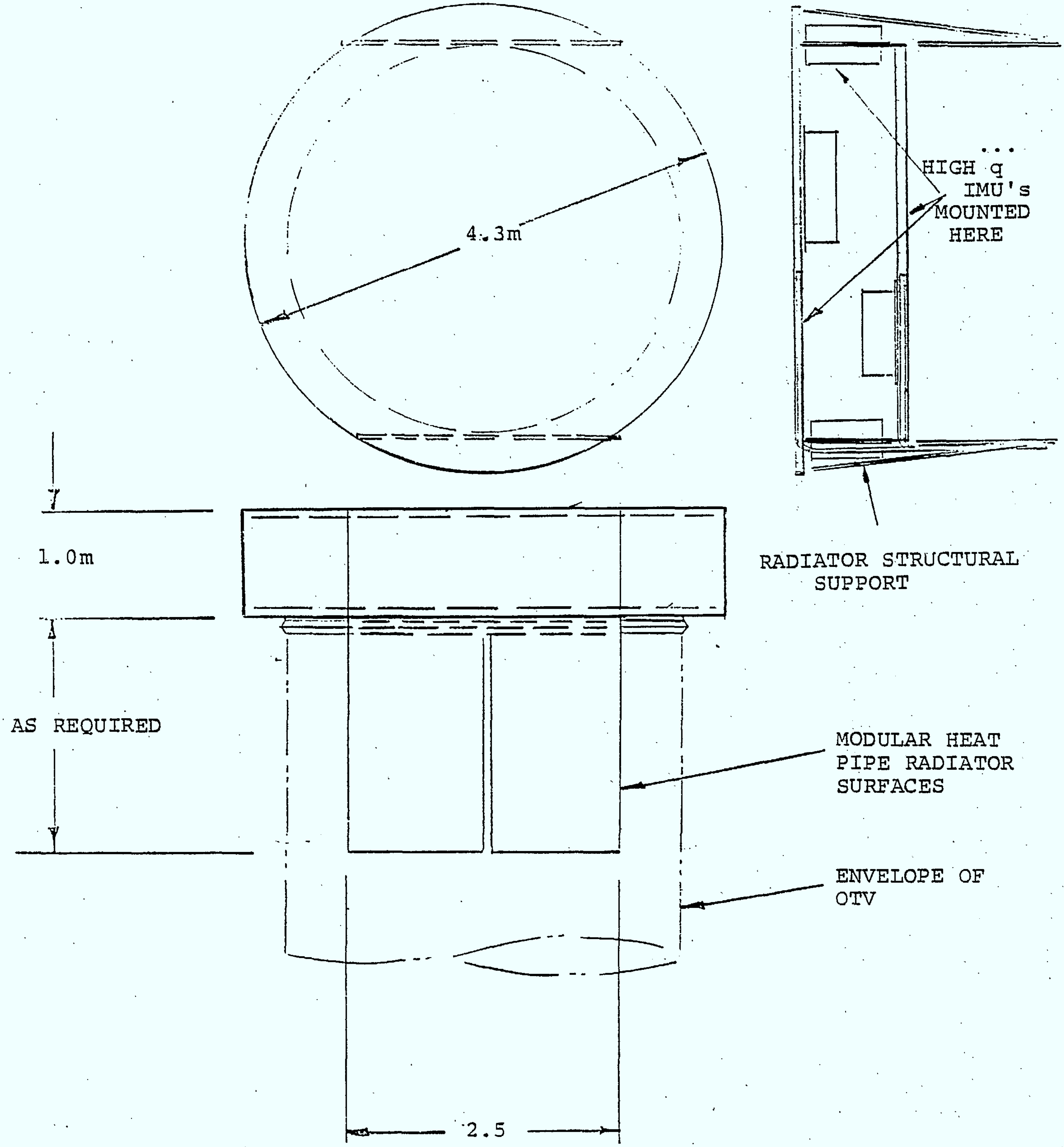
O SYSTEM PARAMETERS

PARAMETER	CONFIGURATION 5 P/L	3 P/L
POWER REQ'T	9.33 KW-HR	2.22 KW-HR
NUMBER OF BATTERIES	6	2
CELL-PACKS/BATT	2	2
CELLS/PACK	14	14
CELL SIZE	50 A-H	35 A-H
TOTAL MASS (INC. ELEC.)	481.5 KG	125.3 KG

The power dissipation level for the 3 P/L MSP is similar to CTS, and thermal control can be achieved by similar techniques. The 5 P/L MSP will require greater radiating surface area.

The basic design approach is to provide the 4.4 m diameter by 1 m long payload and bus platform with a set of N/S facing radiative fins which are at the condenser ends of a set of heat pipes with evaporator ends in the spacecraft body. The heat pipe design is modular, so that either 3 or 5 P/L systems can be accomodated with a minimum of overall configuration change. The IMU's are mounted on the earth and aft facing decks, both of which are well insulated with MLI on their exterior surfaces. The highest dissipation IMU's (the TWTA's) are mounted on the 2.5 m wide flat N/S sides of the S/C body. The surface of the radiator fin has a low α_s/ε finish.

The heat pipes are imbedded in the honeycomb of the forward aft decks and make one right angle bend to enter the aft radiator fins. The imbedded heat pipes serve dual purposes of spreading the heat laterally to avoid hot spots on the equipment decks and also to transfer the heat to the fins.



THERMAL CONTROL OF MSP

A redundant momentum wheel biased momentum system, as was used on CTS, appears to be satisfactory for the spacecraft. The largest disturbance torque is solar torque, and to minimize C of M/C of P offsets, solar reflective sails are placed at various spacecraft locations.

The nominal pointing accuracy for the spacecraft body is ±0.05 degrees in pitch and roll and 1 degree in yaw. It is important to note that the individual antenna boresight pointing accuracies will differ from those of the spacecraft body due to thermal and structural dynamic distortions of the reflector, subreflector and (possibly) feed structures. Thermal gradients of 10°C or more across the cross sections of long booms (i.e. 13 m) can easily produce tip rotations greater than 0.1 degrees. Consequently it is essential that the booms be well designed thermally to minimize gradients.

The required ACS functions are:

- Sun Acquisition at LEO and GEO
- Sun hold and deploy appendages at LEO
- Pitch, Roll and Yaw control at LEO and GEO
- Control during station keeping maneuvers, N/S and E/W

REQUIRED POINTING ACCURACY FOR PAYLOAD BORESIGHTS (DEGREES)

PAYLOAD	PITCH	ROLL	YAW
LOW UHF	0.3	0.5	2
HIGH UHF	0.1	0.1	1
L-BAND	0.2	0.2	1
C-BAND	0.2	0.3	1
KU BAND	0.2	0.3	1

ATTITUDE CONTROL SUBSYSTEM COMPONENTS

- SCANNING IR SENSORS FOR ROLL/PITCH DETERMINATION, MOUNTED ON S/C BODY
- RATE INTEGRATING GYRO
- YAW AND ATTITUDE ACQUISITION SUN SENSORS
- RF SENSORS FOR INDIVIDUAL PAYLOADS
- REDUNDANT N/S ORIENTED MOMENTUM WHEELS. DIAMETER OF 1.1 TO 1.25M
- ON-BOARD COMPUTER (OBC) TO PERFORM ACS/RCS CONTROL DECISIONS AS WELL AS PERFORM OTHER FUNCTIONS

The configuration of any spacecraft using large aperture reflectors and other boom-mounted large surfaces causes solar torque to become the most predominant disturbance torque at GEO. To minimize the offset between the overall spacecraft center of mass and the center of (solar) pressure, the baseline configurations utilize specularly reflective solar sails in various fixed positions so that the solar torque is minimized at all times during the 24 hour orbit. The sail dimensions shown in the deployed configuration drawings were calculated to bring the C of P nominally near the spacecraft body.

The large open mesh reflectors have an effective (100% specular) surface area of approximately 5 to 10% of the actual area when viewed from the boresight and an effective area of closer to 100% of actual area when viewed from the East or West sides. Open construction booms are preferrable to enclosed booms because they offer less surface area. Due to thermal design requirements, the surfaces of the booms are likely to be specular (i.e. low α_S). The spacecraft body East and West sides are likely to be covered with multilayer thermal insulation.

The momentum wheel is sized primarily by the solar torque and the allowable yaw angle error according to

$$\psi \simeq \left(\frac{180}{\pi} \right) \left(\frac{T}{\omega_o h_w} \right)$$

where h_w is the wheel angular momentum required to maintain a yaw error of ψ degrees, ω_o is the orbit rate, and T is the disturbance torque, which can be in the range of 0.2 N.m.

EXTERNAL MOMENTS DUE TO SOLAR TORQUES

- FIRST CUT SOLAR TORQUE CALCULATIONS ARE SHOWN FOR THE 5 PAYLOAD CONFIGURATION USING THE CALCULATED CENTERS OF SOLAR PRESSURE AND THE C OF M COORDINATES USED TO DERIVE THE INERTIA PROPERTIES. SIMILAR CALCULATIONS WERE PERFORMED FOR THE 3 PAYLOAD CONFIGURATION. SOLAR TORQUE IS DESCRIBED BY:

$$T_{xx} = (6.48 \times 10^{-4}\ N/m^2) A_e\ (\bar{y}_s - \bar{y}_{INERTIAL})$$

with:

$$\bar{y}_s = \frac{\sum_{i=1}^{m} A_{Eff_i} * y_i}{\sum_{i=1}^{m} A_{Eff_i}}$$

$$A_{Eff_i} = A_i n_i\ (1+\rho_i)$$

where: A_i = projected area

n_i = 1-transparency

ρ_i = reflectivity

SHEAR EFFECTS WERE NOT CONSIDERED.

SOLAR TORQUE MOMENTS (UNITS OF N AND M)

ELEMENT	EFFECTIVE AREA FOR MIDNIGHT SUN ANGLE	EFFECTIVE AREA FOR 1800 HOUR SUN ANGLE
OTV (SOLAR SAIL)	-	44.7
S/C BODY	-	6.5
26M REFLECTOR	55.8	67.5
26M SUBREFLECTOR	3.5	26.6
7M REFLECTOR	4	60
7M SUBREFLECTOR	4.7	5
3M REFLECTOR	11.9	11
2M REFLECTOR	4.7	5
SOLAR ARRAY	45	45
SOLAR SAILS	32.1	28.5
$\sum_i A_i n_i (1 + \rho_i)$	$161.7m^2$	$299.8m^2$
$\bar{x}_s$	-.14m	-
$\bar{y}_s$	2.38m	1.12m
$\bar{z}_s$	-	3.43m
T_{zz}	-	.204
T_{YY}	.0188	.486
T_{xx}	.242	-

A current technology hydrazine thruster system is considered for attitude control and station keeping since it provides good performance with nominal risk. The overall spacecraft mass properties show that the C of M can be maintained within the bus and payload electronics module; thus the thrusters can be mounted on the sides of the module, in clusters, with thrust vectors through the C of M as appropriate. It is anticipated that 20-30N thrusters will be required for station keeping and 1-5N thrusters for attitude control.

High Isp advanced technologies such as electrically heated thrusters or bipropellant systems may also be considered. For adequate reliability over the 8 year mission, the thrusters must be fully redundant.

HYDRAZINE REQUIREMENTS

BASED ON:

- ESTIMATED Δv = 457 M/S (1500 FT/SEC) FOR 8 YEAR MISSION FOR N/S AND E/W STATIONKEEPING PLUS ATTITUDE CONTROL AND MOMENTUM DUMPING

- $$\Delta v = G\, I_{SP}\, LN \left(\frac{M_E + M_F}{M_E}\right)$$

  AND $I_{SP} \simeq 220$ SEC

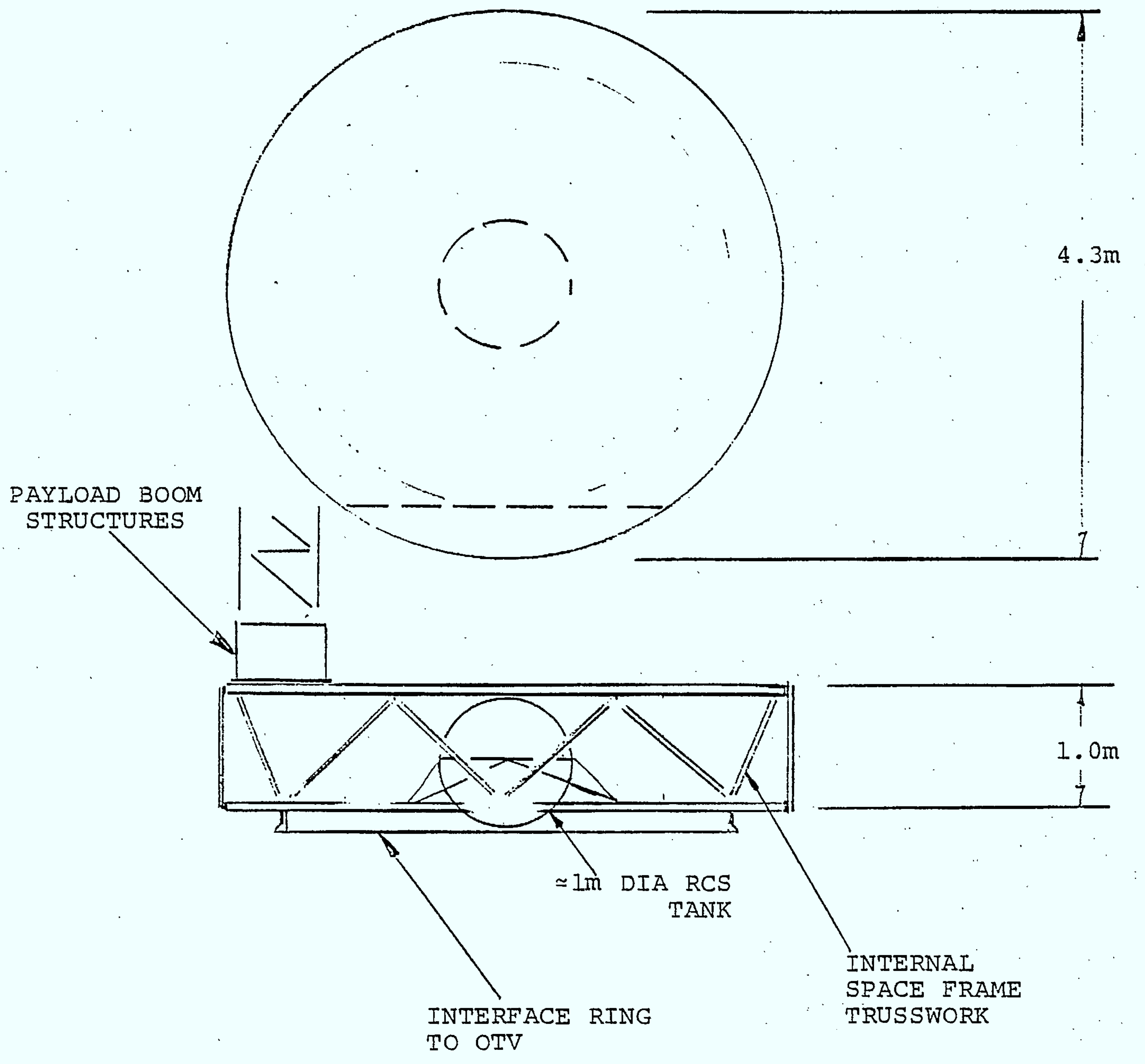
THE REQUIRED HYDRAZINE IS:

CONFIGURATION	DRY MASS (KG)	HYDRAZINE MASS (KG) REQUIRED FOR 8 YEAR MISSION	DIAMETER (M) OF SPHERICAL TANK
3 P/L S/C	1873	450	0.95
5 P/L S/C	2690	643	1.07

The bus structure consists of the 4.3 m diameter x 1 m deep equipment structure, made from honeycomb panels and supported internally by a space frame truss system. The interface to the OTV is made using a standard V-band clamp attachment ring, nominally 3.66 m in diameter. The payload structure consists of the booms and motor driven hinges required to configure the reflectors, solar arrays, and solar sails.

The structure is primarily designed to withstand the STS acceleration and vibro-acoustic environments. A separate cradle will be required in the cargo bay to secure the forward ends of the appendages. Solenoid release systems will be required to free the booms from this cradle prior to separation of the MSP/OTV from the orbiter.

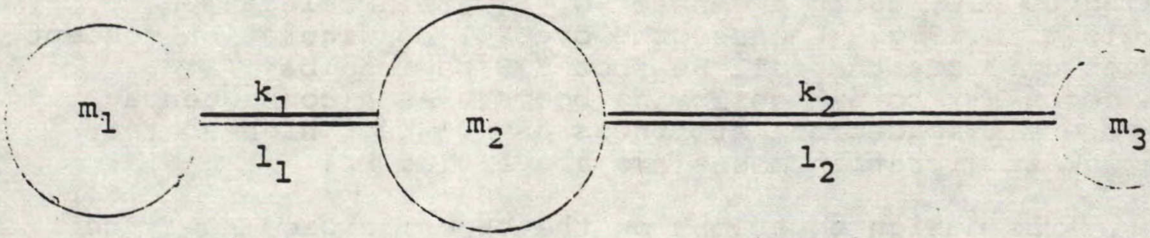
BASIC STRUCTURAL CONFIGURATION



The in-orbit configured MSP should preferably have its lowest modes above ≈ .05 Hz to avoid interaction with the control system. By using hinged rigid booms, with three continuous longerons, adequate member stiffness can be obtained in torsion and bending to accomplish this. The hinge points must also be stiff. A spring loaded locking device, in principle, would provide positive joint stiffness once the proper configuration was made.

PRELIMINARY BOOM STIFFNESS CALCULATIONS

FOR EXAMPLE, CONSIDERING 3 LUMPED MASSES CONNECTED BY BOOMS:



$$\omega_1^2 = \frac{k_1}{m_1} \qquad \omega_3^2 = \frac{k_2}{m_3} \qquad \omega_2^2 = \frac{k_1 + k_2}{m_2}$$

$$B = \omega_1^2 + \omega_2^2 + \omega_3^2$$

THE OVERALL BENDING FREQUENCY IS:

$$\omega_N^2 = \frac{1}{2} \quad B \pm \quad B^2 - 4\omega_1^2\omega_3^2 \left(\frac{m_1 + m_2 + m_3}{m_2}\right)$$

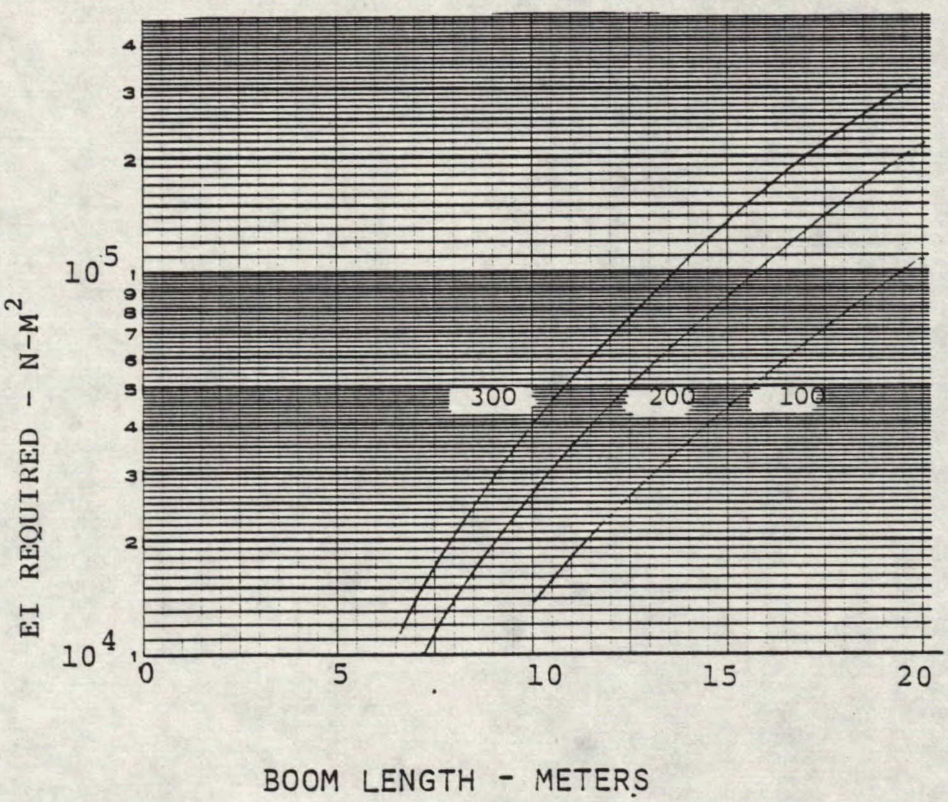
AND IF:

$f_1 = 0.1$ Hz $f_2 = .06$ Hz

$m_1 = 200$ kg $m_2 = 1000$ kg $m_3 = 300$ kg

THEN:

$f_N \simeq .06$ Hz

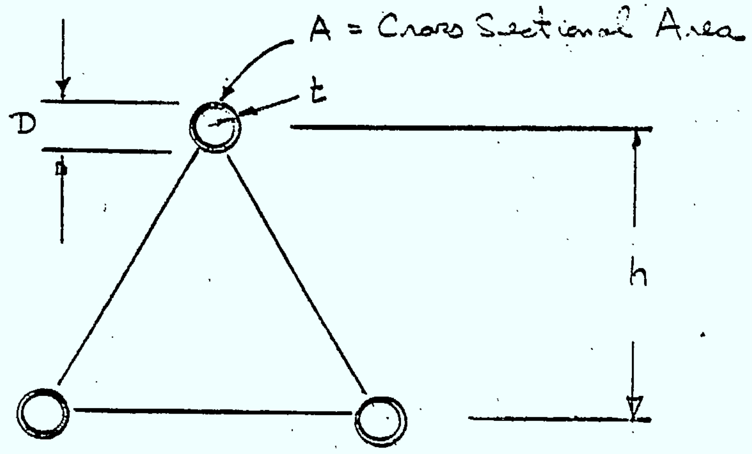


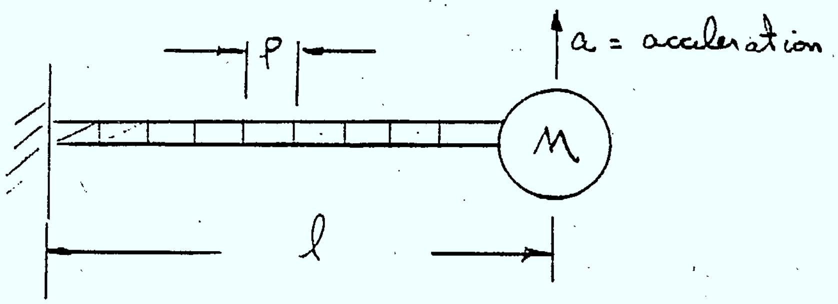
BOOM BENDING STIFFNESS REQUIRED TO MAINTAIN FIRST LOCAL CANTILEVER MODE TO 0.1 HZ FOR 100, 100, 300 KG TIP MASSES

Rigid hinged booms are selected for the strawman configurations because of the strength requirements imposed by deploying the appendages in LEO and subsequently moving to GEO, using a Centaur OTV, with acceleration levels of 0.19 g. Because the overall configuration concept chosen utilizes the full 60 foot STS payload bay, it is not necessary to use deploying booms. As a consequence, the overall spacecraft stiffness can be kept high so that the lowest vibration modes are above 0.05 Hz.

The design equations on the opposite page apply to a three-continuous-longeron boom of length l, supporting a concentrated mass M.

BOOM DESIGN





$$\sigma = \frac{Mal}{Ah}$$

$$f_N = \frac{h}{\pi} \frac{EA}{2Ml^3}$$

$$m_b = \text{BOOM MASS} \simeq 3\rho lA + \text{WEB MASS}$$

$$p \simeq \pi D \frac{E}{2\sigma}$$

This design concept provides a very mass effective support system for the antennas, as evidenced by the estimate of the 26 m antenna support boom mass.

AS AN EXAMPLE IF A BEAM IS MADE FROM 7075 T-6 ALUMINUM

$\rho = 2767 \text{ KG/M}^3$

$E = 69 \times 10^0 \text{ N/M}^2$

$\sigma_{MAX} = 289 \times 10^6 \text{ N/M}^2$ (INCLUDING S.F. = 1.5)

AND IF:

"α" (FOR OTV) = 1.86 M/SEC^2

M = 175 KG (FOR THE 26 M REFLECTOR)

H = 0.4M (≃ 16 INCHES)

THEN:

$$A_{REQ'D} = \frac{M\alpha l}{\sigma h} = \frac{175 \times 1.86 \times 13}{289 \times 10^6 \times 0.4} = .037 \times 10^{-3} m^2$$

(.057 in^2)

$$f_N = \frac{0.4}{\pi} \quad \frac{69 \times 10^0 \times .037 \times 10^{-3}}{2 \times 175 \times 13^3} = 0.23 \text{ Hz}$$

$$M_b = 3 \times 2767 \times 13 \quad .037 \times 10^{-3}$$

= 4 kg + WEB MASS

= ≃ 15 kg

For a continuous 3 longeron boom with a temperature gradient of $\Delta T = (T_1 - T_2)$ across the cross section of the boom if the reference temperature (temperature at assembly) is T_o and all longerons are made from the same material, the deflection at length 1 is

$$\delta = \frac{\alpha\sqrt{3}}{4H}\left[(T_1 - T_o)^2 - 2(T_2 - T_o)^2\right]^{\frac{1}{2}} 1^2$$

and the slope, in radian, is

$$\theta = \frac{2\delta}{1}$$

For booms of the length required on an MSP, thermal distortion minimization is very important. Some form of active control system using strip heaters on the booms or thermostatically controlled louvres may be necessary to maintain the mechanical boresight requirements.

Because of the need to minimize thermal distortions, and maintain torsional stiffness, the three longeron open-webbed boom is a good design choice. The open-ness helps the members to receive nearly equal solar input, thus minimizing the gradients.

POINTING ERROR DUE TO BOOM

THERMAL DISTORTION

SAMPLE CALCULATIONS
FOR A BOOM:

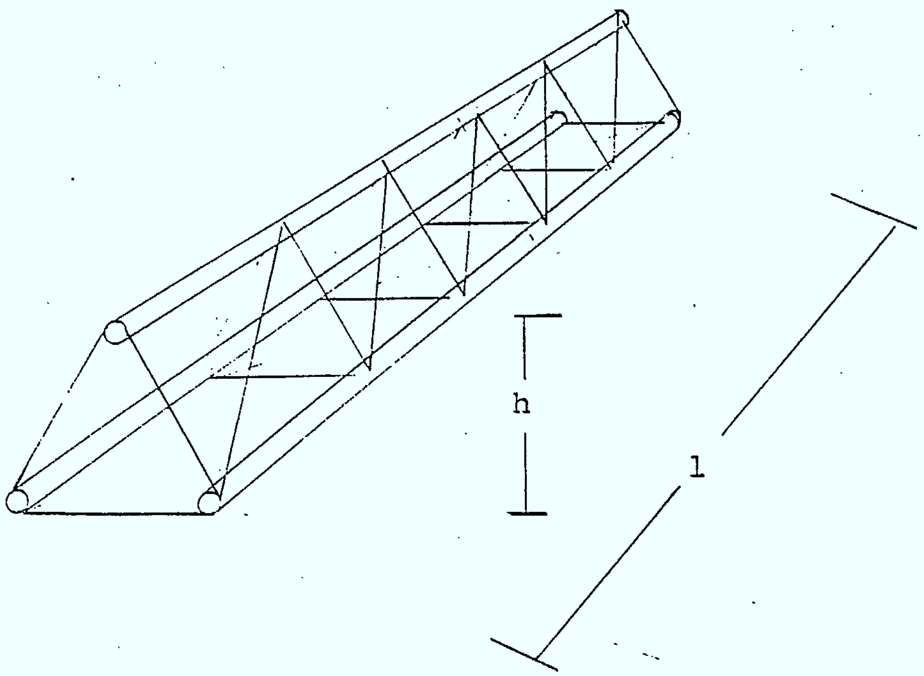
$H = 0.2\text{M}$ $\qquad \alpha = 2 \times 10^{-6}\ /^{0}C$

$T_1 = 50^{0}C \quad T_2 = 20^{0}C \quad T_0 = 0$

THEN:

$$\delta = 4.33 \times 10^{-6} \left[50^2 - 2(20)^2\right]^{\frac{1}{2}} 13^2 = .03\text{M}$$

$$\theta = 0.26^{0}$$



The configurations arrived at, and preliminary calculations made, have shown that it would likely be technically feasible to meet all the mid 1990's Canadian needs on a common spacecraft using technology available for 1987 launch. Whether it is desirable to do so depends more on institutional and cost factors than technical.

Both the needs of Canadian community, and the likely state of technology evolution are too ill-defined to ascertain whether similar feasibility exists for later generations.

CONCLUSIONS OF STRAWMAN CONFIGURATION EXERCISE

- O TECHNICALLY FEASIBLE TO MEET ALL CANADIAN NEED OF NEXT GENERATION ON AN MSP
  - O COST & INSTITUTIONAL FACTORS WILL DRIVE DECISION
- O FOLLOW-ON GENERATIONS TOO ILL-DEFINED TO DETERMINE IF FEASIBILITY EXISTS

5.0 ECONOMICS OF MULTIFUNCTION SPACE PLATFORMS

5.1 Introduction

Economic trade-offs have been a pivotal element in considerations of whether to develop operational multi-function space platform systems. Early proponents[3] predicted that the potential savings alone would be great enough to overcome the incompatibilities encountered, and convince users to place their services on MSP's instead of single-payload satellites. Others[3,19] argued that the overhead required to construct and maintain the spacecraft in orbit would more than offset these savings.

In order to resolve the differences a number of studies[29,78,79] have been undertaken to compare the cost of meeting a set of requirements with either a multifunction platform or individual satellites. All three of the studies confirmed that platforms were more cost effective than individual satellites for the specific situation studied and set of assumptions made. However, the reasons for the cost savings not only differed among the studies, but were somewhat inconsistent, indicating that further development of cost modelling is required.

- MSP'S WERE PREDICTED TO LOWER THE OVERALL COST TO THE USER OF SATELLITE SERVICES BY:
  - AVOIDING WASTEFUL DUPLICATION OF PLATFORM AND SUPPORT SYSTEMS
  - MAKING MORE EFFICIENT USE OF LAUNCH VEHICLE CAPABILITIES.
  - INTRODUCING COMPLEXITY INVERSION
    - PROLIFERATION OF SMALL, INEXPENSIVE EARTH TERMINALS.
    - REMOVAL OF NEED FOR COSTLY TERRESTRIAL BACKHAULS BETWEEN USERS AND GATEWAYS.

- MAJOR COST TRADE STUDIES HAVE BEEN PERFORMED BY:
  - NASA-MARSHALL SFC
  - FUTURE SYSTEMS INCORPORATED
  - GENERAL-DYNAMICS/CONVAIR

- ALL SHOW PLATFORMS TO BE COST EFFECTIVE, BUT:
  - REASONS
  - PAYLOAD MODEL
  - ASSUMPTIONS AND GROUND RULES

  ALL DIFFER AMONG STUDIES

Cost was identified as a major concern of all Canadian users and system operators/planners interviewed during the study. The "bottom line" was universally defined as the dominant driver in a decision to place or not place payloads on an MSP. Equally universal was the respondents' concern that none of their technical requirements be compromised even slightly to achieve the cost savings.

There is at present inadequate information applicable to the Canadian context to allow these concerns to be answered. Not only is the scale of our requirement much less than that used in the cost trade studies, but many of the ground rules and assumptions used are not applicable, due to our different regulatory climate. In addition, very little useful cost information was received during the survey; only already published spacecraft costs and personal estimates of payload fractions were given.

It is beyond the scope of the present study to perform a detailed cost analysis of Canadian MSP's. Rough order of magnitude (ROM) cost estimates have been made for the two strawman configurations, and these have been compared to similar estimates of the cost of meeting the requirements of the baseline mission model using single payload satellites. This comparison will be discussed in section 5.3, along with a qualitative discussion of the Canadian concerns and potential solutions.

The major portion of the chapter (section 5.2) is devoted to a judgmental analysis of the U.S. trade studies' results. These studies represent a major effort using a large data base, and consequently the analysis provides insight into both the relative economics of platforms vs single payload satellites, and the state-of-the-art of cost estimating.

- COST IS THE DRIVER FOR
    - USERS
    - OPERATORS
- TRADE-OFFS TO BE BASED ON SYSTEMS MATCHING ALL REQUIREMENTS
    - NO TECHNICAL COMPROMISES TO BE MADE TO LOWER COST.
- U. S. STUDIES NOT DIRECTLY APPLICABLE
    - DIFFERENT SCALE OF REQUIREMENTS
    - DIFFERENT REGULATORY CLIMATE
- CANADIAN INFORMATION BASE IS POOR.
- MORE DETAILED WORK REQUIRED.

5.2 Economic Trade-Offs

5.2.1 Introduction

Three specific U.S. cost trade studies have been analyzed;[29,78,79] a report containing a fourth[30] was received too late to be included in the analysis.

Two of the studies[78,79] are one-to-one comparisons, in which estimates were made of the cost to meet a specific set of payload requirements on either large platforms or a series of individual satellites. The third[29] is a parametric study of a series of scenarios which include sets of mission requirements, platform evolutionary buildup options, launch vehicle options, servicing options, etc. The intent was to discover the lowest life cycle cost approach to meeting realistic sets of requirements.

The basic conclusions of all three studies are the same: platforms are more cost effective than individual satellites. However, the reasons for the savings differ substantially from study to study, indicating that further analysis and/or work is required.

Each of the studies is discussed individually in the next sections, and then they are summarized as a group.

- O THREE COST STUDIES ANALYZED:
  - O NASA-MARSHALL
  - O FUTURE SYSTEMS INCORPORATED
    - O BOTH SINGLE MISSION MODEL TRADES
    - O SINGLE PLATFORM CONCEPT/STUDY
  - O GENERAL-DYNAMICS/CONVAIR
    - O MULTIPLE MISSION MODELS
    - O MULTIPLE PLATFORM CONCEPTS
    - O LOWEST LIFE CYCLE COST SYSTEM TO BE FOUND
- O PLATFORMS LESS EXPENSIVE THAN INDIVIDUAL SATELLITES
  - O CONSISTENT CONCLUSION
  - O INCONSISTENT REASONING
- O MORE WORK TO BE DONE TO RECONCILE THE RESULTS

5.2.2 NASA-Marshall Space Flight Centre Study

The first published detailed cost trade study was one by NASA-Marshall in 1978.[78]

This study compared the cost of meeting a sixteen year mission model with either individual satellites or a single large platform. The mission model was based on the 1977 "NASA Payload Data Bank" and Battelle's "Outside Users' Model", both of which terminated in 1993. An identical "repeat" cycle was assumed in order to satisfy the 15-20 year lifetime assumption.

The basic technical aspects of the two sets of spacecraft are shown opposite.

TECHNICAL PARAMETERS OF NASA MODEL

- o PAYLOADS
  - o 106 PAYLOADS TOTAL OVER 16 YEARS (1986-2001)
  - o 20 DIFFERENT OPERATING SYSTEMS
  - o WESTERN HEMISPHERE (INCLUDING CANADIAN PAYLOADS)
  - o 2 IDENTICAL 8-YEAR CYCLES
- o INDIVIDUAL SATELLITES
  - o CONVENTIONAL PRESENT TECHNOLOGY SPACECRAFT
  - o 106 SATELLITE LAUNCHES OVER 16 YEARS
  - o EACH SYSTEM OPERATOR DESIGNS 2 FULL SETS OF SPACECRAFT
  - o SPACECRAFT MASSES ~1.1 TIMES ESTIMATE IN BATTELLE REPORT.
  - o UPPER STAGE CAPABILITIES:
    - o SSUS-D: 800 LBS.
    - o SSUS-A: 2100 LBS.
    - o IUS : 5000 LBS.
  - o TOTAL OF 54 SHUTTLE FLIGHTS REQUIRED
  - o UPPER STAGES USED:
    - o SSUS-D: 6
    - o SSUS-A: 78
    - o IUS : 22
- o PLATFORM
  - o ONE 30M ANTENNA SHARED BY 5 USERS
  - o OTHER PAYLOADS HAVE OWN ANTENNAS
  - o BUILT IN LEO, 4 SHUTTLE FLIGHTS
  - o 106 PAYLOADS ADDED OVER 16 YEARS
  - o EACH SYSTEM OPERATOR DESIGNS 2 SETS OF PAYLOADS
  - o PAYLOAD MASSES BASED ON SELECTED FRACTIONS OF INDIVIDUAL SATELLITE MASSES
  - o 35 SHUTTLE FLIGHTS REQUIRED, INCLUDING 4 FOR CONSTRUCTION
    - o 32 OTV FLIGHTS
    - o 31 TRS FLIGHTS
  - o 7030 KG DRY WEIGHT, NO PAYLOADS
  - o MAXIMUM 6073 KG PAYLOAD COMPLEMENT → 46% PAYLOAD

The cost/economic comparison analysis was performed for the space segment only. It was assumed that the ground/mission operations over the 16-year lifetime would be the same for both modes.

The costs are all quoted in millions of 1978 U. S. dollars.

ECONOMICS-RELATED GROUNDRULES AND ASSUMPTIONS

- CONUS PLATFORM (SIC) OPERATIONAL LATE 1986
- STS USED IN BOTH MODES
- COSTS FOR 2 SPACECRAFT AND/OR PAYLOAD EQUIPMENT UPDATES ARE INCLUDED
- GROUND/MISSION COSTS ARE EXCLUDED

BASIC COST ELEMENTS ARE:

ELEMENT	COST (1978 \$M U.S.) PLATFORM	INDIV. SAT
PLATFORM	224	23.2 AVERAGE
PAYLOAD	10.9 AVERAGE	14.6 AVERAGE
REFURBISHMENT	25/FLT	N/A
SHUTTLE/FLT	28.5	28
OTV/FLT	3	2.5 SSUS-D 3.5 SSUS-A 8 IUS
TRS/FLT	1	N/A
OTV R&D	765	N/A
CONSTRUCTION AIDS	238 (TOTAL)	N/A
PAYLOAD GROUND C/O	15 (TOTAL)	N/A

The analysis showed that, on a cost basis alone, the MSP mode was 39% less expensive than the individual satellite mode. Most of this difference was in the spacecraft cost. The total MSP on-orbit system cost was only 44% of that for the individual satellites; whereas, the transportation costs, for the platform were 96% of those for the individual satellites.

The comparison was taken an additional step to take into account the time value of money. A net present value calculation was applied to the time-phased expenditure, using a discount rate of 10%. This reduced the savings from 39% to only 16%. It was also calculated that the internal rate of return for the platform (the point at which the discounted costs for both modes are equal) was 15%. The point was made that this represented a worst case calculation, since all the OTV and assembly aid non-recurring costs were included.

o COST COMPARISON (1978 $M U. S.)

PLATFORM MODE			INDIVIDUAL SAT. MODE	
ON-ORBIT EQUIP. RELATED			SPACECRAFT	
1 PLATFORM	224		106 BUSES	2464
106 PAYLOADS	1160		106 PAYLOADS	1552
5 REFURB.	125			
ASS'Y AIDS	238			
P/L CHECKOUT	15			
TOTAL		1762 ..... 42% OF 4016		
TRANSPORTATION			TRANSPORTATION	
35 SHUTTLE FLTS.	998		54 SHUTTLE FLTS.	1512
32 OTV FLIGHTS	96		84 SSUS FLIGHTS	288
31 TRS FLIGHTS	31		22 IUS FLIGHTS	176
OTV R&D	765			
TOTAL		1890 ..... 96% OF 1976		
GRAND TOTALS		3652 ..... 61% OF 5992		

o COST OF MONEY CONSIDERATIONS

o PRESENT VALUES AT 10 % DISCOUNT RATE

o MSP - 1812   o SATELLITE 2146

... 84% OF ...

The basic assumptions and results were analyzed in light of more recent information, with the result that the cost advantage of the platform was reduced from 39% to 21%, even without taking into account the cost of money.

Revised spacecraft and payload estimates were made; the net result was a small (2%) increase in the total cost of the individual satellites, and an increase of nearly 50% in the platform payload cost. In the original NASA study, the platform payload was expected to cost significantly less than the sum of the individual satellite payloads performing the same functions ($1160M vs $1552M). This large difference in cost was based on the fact that the 30m diameter antenna would be shared by many of the platform payloads, and the cost of this antenna was already considered in the platform cost. However, only 25% of the total payloads actually use this antenna, as opposed to having to provide their own, so it is felt that the cost savings will not be as substantial as predicted.

A major decrease in transportation costs is achieved for the individual satellite case purely by using updated OTV capabilities. The spacecraft masses were matched to currently quoted capabilities to select appropriate upper stages, and the new set of flight combinations was costed, using the Marshall individual flight values. The net saving was $709M or 36%.

Revised Cost Comparison

Platform:	2372 up 35%		Satellites:	4100 up 2%
Transportation:	1890 no change		Transportation:	1267 down 35%
Total	4262 up 17%			5367 down 10%

..... 79% of .....

- New spacecraft and payload estimates ($)
- No other changes of cost assumptions
- Revised SSUS capabilities matched to NASA satellite mass estimates
- No cost of capital included.

5.2.3 Future Systems Incorporated Study

FSI produced a cost-benefit study[79] for NASA headquarters in February 1979, the purpose of which was to compare the costs of large capacity communications platforms with separate, smaller satellites on a systems basis, considering total costs to the end user. Two separate systems were studied: U.S. domestic point to point communications and Intelsat Atlantic service. The capacity requirements were derived from a mission model developed as part of the study, and already referenced in Section 3.3.2 of this report.

The basic technical characteristics of the 'domestic' systems are shown opposite. Both the satellite and platform cases have been designed to provide approximately 3 for 2 redundancy of on-orbit capacity throughout the system lifetime.

TECHNICAL PARAMETERS OF FSI MODEL

DOMESTIC U. S. MODEL

- o PAYLOADS
  - o 700 EQUIVALENT 36 MHz TRANSPONDERS REQUIRED EOL
  - o POINT-TO-POINT SERVICES - U. S. ONLY
  - o 6/4, 14/12 AND 30/20 GHz USED AS REQUIRED
  - o 10 YEAR MISSION LIFE: 1987-96
  - o PATH DIVERSITY AS REQUIRED
- o INDIVIDUAL SATELLITES
  - o ADVANCED TECHNOLOGY: EACH CARRIES 72 EQUIVALENT 36 MHz TRANSPONDERS
  - o 16 SATELLITE LAUNCHES OVER 10 YEARS
  - o 450 W RF POWER, 2350 W DC
  - o 1660 KG TOTAL, 510 ARE COMM'NS, 380 HYDRAZINE
- PLATFORMS
  - o 3 IN ORBIT: AT & T, CONSORTIUM OF SCC'S, COMMON SPARE
  - o MASS & POWER REQUIREMENTS SCALED FROM NASA AND EDELSON/MORGAN CONCEPTS
  - o PHYSICAL LAYOUT HAS 18 ANTENNAS, IS SCALED FROM NASA DESIGN
  - o 3 SHUTTLE FLIGHTS USED TO TRANSPORT TO LEO AND ASSEMBLE, SINGLE OTV TRANSFERS TO GEO.
  - o 7920 KG BOL, WET
  - o 3000 KG PAYLOAD → APPROX. 45-50% OF DRY WEIGHT IS PAYLOAD.
  - o 375 EQUIVALENT 36 MHz TRANSPONDERS EACH
  - o 16 KW EOL.
- o GROUND SEGMENTS
  - o UP TO 10,000 STATIONS BY 1996 FOR PLATFORMS
  - o UP TO 2000 STATIONS BY 1996 FOR INDIVIDUAL SATELLITES
  - o PLATFORM EARTH STATIONS ARE:
    - o SMALLER
    - o LESS EXPENSIVE
    - o CLOSER TO END USER

The concept of the Intelsat model was similar, but the specific values of certain parameters differ.

ATLANTIC INTELSAT MODEL

- o PAYLOADS
  - o 527 EQUIVALENT 36 MHZ TRANSPONDERS REQUIRED EOL
    - o 267 INTERNATIONAL
    - o 260 DOMESTIC LEASE
  - o 6/4, 12/14, 30/20 GHZ USED AS REQUIRED
  - o 10 YEAR MISSION LIFE: 1987-96
- o INDIVIDUAL SATELLITES
  - O ADVANCED TECHNOLOGY:
    - O DOMESTIC SERVICE: 3 VERSIONS

12	24	36	TRANSPONDERS
600	850	1100	KG
450	925	1400	W
14	1	5	LAUNCHED

OVER TEN YEAR PERIOD.

INTERNATIONAL SERVICE

O 96	EQUIVALENT TRANSPONDERS
1900	KG
3000	W
6	LAUNCHED OVER TEN YEARS

- O PLATFORMS
  - O 2 IN ORBIT, EITHER CAPABLE OF CARRYING ALL TRAFFIC
  - O 540 EQUIVALENT 36 MHZ TRANSPONDERS
  - O SAME LAUNCH METHOD AS U. S. DOMESTIC PLATFORMS
  - O 9120 KG BOL, WET
  - O 3300 KG PAYLOAD → APPROXIMATELY 45% PAYLOAD
- O GROUND SEGMENT
  - O FOR PLATFORMS, UP TO
    - O 5180 DOMESTIC SERVICE STATIONS
    - O 155 INTERNATIONAL SERVICE STATIONS
  - O FOR INDIVIDUAL SATELLITES, UP TO
    - O 2000 DOMESTIC SERVICE STATIONS
    - O 155 INTERNATIONAL SERVICE STATIONS

The cost comparisons were based on the total systems: space and ground segments.

The cost elements shown were used to derive the comparison figures, but were not used directly. FSI chose to compare on the basis of revenue requirements, a method which takes into account both system operating cost and cost of capital.

All costs are in millions of 1979 U. S. Dollars.

- ECONOMICS-RELATED GROUND RULES AND ASSUMPTIONS
  - PLATFORMS OPERATIONAL 1987
  - STS USED IN BOTH MODES
  - 10 YEAR LIFETIME, NO REFURBISHMENT
  - GROUND SEGMENT:
    - PLATFORMS: $20 K TO $100 K EACH
    - SATELLITES: $200 K TO $1 M EACH PLUS BACKHAUL
    - HARDWARE COSTS INCREASED BY 40% FOR TRANSPORTATION, INSTALLATION, ETC.
- BASIC COST ESTIMATES

ELEMENT		PLATFORM U.S.	PLATFORM INTELSAT	INDIVIDUAL SAT. U.S.	INDIVIDUAL SAT. INTELSAT I-6	INTELSAT 12	INTELSAT 24	INTELSAT 36
PLATFORM & PAYLOADS	o NON-REC.	137	149	70	90	10	22	35
	o RECURRING	107	114	35	44	17	21	25
SHUTTLE/FLIGHT		30	30	30	{36}	10	15	20
OTV/FLIGHT		15	15	6		3.4	3.4	3.4
EARTH STATIONS - HARDWARE		$50 K		$200 K SINGLE ACCESS $ 1 M MULTIPLE ACCESS				

- ECONOMIC MODEL FORECAST - MAJOR CONSIDERATIONS
  - ANNUAL REVENUE REQUIREMENTS = DEPRECIATION & OPERATION & MAINTENANCE & RETURN ON INVESTMENT
  - ALL INVESTMENTS STRAIGHT LINE DEPRECIATED OVER 10 YEARS
  - ALL CALCULATIONS IN 1979 DOLLARS
    - ROI CHOICE (15%) INCLUDES INFLATION FACTOR
  - ANNUAL AND AVERAGE COST/CIRCUIT CALCULATED
  - NET INVESTMENT = CUMULATIVE INVESTMENT - ACCUMULATED DEPRECIATION
  - COST OF TERRESTRIAL BACKHAUL INCLUDED IN OPERATING COSTS

In order to compare the three cost studies, the FSI model has been used to derive space segment cost comparisons equivalent to those of NASA-MSFC.

For the assumptions made by FSI, it is seen that the total space segment costs of the platforms are 43% and 56% less than for individual satellite systems. In these two cases, however, neither the on-orbit segment nor the transportation can be considered the driver, since both elements have similar cost ratios within the individual models.

COST COMPARISON - SPACE SEGMENT ONLY (1979 $M U.S.)

o U. S. DOMESTIC

PLATFORM MODE		INDIVIDUAL SAT. MODE	
PLATFORM		SPACECRAFT	
DEVELOPMENT	137	DEVELOPMENT	210
RECURRING	321	RECURRING	560
	458... 59% OF ... 770		
TRANSPORTATION		TRANSPORTATION	
9 SHUTTLE FLTS.	270	16 SHUTTLE FLTS.	480
3 OTV FLIGHTS	45	16 OTV FLIGHTS	96
	315... 55% OF ... 576		
GRAND TOTALS	773... 57% OF ... 1346		

o INTELSTAT

PLATFORM MODE		INDIVIDUAL SAT. MODE	
PLATFORM		SPACECRAFT	
DEVELOPMENT	149	DEVELOPMENT	157
RECURRING	228	RECURRING	648
	377... 47% OF ... 805		
TRANSPORTATION		TRANSPORTATION	
6 SHUTTLE FLTS.	180	26 SHUTTLE FLTS.	471
2 OTV FLIGHTS	30	20 OTV FLIGHTS	68
	210... 39% OF ... 539		
GRAND TOTALS	587 ... 44% OF ... 1344		

The average cost per circuit year is the parameter used by FSI to compare the various systems. The annual revenue requirements were normalized by the number of circuits in operation during the year of interest to yield the annual cost per circuit, and these were then averaged to get the average cost per circuit year.

The results show that the relative saving of a platform system over individual satellites is less than might be concluded from a simple examination of the initial cost ratios. This is because the initial investment for platforms is large; whereas, the individual satellite launches are distributed over a longer period, so that the residual value of the system is never very great at a given time, thus lowering the revenue requirement necessary to meet a given ROI.

In the U. S. model, which is most comparable to the NASA case, the space segment costs are within 16% of each other, and it is the proliferation of inexpensive ground terminals which makes platform systems so cost effective.

The difference in ground segment is not so great for the Intelsat cases. In the international trunking model, the difference is likely due to computer rounding; the model is based on an identical ground segment for both systems. The countries leasing Intelsat transponders are expected to have less developed communications systems than the U. S., so the growth of short backhaul/customer premises services which keep the U. S. ground segment inexpensive in platform systems is not expected, and hence the relative saving in going to platforms is less dramatic.

Cost Comparison Using Revenue Requirements

1979 $K U.S. per circuit year

o U. S. domestic service comparison

	PLATFORM			INDIVIDUAL SATELLITES
SPACE	0.46	....	84% OF	0.55
GROUND	1.04	....	39% OF	2.69
TOTAL SYSTEM	1.50	....	46% OF	3.24

o Intelsat International Service comparison

	PLATFORM			INDIVIDUAL SATELLITES
SPACE	0.52	....	67% OF	0.78
GROUND	0.32	....	97% OF	0.33
TOTAL SYSTEM	0.84	....	76% OF	1.11

o Intelsat domestic lease service comparison

	PLATFORM			INDIVIDUAL SATELLITES
SPACE	0.52	....	57% OF	0.91
GROUND	1.75	....	74% OF	2.36
TOTAL SYSTEM	2.27	....	69% OF	3.27

o Intelsat combined space segment ratio is 61%, vs. 44% at cost

o Domestic ratio is 84%, vs. 57% at cost.

FSI conducted a series of analyses to test the sensitivity of the results to changes in assumptions. The model tested was the U. S. domestic service.

The ratios of the total revenue requirements changed very little, indicating that the model is relatively insensitive to errors in platform development cost estimates or traffic estimates. The results do, however, point out the criticality of the assumption of small earth station proliferation to the overall conclusions. The space segment trade-offs all show relatively little advantage for platforms; one in fact shows them to be more expensive than conventional satellites, but the net advantage is still retained because of the ground segment savings.

- SENSITIVITY ANALYSIS RESULTS

- PLATFORM DEVELOPMENT COSTS AND CONSTRUCTION COSTS INCREASE 50%; ALL OTHER COSTS DON'T CHANGE

	PLATFORM		INDIVIDUAL SATELLITES	BASELINE RATIO
SPACE	0.59	....107 % OF	0.55	84 %
GROUND	1.04	.... 39 % OF	2.69	39 %
TOTAL SYSTEM	1.63	.... 50 % OF	3.24	46 %

- TRAFFIC 50% BELOW BASELINE

	PLATFORM		INDIVIDUAL SATELLITES	BASELINE RATIO
SPACE	0.72	.... 76 % OF	0.95	84 %
GROUND	1.45	.... 36 % OF	4.03	39 %
TOTAL SYSTEM	2.17	.... 44 % OF	4.98	46 %

- TRAFFIC 50% ABOVE BASELINE

	PLATFORM		INDIVIDUAL SATELLITES	BASELINE RATIO
SPACE	0.34	..... 74 % OF	0.46	84 %
GROUND	0.89	..... 39 % OF	2.26	39 %
TOTAL SYSTEM	1.23	..... 45 % OF	2.72	46 %

5.2.4 General-Dynamics/Convair Study

The General-Dynamics/Convair study [29] is a detailed analysis of the configuration options for operational multifunctions space platforms, and an attempt to define a 'preferred' concept. This is the one which is determined to have the minimum total space segment life cycle cost.

No ground segment costs were explicitly included in the study. However, the communications architecture was based on the recommendations in the Aerospace Corporation's 'Geostationary Platform Feasibility Study' [71], which included both high volume trunking and direct-to-user systems. The particular architecture was chosen not only for operational flexibility, but also because it was believed to provide the most cost effective ground segment.

Two sets of mission models were defined for detailed analysis, and a series of trade studies performed. Low and high mission models were developed for both the Western Hemisphere and Atlantic Ocean regions, covering the requirements over a 16 year period commencing in the early 1990's. The mission set used for comparison with the NASA and FSI models is the 'Nominal-Western Hemisphere' one, which has the requirements listed opposite.

- Mission Set Used
    - Western Hemisphere
    - Payloads in 24 categories
    - 9230 KG payload mass
    - 37,700 W payload power

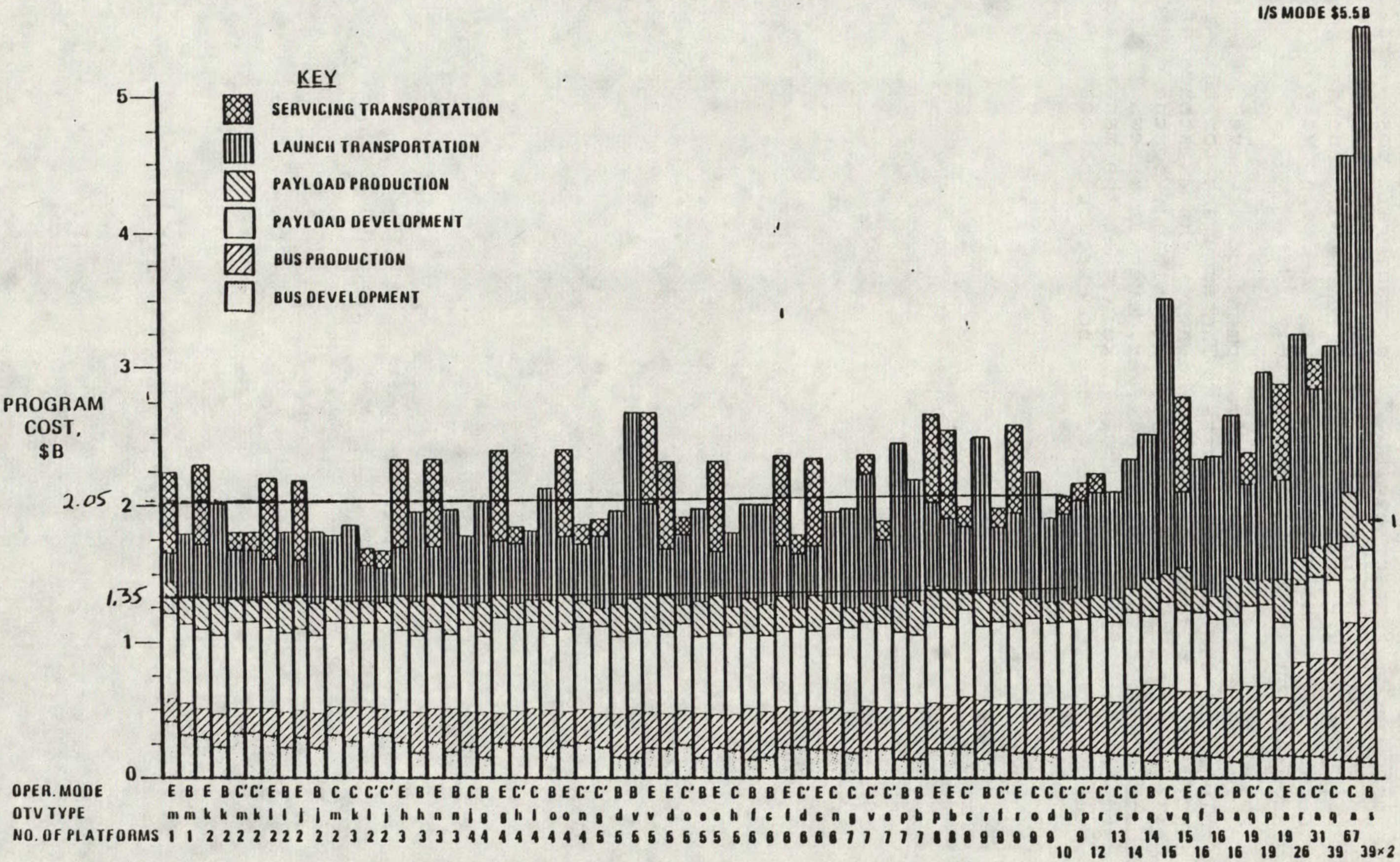
- Ground Rules of G-D/C Studies
    - System IOC date ≈ 1990
    - Common platform elements for western hemisphere and Atlantic missions - design goal.
    - Lifetime
        - 16 years - a design goal
        - Baseline - unmanned servicing at GEO
        - Alternate - long life, nonserviced system
    - Minimum development & operations cost - design goal
    - Maximum use of existing & Projected (1990's) technology
    - STS
        - 65 KLB Shuttle
        - existing and improved upper stages
        - new OTV family

- Trade Study Areas
    - Servicing vs nonservicing
    - Single vs multiple platforms
    - Evolutionary buildup options (time phasing)
    - Construction location options (LEO or GEO)
    - Transportation options (OTV capabilities)
    - Structural options
    - Development/Assembly options
    - Construction base options
    - Logistic support options

Because of the large number of cases studied, a simple cost element matrix and resultant cost comparison can not be made as was done in the NASA and FSI cases.

It can be noted from the study results presented opposite, however, that the total costs for the system are relatively constant for all concepts containing up to a dozen platforms. Consequently, approximate average spacecraft and transportation costs can be determined for comparison with the individual satellite case.

PROGRAM COST SUMMARY
MISSION SET N
BUILDUP MODE K



The dominant factor in the cost saving in this study is seen to be transportation. The spacecraft costs are 29% less for platforms, but the transportation costs are 81% less. The driver behind the large number of launches required for the individual satellite case is the relatively low payload mass fraction assumed (approximately 21%).

In addition, no OTV development costs have been included in the platform costs. The argument for this is that an OTV will be developed independent of the existence of MSP's, which will at most affect its timing, so the development costs are in fact 'sunk'. However, even if a new OTV is used for other missions, it is likely that the manufacturer would factor at least some of the non-recurring costs into his price.

- INDIVIDUAL SATELLITE CASE
  - 8 YEAR LIFETIME
  - 2 GENERATIONS OF 39 SPACECRAFT REQUIRED TO MEET MISSION REQUIREMENTS
  - PAYLOAD MASS FRACTION - 21%
- PLATFORMS: 'AVERAGE' OF 1-12 PLATFORM CASES
  - PAYLOAD MASS FRACTION IN RANGE OF 24-60%
- COST COMPARISON: ($M U.S. 1980)

	PLATFORM					INDIVIDUAL SATELLITE
PLATFORMS	1350	.....	71%	OF	.....	1900
TRANSPORTATION	700	.....	19%	OF	.....	3600
GRAND TOTAL	2050	.....	37%	OF	.....	5500

A series of more detailed trade studies were performed with some of the lower cost options from both mission sets to define the preferred concept. The results were found to be relatively insensitive to the mission model used.

The major trade items studied are listed opposite, along with the preferred concept. It is worth noting the degree to which this differs from early MSP concepts.

- O COST SENSITIVITY ANALYSES PERFORMED AND MAJOR CONCLUSIONS
  - O MISSION SET - CONCLUSIONS/RECOMMENDATIONS INDEPENDENT OF TRAFFIC MODEL
  - O OTV DEVELOPMENT - 2 STAGE OTV'S ARE BEST
  - O BUILDUP-MODE - DOCKED DEPENDENT MODULE BEST
    - PAYLOAD ADDITION CONCEPT IS MOST EXPENSIVE FORM OF PLATFORM
  - O FUNDING SPREAD - HIGH REDUNDANCY, 8 YEAR SERVICING LEADS TO BEST CASE.

- O BASELINE CONCEPT
  - O BUILD PLATFORM UP OVER 8 YEARS: 1990-1998, AFTER WHICH IT IS A PERMANENT FACILITY
  - O MODULES LAUNCHED 2 TO 4 YEARS APART
    - O CHECKED OUT IN LEO
    - O TRANSFERRED TO GEO BY 2-STAGE REUSABLE OTV
    - O DOCKED TO EXISTING MODULES
  - O MODULES HAVE 16,877 KG MASS
    - O 4000-10,000 KG PAYLOAD
    - O FIRST CARRIES 30-75 KW OF POWER
  - O MODULES ARE HIGHLY REDUNDANT
    - O 16 YEAR DESIGN LIFE
    - O LIFE EXTENDED BY SERVICING EVERY 8 YEARS
  - O PROPELLANT TANKS SIZED FOR 8 YEARS
  - O MODULE STRUCTURE MASS IS 1575 KG
    - O LOW CTE
    - O DEPLOYABLE TRUSS
  - O SINGLE BAY FOR MODULE
    - O DEPLOYED IN LEO
    - O 2 SEPARATE OTV FERRY FLIGHTS
    - O LEO MATING

5.2.5 Summary of Study Results

Cost savings are produced by using platforms instead of single payload satellites according to each of the studies; however, the reasons are vastly different.

All of the savings become smaller if the cost of money is included, either by discounting to present value or performing time phased return on investment calculations.

o COMPARATIVE RELATIVE COSTS FOR PLATFORM SYSTEMS

"UP FRONT" PLATFORM COSTS AS A FRACTION OF INDIVIDUAL SATELLITE COSTS

STUDY	SPACECRAFT	TRANSPORTATION	TOTAL SPACE SEGMENT
NASA-MSFC	44 %	96 %	61 %
FSI-U. S.	59 %	55 %	57 %
- INTELSAT	47 %	39 %	44 %
G-D/C	71 %	19 %	37 %

o BASIC CONCLUSIONS OF THE STUDIES

- o NASA-MSFC
  - o SPACECRAFT COST IS THE DRIVER
  - o TRANSPORTATION IS ROUGHLY CONSTANT
  - o GROUND SEGMENT COSTS ARE ROUGHLY EQUAL (ASSUMED)
- o FSI
  - o BOTH SPACE SEGMENT ASPECTS ARE SIMILAR
  - o GROUND SEGMENT IS THE DRIVER
- o G-D/C
  - o SPACECRAFT COSTS ARE ROUGHLY CONSTANT
  - o TRANSPORTATION IS THE DRIVER
  - o GROUND SEGMENT NOT CONSIDERED

A number of conclusions can be drawn from an analysis of the studies and their internal sensitivity studies.

The two major ones are:

- Cost estimating appears to be as inexact as mission model estimating.

- The proliferation, or not, of inexpensive ground terminals will be a major determinant of the cost effectiveness of platforms, since when full life cycle revenue requirements are taken into account, the relative savings on the space segment can be fairly low (10-20%).

BASIC CONCLUSIONS WHICH CAN BE DRAWN

- COST ESTIMATING IS STILL VERY INEXACT AND STRONGLY DEPENDENT ON THE PARTICULAR ASSUMPTIONS
- FOR A GIVEN SET OF ASSUMPTIONS, THE BASIC TRADE RESULTS ARE INDEPENDENT OF MISSION MODEL
- TRANSPORTATION COST TRADES ARE STRONGLY DEPENDENT ON THE DEVELOPMENT COST RECOVERY SCHEME TO BE EMPLOYED IN PRICING NEW OTV'S
- OVERALL SYSTEM COST TRADES ARE STRONGLY DEPENDENT ON WHETHER LOW-COST USER PREMISES EARTH STATIONS DO PROLIFERATE
- MEDIUM SIZED (SINGLE SHUTTLE BAY) PLATFORMS APPEAR PREFERABLE TO VERY LARGE ONES
- DOCKED, DEPENDENT MODULES APPEAR PREFERABLE TO DOCKED INDEPENDENT OR CLUSTERED MODULES, BUT NOT GREATLY SO
- SERVICING, BUT AT INFREQUENT (E.G. 8 YEAR) INTERVALS APPEARS PREFERABLE.

5.3 Economic Implications of MSP's for Canadian Satellite Systems

5.3.1 Major Canadian Cost Concerns

All three subsets of the Canadian space community interviewed (users, operators, manufacturers) stressed the importance of the cost trade-offs in determining their willingness to place services on MSP's. There was general skepticism that the cost trade results were really valid, and whether they could be applied to the Canadian context. In light of the comparisons made of the results of the U. S. based studies, this skepticism may be well founded. Nevertheless, the true Canadian economic comparisons can only be made if a detailed study of the various means of meeting Canadian needs is undertaken. Because of our smaller set of requirements, the technology required to meet them using 'large' platforms, clusters, or single payload satellites is nearer term than that for the U. S. scale of MSP, and better understood. Some of the basic concerns which have been identified in the present study, and which must be investigated in a cost study, are enumerated opposite.

MAJOR CANADIAN COST CONCERNS REQUIRING INVESTIGATION

- O HOW DOES THE SMALLER SCALE OF OUR NEEDS AFFECT THE COST TRADES?

  E.G.
  - O WITH FEWER SATELLITES, THE RATIO OF SINGLE PLATFORM DEVELOPMENT COSTS TO MULTIPLE INDIVIDUAL SATELLITE DEVELOPMENT COST IS LESS FAVOURABLE.
  - O MANY OF OUR NEEDS ARE COMMON ENOUGH TO PERMIT THE USE OF THE SAME BUS FOR DIFFERENT PAYLOADS.
  - O RELATIVELY FEW LAUNCHES ARE REQUIRED TO MEET OUR NEEDS (TRANSPORTATION TRADE LESS FAVOURABLE)

- O WHAT HIDDEN COSTS HAVE BEEN MISSED?

  E.G.
  - O THE NEED TO HAVE ALL PAYLOADS ON ONE PLATFORM AVAILABLE FOR LAUNCH AT ONCE MAY SIGNIFICANTLY INCREASE SPACECRAFT COSTS, ESPECIALLY DURING THE LAUNCH PREPARATION PHASE

- O WHAT ARE THE COST TRADES FOR "HYBRIDIZING" AN ALREADY LARGE SPACECRAFT SUCH AS A MOBILE SERVICE SATELLITE?
  - O THIS FORM OF TRADE HAS NOT BEEN LOOKED AT IN THE U.S. STUDIES.

- O WHAT FORM(S) OF MSP WOULD BEST SERVE OUR NEEDS?
  - O CLUSTERS OF HYBRIDS?
  - O CLUSTERS OF SINGLE PAYLOAD SATELLITES?
  - O DOCKED MODULES?
  - O SINGLE LAUNCH PLATFORMS?

MAJOR CANADIAN COST CONCERNS REQUIRING INVESTIGATION (CONTINUED)

- WHAT ARE THE TRUE COST TRADES OF JOINING INTERNATIONAL PROGRAMS VS. USING DOMESTIC SINGLE PAYLOAD SATELLITES?

  E.G. O ELEMENTS REQUIRING CONSIDERATION ARE:

  - WHAT ARE THE TRUE PAYLOAD COSTS FOR EACH OPTION?
  - ARE LAUNCH & OTV COSTS TRULY LOWERED?
  - IS THE LIFETIME COST OF PLATFORM RENTAL LESS OR GREATER THAN THE TRUE COST OF A DEDICATED BUS?
  - GIVEN THAT TELESAT (E.G.) WOULD NEED DIRECT CONTROL OF OUR PAYLOAD(S), WOULD THERE REALLY BE SAVINGS IN MISSION OPERATION AND CONTROL COSTS? WOULD WE STILL REQUIRE OUR OWN TT&C STATION?

- CAN SIGNIFICANT OVERALL COST SAVINGS BE ACHIEVED IF THE REGULATORY/OWNERSHIP POLICY IS CHANGED TO ALLOW OR ENCOURAGE THE PROLIFERATION OF USER-OWNED ON-SITE SMALL EARTH TERMINALS?

5.3.2 Cost Trade-offs - Baseline Mission Model

A rough order of magnitude cost estimate was made for both of the strawman platform configurations described in Section 4.4. In addition, ROM cost estimates were made for single payload satellites meeting the requirements of the baseline mission model. In each case one operational spacecraft and one on-orbit spare were assumed. The estimates were made in 1980 U.S. dollars and converted to Canadian at 1.15:1 exchange rate.

In deriving the costs for the multiple-satellite system (case 3) a combined low UHF/L-band payload spacecraft similar to MUSAT has been assumed. It is unlikely that the restricted UHF coverage (requiring a large antenna) would be chosen unless the payload were carried on a large platform, and currently published concepts contain both UHF and L-band payloads.

All three systems consist of eight-year lifetime satellites launched in the late 1980's, so the acquisition/launch cost comparisons are reasonable representations of the relative economics of the concepts.

As discussed in Section 4.4, the choice of platform payloads for the hybrid system (case 2) was based mainly on service interconnection concerns and not cost. The two civil mobile payloads and the C-band fixed payload which would provide the central station backhaul for these services were seen as the most likely to be interconnected, if any were. In addition, this choice of payload combination has the advantage of segregating the two payloads having the most distinctive individual characteristics. The low UHF payload is military, and hence it may be desirable to segregate it for operational reasons, and the Ku-band payload is the major power consumer, and removing it allowed us to see the effects of relaxed power requirements on the technical trade-offs. In any final system design, it would be valuable to try other payload combinations in order to perform more detailed technical and cost trades before a final system configuration is defined.

THREE SYSTEMS WERE COMPARED

1) LARGE PLATFORM, CARRYING ALL FIVE PAYLOADS

2) SMALL PLATFORM, CARRYING THREE PAYLOADS:

- O HIGH UHF
- O L-BAND
- O C-BAND

PLUS

TWO SINGLE PAYLOAD SATELLITES:

- O LOW UHF
- O KU-BAND

3) THREE SINGLE-PAYLOAD SATELLITES:

- O HIGH UHF
- O C-BAND
- O KU-BAND

PLUS

ONE DUAL-PAYLOAD SATELLITE:

- O LOW UHF
- O L-BAND

IN ALL CASES ONE SPACECRAFT CARRIES THE FULL PAYLOAD, AND IS BACKED UP BY AN ON-ORBIT SPARE

The platform ROM costs were estimated subsystem-by-subsystem. They are based on published information, engineering judgment, and other estimates for similar systems. The expected accuracy is 20-25%.

Where the individual element costs differ for the two platform versions, the three payload case estimates are indicated in parentheses following the five payload case estimates.

PLATFORM COSTS - 1980 $M U.S.

CATEGORY	NON-RECUR LARGE	NON-RECUR (SMALL)	RECUR LARGE	RECUR (SMALL)	TOTAL (2 S/C) LARGE	TOTAL (2 S/C) SMALL
BUS						
STRUCTURE	25	(20)	7	(5)	39	30
THERMAL	5	(4)	1		7	6
ACS	20	(15)	4	(3.5)	28	22
RCS	3		3		9	9
POWER	15	(10)	10	(5)	35	20
SOL. SAILS	1		1		3	3
TT&C	8	(7)	2	(1.5)	12	10
TOTAL					133	100
$CDN					153	115
PAYLOAD						
ANT. 26M	8	(7)	7	(6.5)	22	20
7M	3.5		2.3		12.7	12.7
3M	1.7		1.15		4	4
2M	1.7		1.15		6.3	4
REP. LOW UHF	5.8		2.3		10.4	0
HIGH UHF	9.2		4.6		18.4	18.4
L-BAND	5.8		2.3		10.4	10.4
C-BAND	4.6		7		18.6	18.6
KU-BAND	4.6		7		18.6	0
TOTAL					121.4	88.1
$CDN					140	101
SYSTEMS						
INT & TEST	3		4		11	10% LESS
GSE	4		2		8	
PROD. ASS.	3		2		7	
PMO/SYST. ENG	6		3		12	
TOTAL					38	35
$CDN					44	40
SPACECRAFT TOTALS; $ CDN					337	256
LAUNCH (CENTAUR)			62		124	124
$CDN					143	143
SPACE SEGMENT TOTALS; $CDN					480	399

The ROM costs of the single-and dual-payload satellites were estimated based on historical information, engineering judgment, and the CAL computer program COMSATMOD.

Three of the five spacecraft are of the SSUS-D class; the other two require IUS. In the case of the Ku-band spacecraft, the large battery mass required to support full eclipse operation is the major driver in the IUS requirement.

The expected accuracy of these estimates is 10-20%.

INDIVIDUAL SATELLITE COSTS - 1980 $M U.S.

SPACECRAFT PAYLOAD(S)	LOW UHF	HIGH UHF	UHF/L	C	KU
- BUS RELATED	45	80	50	45	51
- PAYLOAD REL.	25	35	30	24	25
TOTAL	70	115	80	69	76
LAUNCH VEHICLE					
- SHUTTLE	22	46	22	22	46
- UPPER STAGE	8	26	8	8	26
TOTAL	30	72	30	30	72
TOTAL SPACE SEGMENT	100	187	110	99	148
$CDN	115	215	126	114	170

NOTES:

1) INT/TEST, SYSTEMS ETC. ARE INCLUDED IN SPACECRAFT COSTS

2) TWO SPACECRAFT PER SYSTEM ARE ASSUMED (OPERATIONAL & ON-ORBIT SPARE)

3) LAUNCH COSTS ARE:
   SSUS-D: $11M SHUTTLE + $4M UPPER STAGE
   IUS : $23M SHUTTLE + $13M UPPER STAGE

The total space segment cost estimates for the three systems meeting the requirements of the baseline mission model are shown opposite.

The single large platform appears to be the most cost effective way of meeting the needs; however, the differences are small, and hence strongly dependent on the accuracy of the estimates. The results do appear to support the conclusion of the General-Dynamics/Convair study that it is transportation, not the spacecraft cost itself, which makes the major difference.

The hybrid system, consisting of the smaller platform and two single payload systems is the most expensive. This is not surprising, since the economics of the platform are not fully utilized in this case. The 'bus' is only 21% less expensive than the larger one, and the transportation costs are the same; in addition, two single-payload spacecraft systems must still be launched. Consequently, this case represents a compromise which provides neither the operational flexibility of individual satellites nor the economy of scale of platforms.

COMPARATIVE COSTS - 1980 $M CDN

	SPACECRAFT	TRANSPORTATION	TOTAL
CASE 1 - LARGE PLATFORM	337	143	480
CASE 2 - SMALL PLATFORM	256	143	399
- LOW UHF SAT.	81	34	115
- KU-BAND SAT.	87	83	170
SYSTEM TOTAL	424	260	684
CASE 3 - HIGH UHF SAT.	132	83	215
- LOW UHF/L-BAND	92	34	126
- C-BAND SAT.	80	34	114
- KU-BAND SAT.	87	83	170
SYSTEM TOTAL	391	234	625

- PLATFORM IS 23% CHEAPER THAN THE FOUR SATELLITE CASE
  - SPACECRAFT IS 14% LESS, TRANSPORTATION IS 39% LESS
- HYBRID SYSTEM IS MOST EXPENSIVE
  - 9% MORE THAN FOUR SATELLITES
  - 43% MORE THAN A SINGLE PLATFORM

6.0 INSTITUTIONAL ASPECTS OF MULTIFUNCTION SPACE PLATFORMS

6.1 Introduction

The institutional problems associated with multifunction platforms are well recognized, but little work has apparently been done to attempt to resolve them. This is largely because the MSP concept was developed by technologists, who have natural biases towards technical and, to a lesser degree, cost concerns. It has been generally acknowledged in the literature that implementation of operational MSP systems will not occur until workable institutional arrangements have been made; however, there is disagreement as to whether it is necessary to start tackling institutional problems now instead of waiting until experimental/development platform programs commence.

Two papers (80,81) by the same author have been published which provide some insight into potential institutional arrangements, and other studies (79) have considered institutional concerns in developing their systems architecture; however, even these papers address only one of many problem areas, that of shared ownership and operation of the space segment. Much additional work is required before any real advances are made.

- MAJOR INSTITUTIONAL CONCERNS ARE:
  - ACKNOWLEDGED
  - LACKING PROGRESS TOWARDS RESOLUTION

- THEY RELATE TO:
  - METHOD OF OWNERSHIP SHARING
  - METHOD OF RESOURCE ALLOCATION (COMMON PLATFORM SUBSYSTEMS)
  - METHOD OF OPERATIONAL CONTROL

- OTHER CONCERNS, BOTH GENERIC & CANADIAN-SPECIFIC, HAVE BEEN IDENTIFIED:
  - THEY ARE NOT GENERALLY REFERENCED IN THE LITERATURE

- SOME PARTIES BELIEVE THAT INSTITUTIONAL PROBLEMS MUST BE SOLVED EARLY, BEFORE FLIGHT EXPERIMENTS CAN COMMENCE

- OTHERS FEEL THAT THE INSTITUTIONAL PROBLEMS WILL SORT THEMSELVES OUT, AND CAN BE IGNORED BY TECHNOLOGISTS AT THIS TIME

- THEY <u>MUST</u> BE FULLY SOLVED BEFORE COMMENCEMENT OF ANY OPERATIONAL MSP PROGRAM.
  - THEIR SOLUTION WILL REQUIRE A SERIES OF EVOLUTIONARY STEPS
  - LITTE WORK HAS YET BEEN DONE TO START THIS EVOLUTION
  - INSTITUTIONAL ARRANGEMENTS AND CONCERNS WILL LIKELY BE THE PACING ITEMS IN THE GROWTH OF MSP SYSTEMS, NOT TECHNICAL PROBLEMS.

6.2 Major Institutional Aspects of MSP's

For purposes of the present study, institutional concerns are defined to be all the non-technical and non-economic considerations which impact the development of space systems. They include all political (domestic and international) and managerial/operational factors which can potentially drive platform system architecture in a direction different to that which would occur if only technical and/or financial aspects were involved.

A number of institutional factors which are generic to all (or most) platform systems have been defined during the study; they are listed opposite.

DOMINANT INSTITUTIONAL FACTORS & CONSIDERATIONS

- DEVELOPMENT OF WORKABLE ARRANGEMENTS FOR THE SHARING OF A PLATFORM BY MANY OPERATING ENTITIES, WHO MAY EVEN BE COMPETING WITH EACH OTHER.
  - WHO OWNS THE PLATFORM ITSELF?
  - WHO PAYS THE HIGH DEVELOPMENT COST?
  - WHO MANAGES & CONTROLS PLATFORM OPERATION?
  - WHAT ARE THE USER CHARGING SCHEMES?
  - WHO ALLOCATES LIMITED RESOURCES & ON WHAT BASIS? (E.G. ECLIPSE POWER IF BATTERIES DEGRADE BELOW FULL CAPABILITY)
- REMOVAL OF OPERATIONAL FLEXIBILITY.

  E.G.
  - TIMING OF PAYLOAD LAUNCHING
    - SYSTEM GROWTH
    - CHANGES IN ARCHITECTURE TO MATCH CHANGES IN DEMAND
  - CHOICE OF ORBIT SLOTS
    - COVERAGE
    - SPACING

  NON-TECHNICAL FACTORS WHICH MORE STRONGLY INFLUENCE THESE IN PLATFORM SYSTEMS ARE:
  - WHO DETERMINES PLATFORM LOCATIONS?
    - ON WHAT BASIS?
  - WHO DETERMINES WHEN PAYLOADS ARE TO BE ADDED OR MODIFIED?
    - ON WHAT BASIS?
  - WHAT EFFECT DOES THE DECREASE IN OPERATIONAL FLEXIBILITY HAVE ON CARRIERS' ABILITIES TO RESPOND TO THEIR MARKETS?
- THE IMPACT OF POLITICAL FACTORS ON TECHNOLOGICAL DECISION MAKING.

  E.G.
  - POTENTIAL PLANNING OF THE GLOBAL SATELLITE COMMUNICATIONS SYSTEM AT THE 1984/85 WARC (PRESSURE FROM LDC'S)
  - DECISIONS BY NATIONAL GOVERNMENTS TO DEVELOP AND/OR PROTECT CERTAIN INDUSTRIES

- THE EFFECTS ON THE AEROSPACE INDUSTRY
  - THE CURRENT LARGE INVESTMENT IN BUILDING CONVENTIONAL SATELLITES WILL CREATE INERTIA ON THE PART OF CONTRACTORS
  - ALTHOUGH PLATFORMS MAY PROVIDE THE END USER WITH LESS EXPENSIVE SERVICE, THE FACT THAT FEWER, LARGER SPACECRAFT ARE BUILT COULD FORCE A MAJOR RESTRUCTURING OF THE SPACECRAFT INDUSTRY
- THE LACK OF ONGOING WORK TO SOLVE THE INSTITUTIONAL PROBLEMS.
  - THIS IN ITSELF IS AN INSTITUTIONAL PROBLEM, SINCE THE LACK OF SOLUTIONS COULD DELAY THE DEPLOYMENT OF OPERATIONAL SYSTEMS.
  - A PROBABLE EVOLUTIONARY STEP WHICH CIRCUMVENTS THIS PROBLEM IS THE DEPLOYMENT OF PLATFORMS BY LARGE CARRIERS WHO COULD UTILIZE THE FULL CAPABILITY, SUCH AS INTELSAT OR AT & T.

Some of the 'generic' institutional factors have different effects in the Canadian context than in the U. S. context in which they were originally studied. In addition, there are some Canadian-specific institutional concerns.

INSTITUTIONAL FACTORS IN THE CANADIAN CONTEXT

- O GENERAL ASSUMPTIONS
  - O GENERAL: A STRONG, INDEPENDENT CANADIAN IDENTITY IS TO EXIST
  - O SPECIFIC
    - O TELESAT WILL CONTINUE AS THE PROVIDER OF OPERATIONAL DOMESTIC SATELLITE COMMUNICATIONS SERVICES
    - O SPAR WILL CONTINUE TO GROW AS A PRIME CONTRACTOR, & WILL BUILD ALL DOMESTIC SPACECRAFT
    - O CANADIAN INDUSTRY WILL BE INVOLVED EARLY & AS A MAJOR PARTICIPANT IN BUILDING ALL SHARED PLATFORMS
    - O TELESAT WILL RETAIN FULL OPERATIONAL CONTROL OF ALL PAYLOADS PROVIDING CANADIAN DOMESTIC SERVICE

- O 'GENERIC' CONCERNS AS THEY APPLY TO CANADA
  - O SHARING
    - O SINCE TELESAT IS THE SOLE OWNER & OPERATOR OF OPERATIONAL SATELLITE COMMUNICATIONS SERVICES, AND THUS WOULD OWN, OPERATE AND SELL CAPACITY ON ALL CANADIAN MSP'S,

      THIS PARTICULAR CONCERN IS NON-EXISTENT FOR A DOMESTIC SYSTEM.
  - O FLEXIBILITY
    - O AS DISCUSSED IN SECTION 4.3, THIS IS THE MAJOR CANADIAN CONCERN WRT MEETING DOMESTIC REQUIREMENTS ON AN MSP

      UNLESS DRIVEN TO A COMPROMISE POSITION BY EXTERNAL POLITICAL FORCES (SUCH AS RESTRICTED ORBIT ALLOCATION AFTER 1985), IT IS UNLIKELY THAT, AN MSP WOULD BE CHOSEN FOR AN OPERATIONAL CANADIAN SYSTEM.

- O POLITICAL FACTORS

  - O THE EXTERNAL POLITICAL FACTORS ARE ESSENTIALLY ADDRESSED IN THE PREVIOUS TOPIC. CANADA HAS CHOSEN TO DEVELOP & PROTECT A DOMESTIC AEROSPACE INDUSTRY; THIS IS REFLECTED IN THE 'GENERAL ASSUMPTIONS'.

- O INDUSTRY EFFECTS

  - O THE CANADIAN AEROSPACE INDUSTRY IS MUCH SMALLER THAN THAT IN THE U.S., AND BOTH TELESAT & SPAR PERSONNEL EXPRESSED STRONG CONCERN THAT MASSIVE SWINGS IN BUSINESS & MANPOWER NEEDS WOULD RESULT IF A DECISION WERE MADE TO PUT ALL PAYLOADS ON AN MSP, INSTEAD OF ON TIME-PHASED SINGLE SATELLITES. THIS WAS SEEN AS POTENTIALLY DISASTROUS TO THE INDUSTRY.

    <u>BUT</u>

    - O THE TELESAT PROCUREMENT SCHEDULE WOULD NOT CHANGE GREATLY IF MSP'S WERE INTRODUCED, SINCE BOTH C & KU-BAND SATELLITE PROGRAMS ARE CONCURRENT AT PRESENT.

      ∴ THE INCREASE IN AMPLITUDE OF MANPOWER REQUIREMENT FLUCTUATIONS MAY BE SMALL.

    - O <u>IF</u> TRUE COST SAVINGS WERE TO BE MADE BY PUTTING ALL THE COMMUNICATIONS PAYLOADS ON MSP'S, THERE WOULD BE ROOM FOR ADDITIONAL SATELLITE PROGRAMS WITHIN THE EXISTING BUDGET. THIS WOULD HAVE TWO EFFECTS.

      (I) ADDITIONAL USER DESIRES FOR SATELLITE SERVICES COULD BE SATISFIED.

      (II) THE NEW PROGRAMS WOULD COMPLEMENT THE SMOOTHING EFFECT THAT EXISTING REMOTE SENSING, SCIENTIFIC ETC PROGRAMS WERE ALREADY HAVING ON SPAR'S LOADING (ASSUMING ALL PROGRAMS ARE PROPERLY PHASED).

CONCLUSION

- O THE TELESAT & SPAR CONCERNS ARE VALID
- O THE EFFECTS OF MSP'S MAY NOT BE AS SEVERE AS FEARED
- O MORE DETAILED STUDY IS REQUIRED, ESPECIALLY INTO COST TRADES & POTENTIAL FOR ADDITIONAL SPACE PROGRAMS

O LACK OF INSTITUTIONAL PLANNING

- O THIS IS LESS CRITICAL IN CANADA, BECAUSE OF THE TELESAT MANDATE

O THE MAJOR ADDITIONAL (CANADIAN SPECIFIC) INSTITUTIONAL CONCERN IS THE BASIC INCOMPATIBILITY BETWEEN THE CANADIAN & PUBLISHED U.S. PERSPECTIVES OF INTERNATIONAL MSP'S SERVING CANADIAN DOMESTIC NEEDS.

- O U.S. STUDIES
  - O ASSUME WESTERN HEMISPHERE COVERAGE TO MAXIMIZE ECONOMY OF SCALE
  - O INCLUDE (& RECOMMEND) COVERAGE OF CANADA ON A PLATFORM DEVELOPED IN U.S.
  - O EXPLICITLY STATE THAT U.S. OWNERSHIP & CONTROL OF PLATFORM IS DESIRABLE (OR MANDATORY)
  - O HYPOTHESIZE THAT TELESAT WOULD EITHER PLACE ITS OWN PAYLOAD ON RENTED PLATFORM REAL ESTATE OR PURELY RENT CAPACITY.
- O CANADIAN VIEW
  - O SIGNIFICANT CANADIAN PARTICIPATION IN
    - O PLANNING
    - O CONSTRUCTING
    - O OPERATING

    OF ALL SHARED PLATFORM MISSIONS
  - O FULL OPERATIONAL MANAGEMENT & CONTROL OF OUR OWN PAYLOADS.

CONCLUSION

- O NO MATTER WHAT ECONOMIES (FOR THE USER) MIGHT RESULT FROM PARTICIPATION IN AN INTERNATIONAL MSP PROGRAM, NONE WILL DEVELOP WITHOUT SATISFACTORY RESOLUTION OF SOVEREIGNTY CONCERNS.

O AN ADDITIONAL CANADIAN CONCERN IS APPLICABLE TO THE 'COMMON BUS' MSP CONCEPT; THE USE OF A CLUSTER WOULD CIRCUMVENT IT.

- O MAXIMUM ECONOMY OF SCALE CAN ONLY BE ACHIEVED IN CANADA IF MILITARY COMMUNICATIONS PAYLOADS ARE INCLUDED. AN EQUITABLE COST SHARING ARRANGEMENT (INCLUDING LAUNCH COSTS) MUST BE DEVELOPED, TAKING INTO ACCOUNT THE HIGHER COST OF MILITARY REQUIREMENTS (E.G. HARDENING).

O THE DIFFERENCE BETWEEN THE CANADIAN & U.S. REGULATORY CLIMATES WILL CAUSE THE TWO SYSTEMS TO DEVELOP DIFFERENTLY.

- O U.S.: 'OPEN SKIES'
  - O COMPETITIVE SYSTEMS ALLOWED
  - O USER-OWNED EARTH STATIONS ALLOWED
- O CANADA: MORE REGULATED
  - O TELESAT MANDATE
  - O RESTRICTED EARTH STATION OWNERSHIP
    - O TVRO: BROADCAST UNDERTAKING
    - O 14/12: TELESAT OR COMMON CARRIER
    - O 6/4 : TELESAT ONLY

O UNDER CURRENT REGULATORY CONSTRAINTS, USER-OWNED ON PREMISES EARTH STATIONS COULD NOT PROLIFERATE IN CANADA, THUS REMOVING ONE OF THE MAJOR DRIVERS OF MSP DEVELOPMENT FROM THE CANADIAN CONTEXT.

7.0 CONCLUSIONS

7.1 Introduction

An extensive literature survey has been made to determine the state of the art of multifunction space platform technology and other relevant concerns, such as economic and institutional factors. This has been supplemented by discussions with workers in the field, and potential Canadian builders, operators and users of MSP-based services in order to determine what the major concerns and drivers are likely to be as the technology matures, and to estimate how platform systems will evolve.

The original platform concepts were grandiose, and required a great deal of technology development before they could be realized. Despite this, it was hypothesized that they could be available by the early 1990's. More recent studies have recognized the need for gradual evolution, with the first relatively small platforms planned to be launched near the end of the 1980's, and a gradual growth in the number of platform systems, and scale of platforms within systems, occurring into the next century. This slowdown in implementation is a result of the major technical advances required, which will take significant time, the economics of funding the advances, and a need to resolve significant institutional difficulties.

In parallel with the more general acceptance of the evolutionary nature of the MSP concept, there has been a broadening of the definition of what constitutes a multi-function platform. It is now defined more in terms of its three basic attributes: multiple payloads, connectivity and central subsystem support. Size is not an essential characteristic, nor is the sharing of a single platform structure by all payloads in the system. In fact, for certain requirements, clusters of smaller platforms may be preferable to a single platform from both cost and operational points of view.

Platform systems will develop where they are needed most and workable institutional arrangements can be made. This makes it unlikely that an 'OAF Americas' type of platform will exist in even the mid-term (early 2000's). Not only is there no <u>need</u> outside the U.S. for the high capacity provided, but the development of institutional arrangements allowing the sovereignty concerns of all the countries sharing the platform services to be met would be very slow and arduous. The most likely early users of platforms are single entities such as Intelsat, and possibly AT&T or a consortium of specialized common carriers in the U.S.

A DETAILED UNDERSTANDING OF CURRENT MSP PLANNING WAS OBTAINED:

- O LITERATURE SURVEY
  - O STATE-OF-ART OF PLATFORM TECHNOLOGY
  - O STATE-OF-ART OF SUPPORT SYSTEM TECHNOLOGY
  - O COST TRADE STUDIES
  - O TRAFFIC REQUIREMENT STUDIES
  - O INSTITUTIONAL ARRANGEMENTS
- O DISCUSSIONS
  - O WITH WORKERS IN FIELD
    - O UPDATE UNDERSTANDING OF STATE-OF-ART
    - O INSIGHT INTO PLANS, PERCEIVED CONCERNS
  - O WITH CANADIAN PLANNERS/USERS
    - O DEVELOP MISSION MODEL
    - O UNDERSTAND MAJOR CONCERNS

BASIC CONCLUSIONS ARE

- O PLATFORM TECHNOLOGY WILL EVOLVE MORE SLOWLY THAN ORIGINALLY PREDICTED
- O PLATFORMS MAY BE SIGNIFICANTLY DIFFERENT IN CONCEPT THAN ORIGINALLY HYPOTHESIZED
- O ECONOMICS OF PLATFORMS VS 'CONVENTIONAL' SATELLITES NOT YET WELL UNDERSTOOD
- O INSTITUTIONAL ASPECTS MAY DRIVE THE TECHNOLOGY IN DIRECTIONS OTHER THAN THOSE BASED PURELY ON TECHNICAL CONCERNS
- O DEVELOPMENT OF INSTITUTIONAL ARRANGEMENTS MAY BE THE CRITICAL PATH IN PLATFORM DEVELOPMENT

Currently defined Canadian geostationary satellite service requirements of the late 1980's to mid 1990's could feasibly be met by means of an early generation MSP. However, those interviewed during the course of the study expressed a number of technical and institutional concerns about doing so. Some of the concerns could be resolved if a cluster form of platform were used instead of a common-bus; others are generic to all forms of platform. It is most likely that the latter set would only be over-ridden, and platforms used for domestic satellite communications, if external institutional and/or political factors created a need to do so. Canadian planners and operators must be aware of the potential external drivers, and prepared to counteract them if the need arises.

The institutional arrangements for a domestic multi-function platform based system can be set up much more readily in Canada than the U.S., or for international programs. However, there are additional institutional concerns which are either specific to the Canadian context, or of greater significance to Canada.

MAJOR 'CANADIAN' CONCLUSIONS

- O APPLICABILITY
  - O MISSION MODEL SHOWS MODEST REQUIREMENTS TO MID 1990'S
    - O NO DATA BEYOND THEN
  - O REQUIREMENT DATES FOR VARIOUS SERVICES ARE SIMILAR

    EARLY GENERATION MSP COULD SERVE CANADIAN NEEDS BY NEXT GENERATION
- O TECHNICAL
  - O NO MAJOR BREAKTHROUGHS REQUIRED TO MEET CANADIAN REQUIREMENTS
  - O OPERATIONAL FLEXIBILITY FAVOURS INDIVIDUAL SATELLITES
  - O TWO MOBILE SERVICES REQUIRE LARGE ANTENNAS, & BACKHAUL TO A CENTRAL SWITCHING STATION
    - O THIS COULD PROVIDE A BASIC LARGE BUS TO WHICH OTHER PAYLOADS CAN BE ADDED
- O COST
  - O VERY POORLY DEFINED
- O INSTITUTIONAL
  - O SHARED OWNERSHIP/OPERATION IS NOT A PROBLEM
  - O SOVEREIGNTY/INDEPENDENCE OF OPERATION IS

7.2 Technical Conclusions

The major conclusion that can be drawn about the technology of platforms is that it will evolve gradually, and most of the major technical problems will be solved in due course. The concept of the platform is now much more general than five years ago, and this too is expected to continue evolving as technology improves.

There is great uncertainty as to what the evolutionary path will be, since it will be dictated by specific program needs and financial priorities. However, reasonable estimates can be, and have been, made of the 'earliest available' dates for many of the critical items. These can be used to define the most advanced technology which could be used at any particular time.

An estimate was made of the technology level predicted for the late 1980's, and this was matched to the requirements of a platform designed to meet the identified Canadian needs of 1995. It was found that it will likely be technically feasible to provide all of the next generation domestic services on a single spacecraft.

A number of the technical areas requiring further work are ones in which Canadian expertise exists. They have been identified as potential follow-on study areas.

- O TECHNICAL CONCLUSIONS
  - O PLATFORMS WILL DEVELOP AS THE CAPABILITY DEVELOPS
  - O THE INDIVIDUAL TECHNICAL PROBLEMS WILL BE SOLVED AS THE NEED ARISES

    ∴ THERE WILL BE A GRADUAL EVOLUTIONARY GROWTH IN
    - O SIZE
    - O PERFORMANCE (CAPACITY, RELIABILITY, POINTING, ETC)
- O BECAUSE OF TECHNICAL, ECONOMIC & INSTITUTIONAL CONCERNS, THE EVOLUTIONARY PATH WILL BE DETERMINED MORE BY 'DEMAND PULL' THAN 'TECHNOLOGY PUSH'.
- O THE 'OAF' TYPE OF PLATFORM IS A LONG TERM FINAL STAGE IN THIS EVOLUTION
- O 'SMALL' (~5000 KG) FIRST GENERATION PLATFORMS COULD BE LAUNCHED BY THE LATE 1980'S
- O MOST OF THE MAJOR CANADIAN TECHNICAL CONCERNS ARE APPLICABLE TO THE SINGLE-BUS PLATFORM, BUT OF LESSER IMPORTANCE IF A CLUSTER IS USED
- O TWO TECHNICAL FACTORS WHICH WILL STRONGLY INFLUENCE THE TRAFFIC MODEL, & HENCE NEED FOR PLATFORMS, ARE
  - O ADVANCED MODULATION TECHNIQUES
  - O COMPETING TECHNOLOGIES (E.G. OPTICAL FIBRES)

  THEY BOTH REQUIRE MORE STUDY THAN IS CURRENTLY BEING PERFORMED
- O THE TOTAL COMMUNICATIONS SYSTEM ARCHITECTURE IS NOT UNIQUE TO MSP'S, BUT IS THE DRIVER IN ANY MSP PROGRAM
  - O THE REQUIREMENTS ARE NOT YET WELL DEFINED
- O AREAS IN WHICH SIGNIFICANT CANADIAN CONTRIBUTIONS CAN BE MADE ARE:
  - O LARGE STRUCTURE/ACS INTERACTIONS
  - O POWER SYSTEM TRENDS
    - O PRIMARY POWER SYSTEMS
    - O BATTERY MANAGEMENT SYSTEMS
    - O POWER SYSTEM ARCHITECTURE
  - O LARGE STRUCTURE THERMAL CONTROL
  - O DATA HANDLING & PROCESSING SYSTEM ARCHITECTURE

7.3 Economic Conclusions

Economic trade-offs have been a pivotal element in considerations of whether to develop operational multi-function space platform systems.

A number of studies have been undertaken to compare the cost of meeting a set of requirements with either a multifunction platform or individual satellites. All of the studies confirmed that platforms were more cost effective than individual satellites for the specific situation studied and set of assumptions made. However, the reasons for the cost savings not only differed among the studies, but were somewhat inconsistent. Two of the studies considered only the space segment, and both predicted significant cost savings for platforms; the third study considered both space and ground segments, and looked at revenue requirements, not cost. It concluded that the space segment revenue requirements were very similar, and it was the proliferation of small inexpensive ground terminals which made platforms so cost effective.

Cost was identified as a major concern of all Canadian users and system operators/planners interviewed during the study. The "bottom line" was universally defined as the dominant driver in a decision to place or not place payloads on an MSP.

There is at present inadequate information applicable to the Canadian context to allow these concerns to be answered. Not only is the scale of our requirement much less than that used in the cost trade studies, but many of the ground rules and assumptions used are not applicable, due to our different regulatory climate. In addition, very little useful cost information was received during the survey.

A rough order of magnitude cost comparison was made between the strawman configuration and the individual satellites meeting Canadian needs as defined in the baseline mission model. The platform system appears to be less expensive than the multi-satellite system; however, the differences are small, and strongly dependent on the assumptions and estimates used. Consequently, more detailed analysis, addressing also some of the identified outstanding questions is required.

- O COST STUDY CONCLUSIONS
  - O COST ESTIMATING IS STILL VERY INEXACT & STRONGLY DEPENDENT ON THE PARTICULAR ASSUMPTIONS
  - O FOR A GIVEN SET OF ASSUMPTIONS, THE BASIC TRADE RESULTS ARE INDEPENDENT OF MISSION MODEL
  - O TRANSPORTATION COST TRADES ARE STRONGLY DEPENDENT ON THE DEVELOPMENT COST RECOVERY SCHEME TO BE EMPLOYED IN PRICING NEW OTV'S
  - O OVERALL SYSTEM COST TRADES ARE STRONGLY DEPENDENT ON WHETHER LOW-COST USER PREMISES EARTH STATIONS DO PROLIFERATE
  - O MEDIUM SIZED (SINGLE SHUTTLE BAY) PLATFORMS APPEAR PREFERABLE TO VERY LARGE ONES
  - O DOCKED, DEPENDENT MODULES APPEAR PREFERABLE TO DOCKED INDEPENDENT OR CLUSTERED MODULES, BUT NOT GREATLY SO
  - O SERVICING, BUT AT INFREQUENT (E.G. 8-YR) INTERVALS APPEARS PREFERABLE

- O A NUMBER OF OUTSTANDING QUESTIONS NEED ADDRESSING
  - O HOW DOES THE SMALLER SCALE OF CANADIAN NEEDS AFFECT THE COST TRADES?
  - O WHAT (IF ANY) POTENTIALLY SIGNIFICANT HIDDEN COSTS HAVE BEEN LEFT OUT OF THE TRADE STUDIES?
  - O WHAT ARE THE COST TRADES FOR 'HYBRIDIZING' AN ALREADY LARGE SPACECRAFT?
  - O WHAT ARE THE COST TRADES FOR JOINING INTERNATIONAL PROGRAMS?
  - O WHAT FORM(S) OF MSP WOULD BEST SERVE CANADIAN NEEDS?
  - O WHAT ARE THE COST TRADES FOR RELAXATION OF THE PRESENT EARTH STATION OWNERSHIP RESTRICTIONS?

7.4 Institutional Conclusions

The institutional problems associated with multi-function platforms are well recognized, but little work has apprently been done to attempt to resolve them. It has been generally acknowledged that implementation of operational MSP systems will not occur until workable institutional arrangements have been made; however, there is disagreement as to whether it is necessary to start tackling institutional problems now instead of waiting until experimental/development platform programs commence.

The major institutional problems associated with Canadian systems are different from those for U.S. or 'Western Hemisphere' systems. Because of the strong communications bias which was evidenced by the users, the basic shared ownership concern does not exist in Canada; however, the other 'generic' institutional factors are of significance. In addition, there are concerns which are of relevance to Canadian systems, but not discussed in the literature.

There is a strong tie between the technical and institutional aspects of MSP's. It is probable that the long term operational systems will develop along lines defined by the political/regulatory agencies, and hence will be different from the preferred technical approaches. Technologists must recognize this, and factor it into their planning of future system alternatives.

- INSTITUTIONAL STUDY CONCLUSIONS
  - INSTITUTIONAL FACTORS WILL BE MAJOR DRIVERS OF LONG TERM GLOBAL SATELLITE COMMUNICATIONS SYSTEM ARCHITECTURE
  - THEY ARE AT PRESENT BEING INADEQUATELY ADDRESSED
  - THEY WILL BE THE PACING ITEM FOR MSP SYSTEM EVOLUTION
  - THE MAJOR 'GENERIC' PROBLEM IS THE DEVELOPMENT OF WORKABLE SHARED OWNERSHIP/OPERATION ARRANGEMENTS
  - THIS PARTICULAR CONCERN DOES NOT APPLY TO CANADIAN DOMESTIC SYSTEMS TO AS GREAT AN EXTENT AS ELSEWHERE
  - MAJOR CANADIAN CONCERNS ARE:
    - REMOVAL OF OPERATIONAL FLEXIBILITY
    - THE EFFECTS ON THE HEALTH OF THE AEROSPACE INDUSTRY IF MSP'S WERE TO BE DEVELOPED
    - SOVEREIGNTY & CONTROL OF OUR OWN SYSTEMS (RELEVANT FOR INTERNATIONAL PROGRAMS)
    - MILITARY/CIVILIAN COST SHARING & OPERATIONAL CONTROL
  - MAJOR DIFFERENCE BETWEEN CANADIAN & U.S. SYSTEMS
    - REGULATORY CONSTRAINTS ON PROLIFERATION OF SMALL EARTH TERMINALS

8.0 RECOMMENDATIONS

8.1 Introduction

The basic technical feasibility of meeting future Canadian satellite communications needs with multifunction space platforms has been demonstrated, with two sets of payload combinations suggested. Whether Canadian systems develop along these lines will depend as much on institutional and cost factors as technical ones, and further work is required in all three areas to lay a firmer foundation for any long range decision making.

Three activities which cross the technical/cost/institutional boundaries should be commenced immediately.

The first is a continuation of the monitoring of international trends in MSP system development, in parallel with, and as part of, the preparations for the 1983 RARC and 1984/85 WARC. There are currently technical advantages to providing Canadian communications services on a distributed payload basis; these advantages will likely remain throughout the next two generations, but the flexibility to utilize them may be removed as a result of orbital planning. Consequently, potential system alternatives must be developed.

The second is a continuation of work started during the present study, and other planning activities ongoing within the Government. A better mission model can and should be developed. It would contain not only the geosynchronous orbit missions covered in the present study, but all other low orbit candidate missions. The results would not only provide a better planning base, but would provide information required to answer the industry concerns about program phasing and load levelling.

The third is a more detailed study of potential Canadian MSP configurations. The strawman configurations in this report were both single-bus platforms. The cluster concept should be studied in depth, to determine whether it is more cost effective than individual satellites, and whether it could be used to provide some of the MSP advantages and still satisfy the major industrial concerns.

- O RECOMMENDED 'GENERAL' FOLLOW-ON WORK
  - O COMMENCE IMMEDIATELY

1)
- O CONTINUE TO MONITOR INTERNATIONAL MSP WORK CLOSELY
  - O APPLY TO (UPDATED) CANADIAN REQUIREMENTS
- O MONITOR, IN PARALLEL, OTHER COUNTRIES' WARC POSITIONS
  - O DETERMINE POTENTIAL EFFECTS, CONSTRAINTS ON CANADIAN SYSTEM IMPLEMENTATION PLANS, IF ANY
  - O ESTIMATE LIKELIHOOD OF THESE CONSTRAINTS BEING IMPOSED
- O INVESTIGATE POTENTIAL USE OF MSP'S TO MEET CANADIAN NEEDS BASED ON RESULTS OF ABOVE MONITORING

2)
- O DETERMINE FULL RANGE OF POTENTIAL CANADIAN SATELLITE MISSIONS
- O ESTABLISH BASELINE (FIRM) REQUIREMENTS - E.G. TELESAT FOLLOW-ON
- O ESTIMATE COST TRADES FOR MEETING THESE REQUIREMENTS ON MSP'S VS INDIVIDUAL SATELLITES
- O ESTIMATE MANPOWER LOADING TRADES FOR SAME
- O DETERMINE WHETHER COST SAVINGS CAN BE USED TO IMPLEMENT ADDITIONAL PROGRAMS

3)
- O DEVELOP BOTH SINGLE-BUS & CLUSTER SCENARIOS IN DETAIL (DUAL CONCEPT DEFINITION STUDY)
  - O TOTAL PAYLOAD
  - O PAYLOADS PER BUS COMBINATIONS (LEVELS OF HYBRIDIZATION)
- O INVESTIGATE (TRADE STUDIES)
  - O RELATIVE COST (INCLUDING EFFECTS OF ISL'S)
  - O POTENTIAL ADVANTAGES ARISING FROM INHERENT MODULARITY OF CLUSTERS

    E.G.
    - O REPLENISHMENT
    - O REPLACEMENT OF FAILED 'MODULES'
    - O EASE OF ADAPTATION TO CHANGING NEEDS
    - O SMOOTHING OF LOADING PEAKS

8.2 Technical Recommendations

A series of technical studies should be conducted in areas in which Canadian expertise now exists. They are in areas which are not necessarily restricted to MSP's, but tie in to the "next generation" of satellites in general, such as advanced mobile communications satellites.

They are all short-to-mid-term needs. They should start within the next one-to-two years to develop or retain a Canadian lead. No priorities are implied by the order in which they are listed.

RECOMMENDED TECHNICAL STUDIES

1) LARGE STRUCTURE/ACS INTERACTIONS

   - O DIRECT CONTROL OF FLEXIBLE MODES
   - O ON-BOARD STATE ESTIMATION
   - O NON-STANDARD METHODS OF BORESIGHT SENSING AND CONTROL

2) POWER SYSTEM ARCHITECTURE

   - O TRADE STUDY INITIALLY

3) ADVANCED PRIMARY POWER SYSTEMS

   - O SPECIFICALLY RELATED TO MSP NEEDS
   - O MATCHED TO RESULTS OF 2)

4) ADVANCED BATTERY MANAGEMENT SYSTEMS

   - O SPECIFICALLY RELATED TO MSP NEEDS
   - O MATCHED TO RESULTS OF 2)

5) LARGE STRUCTURE THERMAL CONTROL

   - O DEVELOPMENT TRENDS IN LOW CTE MATERIALS
   - O ACTIVE CONTROL TECHNIQUES - ESPECIALLY FOR LARGE ANTENNAS & BOOMS

6) ADVANCED DATA HANDLING & PROCESSING SYSTEMS

   - O ARCHITECTURE TRADE-OFFS
     - O DISTRIBUTED VS CENTRAL PROCESSING
   - O ASSESSMENT OF FUNCTIONS TO BE INCLUDED
   - O FLEXIBILITY/ADAPTABILITY
   - O ENTIRE CONCEPT OF 'HOW TO USE ON BOARD COMPUTERS'

7) DEPLOYMENT OF LARGE STRUCTURES

8.3 Cost Study Recommendations

The Canadian mission model requires technology which is near term and well characterized. A detailed cost study can and should be made before any overall satellite program plan is developed. The parametric cost data derived would be used as background material for the second and third studies identified in section 8.1, and hence this study should be commenced immediately.

- O RECOMMENDED COST STUDY
    - O DEVELOP A COST MODEL FOR THE SYSTEM ELEMENTS OF THE TWO 'GENERIC' STUDIES
        - O GEOSYNCHRONOUS SATELLITES
        - O MSP'S CARRYING SAME PAYLOADS AND/OR COMBINATIONS THEREOF
        - O LOW ORBIT SATELLITES
        - O GROUND SEGMENT
            - O CONSIDER EFFECTS OF POTENTIAL RELAXATION OF EARTH TERMINAL OWNERSHIP REGULATIONS
    - O INCLUDE ESTIMATES OF FUTURE/ADVANCED TECHNOLOGY ASPECTS

8.4 Institutional Recommendations

Since the only user requirements identified are communications oriented, the mandate of Telesat greatly simplifies Canadian institutional arrangements, and no specific studies are recommended. Some of the already recommended activities have institutional components, and these must be considered as seriously as the technical and cost elements.

INSTITUTIONAL CONCERNS APPEAR IN THE FOLLOWING STUDIES

- O WARC PLANNING/MSP MONITORING
- O REVISED MISSION MODEL TRADE-OFF
- O CLUSTER/SINGLE-BUS TRADE-OFF
- O COST MODEL

APPENDIX A

DSS STATEMENT OF WORK

DSS STATEMENT OF WORK

Tasks

i) To carry out a technology forecast regarding large, multifunction space platforms, including time-frame, necessary supporting technologies, costs, and other factors leading to the development of this technology.

ii) To define Canadian satellite mission models for the most likely time-frame of the large space platform, including fixed and mobile communications, direct broadcasting, data collection, search and rescue, meterological and other satellite systems.

iii) To study the application of the large space platform to meet aggregated Canadian satellite needs defined in the mission models.

iv) In broad terms, to consider technical aspects of meeting Canadian needs with a large space platform, including concepts and general parameters, spectrum and EMI considerations impact on communications systems, and other factors important in initial considerations of using this technology.

v) To study the economics of the use of a large platform to meet Canadian needs, including factors such as long-life capabilities and consideration of dedicated platforms shared with other nations.

vi) To provide a technology assessment of using large space platforms by discussing the advantages and disadvantages of this approach, including identification of technical, political, economic and regulatory problem areas.

APPENDIX B

MISSION MODEL SURVEY QUESTIONNAIRE

LARGE MULTIFUNCTION SPACE PLATFORM STUDY
CANADIAN SATELLITE MISSION MODEL SURVEY

March 1980.

CANADIAN ASTRONAUTICS LIMITED

SURVEY INTRODUCTION

Canadian Astronautics Limited is presently performing a study for the Federal Department of Communications, to assess the potential impact of large multifunction space platforms on Canadian satellite systems. In recent years, there has been a growing international interest in the possibility of using such large, hybrid spacecraft to carry large and/or multiple payloads. The purpose of the present study is to carry out a technology forecast regarding the availability and characteristics of large multifunction space platforms, to define likely Canadian satellite mission models for the relevant time frame (next 20 years), and then to study the potential application of the large space platform to meet the aggregated Canadian satellite needs. This is a long range planning study, designed to assess this technology which is presently being developed and evaluated in many countries that make extensive use of space techniques.

In order to determine the potential Canadian missions for inclusion on a multifunction space platform, a survey of operators and possible users of satellite services is being conducted. This survey consists of two questionnaires, one for each of two groups of respondents. The first (Attachment 1) is for common carriers, satellite system operators, and satellite system planners. Its aim is to determine the views of those most directly involved in the provision of satellite services with respect to the envisaged nature and size of future requirements, as well as their specific feelings and concerns about meeting these requirements with multifunction space platforms. The second questionnaire (Attachment 2) is for potential users of geosynchronous satellite services. It is aimed primarily at determining the nature and level of the services which must be provided to the users, and hence is most concerned with the performance and institutional aspects of satellite service provision, and less concerned with the technical means of providing the service.

It is intended that the questionnaires be answered in the presence of the CAL Study Manager and DOC Project Manager, with two relatively short (approximately 1 hour) sessions most likely being required. The first session will provide an opportunity for the respondent to understand the goals and nature of the questionnaire, express some preliminary views, and possibly provide many of the answers.

The second session has been planned for approximately one week later, to allow the respondents time to consolidate their views, obtain any additional information required, and possibly sound out others within their organization. It is hoped that this method will maximize the efficiency of the meetings, and minimize the time involvement of the respondents.

The purpose of the study is to provide a basis for long range planning, and to indicate general directions. It is recognized that the replies are meant to represent only a best estimate of a number of experts in the field, and are not firm commitments. It is also recognized that some respondents may wish to not answer all questions. It is, however, hoped that the questionnaire will serve as a catalyst in getting potential users and suppliers of satellite service to freely express their views.

ATTACHMENT 1

QUESTIONNAIRE FOR

- COMMON CARRIERS
- SATELLITE SYSTEM OPERATORS
- SATELLITE SYSTEM PLANNERS

(1) This question is designed to derive the scope and characteristics of the major services which will be provided by geostationary satellites in the next twenty years. It has been broken down into four categories:

- Fixed Communications
- Mobile Communications
- Broadcasting
- Specialized Services,

and suggested subgroups within each category. Please feel free to modify the groupings, add additional ones, or elaborate on the answers.

A separate set of forms is attached for each category.

Question (1) - FIXED COMMUNICATIONS SERVICE

(a) When do you see these services being introduced operationally by satellite?

SERVICE SUBGROUP	Now	1985	1990	1995
Voice - via common carrier (c.c.)				
- user direct to satellite (u.d.)				
Data - low speed (eg. Telex, Fax) - c.c.				
- u.d.				
- high speed ≥9600 bps - c.c.				
- u.d.				
- specialized (eg. weather) - c.c.				
- u.d.				

(b) What carrier frequency(ies) will be used for this service?

SERVICE SUBGROUP	FREQUENCY(IES)
Voice	
Data - low speed	
- high speed	
- specialized	

Question (1) - FIXED COMMUNICATIONS SERVICE, Continued

(c) What total satellite capacity (Bandwidth) do you see being required for this service in Canada in each of the listed years? What percentage of the total Canadian traffic in each subgroup will be carried by satellite?

SERVICE SUBGROUP	1985 BW	1985 %	1990 BW	1990 %	1995 BW	1995 %
Voice						
Data - low speed						
- high speed						
- specialized						

(d) What will be the most desirable downlink antenna coverage pattern for each service subgroup (Global, hemisphere, all-Canada, time zones, regional, local spot beams)?

SERVICE SUBGROUP	COVERAGE
Voice	
Data - low speed	
- high speed	
- specialized	

What will be the most desirable uplink antenna coverage pattern for each service subgroup (Global, hemisphere, all-Canada, Canada & coastal zone, time zones, regional, local spot beams)?

Voice

Data - low speed
- high speed
- specialized

Question (1) - FIXED COMMUNICATIONS SERVICE, Continued

(e) What are the anticipated major performance characteristics of the downlink earth stations? (eg. dish size, G/T)

SERVICE SUBGROUP	PERFORMANCE CHARACTERISTIC
Voice - common carrier	
- user direct to satellite	
Data - low speed	
- common carrier	
- user direct	
- high speed	
- common carrier	
- user direct	
- specialized	
- common carrier	
- user direct	

(f) Who are the most likely owner/operators of the earth stations? (eg. Telesat, common carriers, users, mixture of preceding).

SERVICE SUBGROUP	OWNER
Voice	
Data - low speed	
- high speed	
- specialized	

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Question (1) - FIXED COMMUNICATIONS SERVICE, Continued

(g) For each of the service segments which interconnect with other services or segments, indicate whether this interconnection could be provided by means of (i) sharing a common Canadian domestic Multifunction Space Platform between the two services ('Dom. MSP'), (ii) placing the payload on a multi-national shared platform containing more than one service ('Int. MSP') or (iii) joining the two services on separate satellites by means of an inter-satellite link ('ISL')

SERVICE SUBGROUP	Dom. MSP	Int. MSP	ISL

(h) What do you estimate the cost of providing this service by satellite to be, if it uses its own dedicated space-craft, and how much of this cost is for the payload only?

SERVICE SUBGROUP	COST (1980 $)	PAYLOAD %

Question (1) - MOBILE COMMUNICATIONS SERVICE

(a) When do you see these services being introduced operationally by satellite?

SERVICE SUBGROUPS	Now	1985	1990	1995
Voice - Land				
- Personal Communications Terminals				
- Emergency Services				
- Sea				
- Air				
Low Speed Data - Land				
- Sea				
- Air				
High Speed Data				

(b) What carrier frequency(ies) will be used by this service?

SERVICE SUBGROUP	FREQUENCY(IES)
Voice/Low Speed Data	
Land	
Sea	
Air	
High Speed Data	

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Question (1) - MOBILE COMMUNICATIONS SERVICE, Continued

(c) What total satellite capacity (Bandwidth) do you see being required for this service in Canada in each of the listed years? What percentage of the total Canadian traffic in each subgroup will be carried by satellite?

SERVICE SUBGROUP	1985 BW	1985 %	1990 BW	1990 %	1995 BW	1995 %
Voice/Low Speed Data						
Land						
Sea						
Air						
High Speed Data						

(d) What will be the most desirable downlink antenna coverage pattern for each service subgroup? (Global, hemisphere, all-Canada, Canada & coastal zone, time zones, regional, local spot beams)

SERVICE SUBGROUP	COVERAGE
Land	
Sea	
Air	
Combination?	

What will be the most desirable uplink antenna coverage pattern for each service subgroup? (Global, hemisphere all-Canada, Canada & coastal zone, time zones, regional, local spot beams)

SERVICE SUBGROUP	COVERAGE
Land	
Sea	
Air	
Combination?	

Question (1) - MOBILE COMMUNICATIONS SERVICE, Continued

(e) What type(s) of earth station antenna (eg. dish, helix, omnidirectional) will be required for each service subgroup? What are the anticipated major performance characteristics (eg. size, G/T)?

SERVICE SUBGROUP	TYPE	CHARACTERISTIC
Voice/Low Speed Data		
- Land		
- Sea		
- Air		
High Speed Data		

(f) Who are the most likely owner/operators of the earth stations? (eg. Telesat, common carriers, users, mixture of preceding)

SERVICE SUBGROUP	OWNER
Land	
Sea	
Air	

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Question (1) - MOBILE COMMUNICATIONS SERVICE, Continued

(g) For each of the service segments which interconnect with other services or segments, indicate whether this interconnection could be provided by means of (i) sharing a common Canadian domestic Multifunction Space Platform between the two services ('Dom. MSP'), (ii) placing the payload on a multi-national shared platform containing more than one service ('Int. MSP') or (iii) joining the two services on separate satellites by means of an inter-satellite link ('ISL')

SERVICE SUBGROUP	Dom. MSP	Int. MSP	ISL

(h) What do you estimate the cost of providing this service by satellite to be, if it uses its own dedicated spacecraft, and how much of this cost is for the payload only? (Please indicate any combinations of subgroups which you feel would most logically be combined as a single spacecraft payload)

SERVICE SUBGROUP	COST (1980 $)	PAYLOAD %
Voice/Low Speed Data		
- Land		
- Sea		
- Air		
High Speed Data		

Question (1) - BROADCASTING SERVICE

(a) When do you see these services being introduced operationally by satellite?

SERVICE SUBGROUP	Now	1985	1990	1995
Radio - Network Linking				
- Direct to Receiver				
TV - Network links				
- Community Reception				
- Educational TV				
- Direct to home				
- Pay TV				
- Specialized (eg. Tele-medicine)				

(b) What frequency(ies) will be used by this service?

SERVICE SUBGROUP	FREQUENCY(IES)
Network Feeds	
Direct - Radio	
- TV (including pay)	
Community Reception	
Educational TV	
Specialized Services	

Question (1) - BROADCASTING SERVICE, Continued

(c) What total satellite capacity (Bandwidth) do you see being required for this service in Canada in each of the listed years? What percentage of the total Canadian traffic in each subgroup will be carried by satellite?

SERVICE SUBGROUP	1985 BW	1985 %	1990 BW	1990 %	1995 BW	1995 %
Network Feeds						
Direct - Radio						
- TV						
Community Reception						
Educational TV						
Specialized Services						

(d) What will be the most desirable downlink antenna coverage pattern for each service subgroup? (All-Canada, time zones, regional, local spot beams)

SERVICE SUBGROUP	COVERAGE
Network Feeds	
Direct - Radio	
- TV	
Community Reception	
Educational TV	
Specialized Services	

Question (1) - BROADCASTING SERVICE, Continued

(d) What will be the most desirable uplink antenna coverage pattern for each service subgroup? (All-Canada, time zones, regional, local spot beams)

SERVICE SUBGROUP	COVERAGE
Network Feeds	
Direct - Radio	
- TV	
Community Reception	
Educational TV	
Specialized Services	

(e) If you anticipate that a reception antenna other than a dish will be required for any of these service subgroups (eg. omnidirectional UHF antenna for direct radio), please indicate what type is likely. What are the major performance characteristics (eg. size, G/T) for each of the downlink earth stations?

SERVICE SUBGROUP	TYPE	CHARACTERISTIC
Network Feeds		
Direct - Radio		
- TV		
Community Reception		
Educational TV		
Specialized Services		

Question (1) - BROADCASTING SERVICES, Continued

(f) Who are the most likely owner/operators of the earth stations? (eg. Telesat, common carriers, users, mixture of preceding)

SERVICE SUBGROUP	UPLINKS	DOWNLINKS
Network Feeds		
Direct Broadcasting		
Community Reception		
Educational TV		
Specialized Services		

(g) For each of the service segments which interconnect with other services or segments, indicate whether this interconnection could be provided by means of (i) sharing a common Canadian domestic Multifunction Space Platform between the two services ('Dom. MSP'), (ii) placing the payload on a multi-national shared platform containing more than one service ('Int. MSP') or (iii) joining the two services on separate satellites by means of an inter-satellite link ('ISL')

SERVICE SUBGROUP	Dom. MSP	Int. MSP	ISL

Question (1) - BROADCASTING SERVICE, Continued

(h) What do you estimate the cost of providing this service by satellite to be, if it uses its own dedicated spacecraft, and how much of this cost is for the payload only?

SERVICE SUBGROUP	COST (1980 $)	PAYLOAD %
Network Feeds		
Direct - Radio		
- TV		
Community Reception		
Educational TV		
Specialized Services		

Question (1) - SPECIALIZED SERVICES

(a) When do you see these services being introduced operationally by satellite?

SERVICE SUBGROUP	Now	1985	1990	1995
Teleconferencing - audio only				
- video				
Electronic Funds Transfer				
Electronic Mail				
Remote Printing				
Telidon				
Other (please specify)				

(b) What frequency(ies) will be used by this service?

SERVICE SUBGROUP	FREQUENCY(IES)
Teleconferencing - audio	
- video	
Electronic Funds Transfer	
Electronic Mail	
Remote Printing	
Telidon	
Other	

Question (1) - SPECIALIZED SERVICES, Continued

(c) What total satellite capacity (Bandwidth) do you see being required for this service in Canada in each of the listed years? What percentage of the total Canadian traffic in each subgroup will be carried by satellite?

SERVICE SUBGROUP	1985 BW	1985 %	1990 BW	1990 %	1995 BW	1995 %
Teleconferencing - audio						
- video						
Electronic Funds Transfer						
Other						

(d) What will be the most desirable downlink antenna coverage pattern for each service segment? (Global, hemisphere, all-Canada, Canada & coastal zone, time zones, regional, local spot beams)

SERVICE SUBGROUP	COVERAGE
Teleconferencing - audio	
- video	
Electronic Funds Transfer	
Electronic Mail	
Remote Printing	
Telidon	
Other	

Question (1) - SPECIALIZED SERVICES, Continued

(d) What will be the most desirable uplink antenna coverage pattern for each service subgroup (Global, hemisphere, all-Canada, Canada & coastal zone, time zones, regional, local spot beams)

SERVICE SUBGROUP	COVERAGE
Teleconferencing - audio	
- video	
Electronic Funds Transfer	
Electronic Mail	
Remote Printing	
Telidon	
Other	

(e) What are the anticipated major characteristics of the downlink earth stations (eg. dish size, G/T)?

SERVICE SUBGROUP	CHARACTERISTIC
Teleconferencing - audio	
- video	
Electronic Funds Transfer	
Electronic Mail	
Remote Printing	
Telidon	
Other	

Question (1) - SPECIALIZED SERVICES, Continued

(f) Who are the most likely owner/operators of the earth stations? (eg. Telesat, common carriers, users, mixture of preceding).

SERVICE SUBGROUP	OWNER
Teleconferencing	
Electronic Funds Transfer	
Electronic Mail	
Remote Printing	
Telidon	
Other	

(g) For each of the service segments which interconnect with other services or segments, indicate whether this interconnection could be provided by means of (i) sharing a common Canadian domestic Multifunction Space Platform between the two services ('Dom. MSP'), (ii) placing the payload on a multi-national shared platform containing more than one service ('Int. MSP') or (iii) joining the two services on separate satellites by means of an inter-satellite link ('ISL')

SERVICE SUBGROUP	Dom. MSP	Int. MSP	ISL

Question (1) - SPECIALIZED SERVICES, Continued

(h) What do you estimate the cost of providing this service by satellite to be, if it uses its own dedicated spacecraft, and how much of this cost is for the payload only? (Please indicate any combinations of subgroups which you feel would most logically be combined as a single spacecraft payload)

SERVICE SUBGROUP	COST (1980 $)	PAYLOA
Teleconferencing - audio		
- video		
Electronic Funds Transfer		
Electronic Mail		
Remote Printing		
Telidon		
Other		

Question (1) - Continued

(i) Please indicate with which other service subgroups each of the "primary" service subgroups will interconnect. Indicate whether the interconnection will be with Canadian domestic (D), international (I), or both (B) services.

Inter-connecting Services / "Primary" Service	FIXED				MOBILE						BROADCASTING							SPECIALIZED									
	Voice	Data			Voice & Low Speed Data			High Speed Data			Radio		Television					Video Teleconference	Audio only Teleconference	Electronic Funds Transfer	Electronic Mail	Remote Printing	Telidon				
		Low Speed	High Speed	Specialized	Land	Sea	Air	Land	Sea	Air	Network Links	Direct	Network Links	Community Reception	Educational	Direct to Home	Specialized										
Voice																											
Low Speed																											
High Speed																											
Specialized																											
Land																											
Sea																											
Air																											
Land																											
Sea																											
Air																											
Network Links																											
Direct																											
Network Links																											
Community Reception																											
Educational																											
Direct to Home																											
Specialized																											
Video Teleconference																											
Audio only Teleconference																											
Electronic Funds Transfer																											
Electronic Mail																											
Remote Printing																											
Telidon																											

(2) Do you, as a provider of satellite-based service, prefer to retain separate satellites for each (type of) service, or do you prefer to place multiple services on a common (hybrid) spacecraft? Please state your major reasons.

(3) Would you be willing to have your payload(s) carried on multifunction space platforms? If not, please state your major reasons.

(4) This question is designed to explore some institutional and operational aspects of multifunction space platform usage. For each subsection please provide two sets of answers, one expressing your views on a totally Canadian multifunction space platform, and the second on an international program in which Canadian payloads might share a common platform with those from other countries. It is recognized that this topic is likely to be controversial, and that the replies represent opinions only. Its intent is to gather these opinions in order to determine the scope of any potential controversy.

Domestic | International

(a) Ownership of the space segment.

Would you wish to:

- own the space segment and lease portions to others?
- be part owner of a (set of) spacecraft?
- own a separate communications payload but lease the platform facilities from an external entity?
- purely lease payload capacity?

(b) Independent control of the technical interfaces with the platform.

- Power: Would you accept a guaranteed power interface with the platform,
  or,
  prefer to provide your own power (total or eclipse only)?
- ACS: Would you prefer to accept the platform pointing capability,
  or,
  provide your own separate antenna steering?
- T&C: Would you prefer independent telemetry and command of your own payload,
  or,
  a feed of relevant telemetry data from the master control station (MCS) with 'command on request' through the MCS,
  or,
  telemetry and command of the entire spacecraft.

	Domestic	International

(c) How early in the platform planning stage would you wish to be involved?

(d) What are your major technical concerns with respect to putting a payload on a multifunction space platform as opposed to a dedicated single-service satellite? e.g..

- RF interference from other payloads
- cascading of failures
- thermal crosstalk
- incompatibility of attitude control requirements
- incompatibility of station-keeping requirements
- lack of freedom of choice of orbit slots
- finger trouble
- flexibility of launch period

	Domestic	International
(e) What would you consider to be major institutional concerns? e.g.		

- lack of direct control of own spacecraft
- equity of failure accommodation (e.g. if batteries fail, who is cut-off first)
- equity of charging scheme
- complexity of legal/contractual arrangements
- service costs

(f) What would be the dominant driver in your choice to place, or not to place, your service on a multifunction space platform?

(g) Would the capability for on-orbit servicing or replacement be a prerequisite for you to place your services on a multifunction space platform?

(5) In what major aspects do you see an international multifunction space platform differing from a domestic one?

(6) Independent of your preferences as expressed in 4(a) and 4(b), who do you see as the most likely Canadian multifunction space platform owner?

- operator?

(7) What do you see as the most likely cost sharing and charging scheme for a Canadian multifunction space platform? e.g.

- single owner, all payload users lease service only
- each user owns payload, shares in ownership of platform
- each user owns payload, leases 'real estate' from an arms length platform owner

(8) Please indicate any other questions or comments you may have.

ATTACHMENT 2

QUESTIONNAIRE FOR
USERS OF SATELLITE SERVICES

(1) Are you presently a direct user of satellite services (e.g. communications, weather, data collection)?

(2) The goal of this question is to determine, from the users' points of view, what the potential market for satellite services is. It is recognized that not all of the potential services identified here will materialize, and later questions will be used to perform the required filtering and define the conditions under which each suggested service would be utilized.

In answering this question, please try to be as free-thinking as possible, identifying any services which you would potentially use. Keep in mind, also, that one of the main objectives of developing multifunction space platforms is to enable economies of scale to significantly lower the cost of satellite services, making them even more viable to users.

For each of the services listed below, please indicate:

- if you presently use satellites
- if you presently use an alternate to satellites (please state what it is)
- if you would potentially use satellites if they were available to you at some time in the future

SERVICE	Present Use of Satellite	Present Use of Alternate	Potential Future Use of Satellite
Fixed Communications			
(Note: Unless you anticipate a drastic change in your level of usage, please exclude all traffic carried by the common carriers (e.g. telephone, Telex), and include only services in which you would desire direct access to the satellite.)			
Voice communications			
Data Transfer - low speed (e.g. Fax rate)			
- high speed (≥9600 bps)			
- specialized (e.g. weather)			
Mobile Communications			
Voice & low speed data - land			
- emergency services			
- personal communications term.			
- sea			
- air			
High speed data			

SERVICE	Present Use of Satellite	Present Use of Alternate	Potential Future Use of Satellites
Broadcasting			
Radio - network links			
- direct to receiver			
TV - network links			
- Community Reception			
- educational TV			
- direct to home			
- pay TV			
- special services (e.g. telemedicine)			
Specialized Services			
Teleconferencing - video			
- audio only			
Electronic Funds Transfer			
Remote Sensing Payloads			
Search and Rescue			
Electronic Mail			
Remote Printing			
Telidon			
Other (please specify)			

(3) This question is aimed at defining the conditions under which the actual demand would materialize for each of the potential markets you have identified in question 2.

(a) What alternates to satellites do you now employ, or are you considering employing?

SERVICE	ALTERNATE

(b) What would be the considerations that would make you choose a satellite service over the alternate? (e.g. relative price, quality of service, volume of need, security of communications?)

SERVICE	CONDITIONS

(c) What do you consider the most likely time frame for either your need for this service, or its introduction? (or both)

SERVICE	TIME FRAME			
	PRESENT	1985	1990	1995

(d) What would your likely volume of usage be? (Please state this in your own units; they can be converted to required satellite capacity.)

SERVICE	VOLUME

(e) If you had an option to either access the satellite directly from your own premises, or operate through an intermediary, such as a common carrier, which would you prefer, and why?

SERVICE	ACCESS MODE

(f) Would the availability of inexpensive ground terminals installed on your own premises increase your willingness or desire to use satellites in place of alternates?

What would your definition of 'inexpensive' be?

(g) What availability of service would you require?
e.g.

- 24 hour/day, or, business hours only
- immediate access, or, delays allowable (up to __)
- have a backup available, so willing to be pre-empted if it doesn't occur often and I'm charged less.
- priority user - reserve right to exercise operational control or have say in operational decisions, and must have priority over others in case of reduced capacity.

(h) What coverage pattern does each service require? (global, hemisphere, all Canada, Canada + coastal zones, time zones, single regions, local spot beams)

SERVICE	PATTERN

(i) Please indicate any services for which interconnection with other services would be either desirable or necessary, indicate the degree of option (desirable or necessary), and name the interconnecting services.

SERVICE	INTERCONNECTIONS	DEGREE OF OPTION

(j) For <u>each</u> potential service you have identified, please indicate

- if you would be willing to place it on a multi-function space platform (domestic or international or both)
- any specific payloads (or types) you would prefer either included on or excluded from the same satellite, with reasoning

SERVICE	"WILLINGNESS" DOMESTIC	INT'L	OTHER PAYLOADS OF CONCERN

(4) This question is aimed at determining the desires of the user community with respect to the space segment.

(a) Would you prefer to purely lease capacity to provide your service, or be a part owner of the space segment (owning either your own payload module, or also part of the multifunction space platform itself)?

(b) Would you prefer to be involved in the early planning stages of the multifunction platform (either as a user or part owner) in order to ensure that your requirements were met, or would you be willing to accept interfaces already defined by someone else? (Note that to a payload owner these would be the payload/platform interfaces, and to a pure lessee of services these would be performance interfaces.)

(c) Would you be willing to participate in an international multifunction space platform program?

If so, under what conditions?

(5) If you know the type of earth station(s) likely to be employed for your service(s), please list them below. The types of information desired are:

- Fixed (rigidly mounted), Transportable (can be moved, but operates from a single location), or Mobile (in motion while operating)

- Performance: This is preferably expressed in terms of the 'figure of merit' (G/T). However, if you do not know this, but do know the antenna type and size, please indicate so. Typical sizes and types are:

  - Parabolic dishes: 30 m dia (98'), 10 m dia (33'), 5 m dia (15'), 3 m dia (10'), approx. 1 m dia (3')

  - Helices

  - Omnidirectional

SERVICE	EARTH STATION TYPE

(6) Please indicate any other concerns or comments you may have.

APPENDIX C

PRELIMINARY LINK CALCULATIONS
BASELINE MISSION MODEL

LOW UHF DOWNLINK

- 18 M ANTENNA

OUTPUT AMPLIFIER: 0.5 W	- 3	dBW
TRANSMIT LOSSES	- 1	dB
ANTENNA GAIN (55% EFFICIENCY, 300 MHz)	+29.5	dBI *
EIRP	25.5	dBW
PATH LOSS	- 172.5	dB
GROUND ANTENNA GAIN	3	dBI
POLARIZATION LOSS	- 3	dB
NOISE TEMPERATURE (350K)	- 25.4	dB°K
BOLTZMANN'S CONSTANT	+ 288.6	dB/K/Hz
RECEIVE C/No	56.2	dB-Hz
NOISE BW (18 kHz)	42.6	dB-Hz
C/N + MARGIN	13.6	dB

* GAIN OF 18 M ANTENNA IS 32.5 DB
APPROXIMATION IS MADE THAT DUAL FEEDS, EQUALLY FED PRODUCE A BEAM WITH 3DB LESS EIRP.

HIGH UHF DOWNLINK

26 M ANTENNA

OUTPUT AMPLIFIER: 6.5 W	8.1 dBW
TRANSMIT LOSSES	- 1 dB
ANTENNA GAIN (55% EFFICIENCY, 800 MHz)	44.2 dBi
EIRP	51.3 dBW
PATH LOSS	- 182.8 dB
GROUND ANTENNA GAIN	+ 3 dBi
POLARIZATION LOSS	- 3 dB
NOISE TEMPERATURE (350°K)	- 25.4 dB°K
BOLTZMANNS CONSTANT	+ 228.6 dB/K/Hz
RECEIVE C/No.	71.7 dB-Hz
NOISE BW (18 kHz)	42.6 dB-Hz
CN + MARGIN	29.1 dB

FOR 20 CARRIERS/BEAM THIS CORRESPONDS TO A PER CARRIER

C/N + MARGIN OF	16.1 dB
WITH 2.5 dB BACKOFF	13.6 dB/CARRIER

L-BAND DOWNLINK

- 7 M ANTENNA
- 'PER CARRIER' CALCULATIONS

OUTPUT AMPLIFIER: 1 W	0	DBW
TRANSMIT LOSSES	- 1	DB
ANTENNA GAIN (55% EFFICIENCY, 1500 MHz)	28.2	DBI *
EIRP	27.2	DBW
PATH LOSS	- 188	DB
POLARIZATION LOSS	- 3	DB
GROUND STATION G/T (INMARSAT)	- 4	DB/K
BOLTZMANN'S CONSTANT	+ 228.6	DB/K/HZ
RECEIVE C/No.	60.8	DB-HZ
NOISE BW (18 K HZ)	42.6	DB-HZ
C/N + MARGIN	18.2	DB

* GAIN OF 7M ANTENNA IS 38.2 DBI, BEAM WIDTH IS 2° COVERAGE PATTERN (4° x 10°) COMPOSED OF 10-2° BEAMS EVENLY FED → NET GAIN IS APPROXIMATED AS 28.2 DBI

C-BAND DOWNLINK

- 3 M ANTENNA

	REGIONAL COVERAGE (2°x 3°)	ALL CANADA (3°x 8°)
OUTPUT AMPLIFIER: 5 W	7 DBW	7 DBW
TRANSMIT LOSSES	-3 DB	-3 DB
ANTENNA GAIN (55% EFFICIENCY, 3.7 GHZ)	+36.5 DBI	+30.5 DBI
EIRP	40.5 DBW	34.5 DBW
PATH LOSS	-195.5 DB	-195.5 DB
GROUND STATION G/T (TYP)	+30 DB/K *	+25 DB/K **
BOLTZMANN'S CONSTANT	+288.6 DB/K/HZ	+288.6 DB/K/HZ
RECEIVE C/No	103.6 DB-HZ	92.6 DB-HZ
NOISE BW (40 MHZ)	76.0 DB-HZ	76.0 DB-HZ
C/N + MARGIN	27.6 DB	16.6 DB

* BASED ON TYPICAL 10 M STATION SPECS

** BASED ON TYPICAL 5 M STATION SPECS

KU-BAND DOWNLINK

- 2 M ANTENNA

OUTPUT AMPLIFIER: 50 W	17 dBW
TRANSMIT LOSSES	- 3 dB
ANTENNA GAIN (2° X 3° BEAMS)	+ 36.5 dBI
EIRP	50.5 dBW → 45.5 dBI *
PATH LOSS (12 GHz)	-206.0 dB
BOLTZMANNS CONSTANT	+228.6 dB/K/Hz

	'TRUNK'	'THIN'	'TVRO'
GROUND STATION G/T (TYP)	30 dB/K	25 dB/K	15 dB/K **
RECEIVE C/No	103.1 dB-Hz	98.1 dB-Hz	83.1 dB-Hz
NOISE BW (54 MHz)	77.3 dB-Hz	77.3 dB-Hz	72.6 dB-Hz (18 M Hz)
C/N + MARGIN	25.8 dB	20.8 dB	10.5 dB

* PER-CARRIER EIRP BASED ON 2 CARRIERS/CHANNEL AND 2 dB BACKOFF

** BASED ON 1.5 M ANTENNA-YIELDS MARGINAL PERFORMANCE

APPENDIX D

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APPENDIX E

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