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**LONG TERM SPACE BASED
EARTH OBSERVATION
AND REMOTE SENSING
STRATEGY STUDY**

BERCHA
GROUP

FINAL REPORT

ON

**LONG TERM SPACE BASED
EARTH OBSERVATION
AND REMOTE SENSING
STRATEGY STUDY**

TO

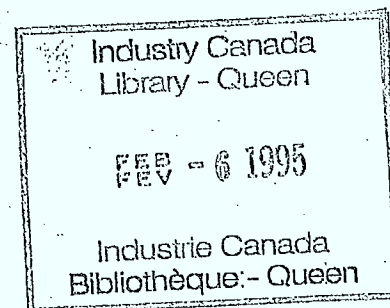
**INDUSTRY, SCIENCE AND TECHNOLOGY, CANADA
SPACE SYSTEMS DIVISION
OTTAWA, ONTARIO**

BY

**F.G. BERCHA AND ASSOCIATES (ALBERTA) LIMITED
CALGARY, ALBERTA**

AUGUST 31, 1990

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18 September 1990

Industry, Science and Technology Canada
Space Systems Division
Aerospace, Defence & Industrial Benefits
6th Floor, 235 Queen Street
Ottawa, Ontario K1A 0H5

Attention: Mr. Peter Lawrence
Project Manager

Peter
Dear Mr. Lawrence:

Re: Final Report - Long Term Space Based Earth Observation and Remote Sensing Strategy
Study

We are pleased to enclose herewith a copy of the Final Report for the above study.

As you will note, following a brief introduction, the report in successive chapters describes the methodology, results of the market analysis, results of the Canadian industrial capabilities evaluation, the strategy assessment, and conclusions and recommendations. Following the main body of the report are references, a glossary, and appendices giving background information on the work.

We are grateful for the opportunity to have conducted this interesting and challenging project and hope you find the results of the work entirely satisfactory given the schedule and budgetary constraints under which it was conducted. If you require any further assistance in this area, please do not hesitate to contact the undersigned at your convenience.

Yours truly,



F.G.
F.G. Bercha, Ph.D., P.Eng.
President

FGB:dr

encl.

ABSTRACT

The purpose of this study was to provide the Federal Government of Canada with the commercial and technical data necessary to formulate effective strategies for the support of the Canadian remote sensing industry through the 1990s. The specific requirement of this study included a review of the international market for remote sensing products and services with projections for future spending in the three main sectors of the earth observation industry; namely, satellite systems and subsystems, ground receiving stations and data distribution, and value added systems and services. The second requirement of the study was to compile a data base of all Canadian companies with capabilities in these sectors. An analysis of the Canadian capabilities and deficiencies in the Canadian technology base was performed. The final requirement was for the generation of optional strategies which will serve to enhance the international market share of the Canadian industry.

The results of the market review indicated a general growth expected in the earth observation industry over the coming decade. Total market volume will likely exceed US\$22 billion over this period. Significant funding has been allocated to this industry and Canadian organizations are well positioned to increase their market share.

An assessment of Canadian capabilities indicated a strong presence in imaging radar technology, power systems, and communications. Other capabilities with application to earth observation satellites include structures, optical sensors, thermal control systems, and electronic subsystems. Specific Canadian deficiencies for complete satellites stem from the lack of a Canadian satellite platform design as well as attitude and orbital control systems. These deficiencies, coupled with the lack of a Canadian launch facility, preclude the development of a complete made-in-Canada earth observation satellite system.

The strategic assessment developed in this report recognizes the need for a strong commitment to the remote sensing industry by the Federal Government of Canada. Central to these strategy recommendations is the development of a policy which strongly supports the application and international marketing of Canadian remote sensing technology. A cornerstone of this policy is a commitment for a follow-on to the Canadian Radarsat program which is expected to generate considerable international prestige and associated revenues beginning in 1994.

ACKNOWLEDGEMENTS

Funding of the work by Industry, Science and Technology Canada, Space Systems Division, is hereby gratefully acknowledged. In addition, acknowledgement is made of the advice on setting the direction of the work by Ms. T.K. Butryn and project management and advice throughout by Mr. Peter Lawrence, ISTC Project Manager. On behalf of F.G. Bercha and Associates (Alberta) Limited, the work was generally directed by Dr. F.G. Bercha, with Project Manager, Mr. D.H. Currie, assisted by Bercha staff; Mr. J. Dechka, Mr. O. Sawicki, and Mr. B.J. Griffin, and word processing by Ms. D. Russell. An important sub-consultant was Mr. Bob Tack of Lions Gate International Management Consultants, and another sub-consultant was Mr. Chuck DeCaro, of Aerobureau Corporation. Finally, grateful acknowledgement is made to all the companies and individuals both in the public and private sector assisting in compiling the substantial data base for this present work.

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The role of Canada's remote sensing industry within the context of global space-related industrial activities has developed to a highly significant level. However, the best strategy for enhancing the future benefits to Canada's space industry from the global remote sensing markets has not been clearly defined.

Remote sensing and other space related activities have a direct application to earth observation programs. A number of high profile earth observation and remote sensing programs are currently in existence, including Landsat and SPOT, or are in the preparatory stages, such as the Canadian Radarsat program, the European Space Agency's ERS-1 satellite program, and the French SPOT 4 program. Canada's optimal strategy within the context of these programs and global market trends and capabilities needs to be better defined.

Recently, a new alliance called the Western Space Initiative has been formed with the purpose of amalgamating western high technology space and remote sensing industrial resources toward the common goal of developing an environmental monitoring capability and space-based sensor technology of global significance. In order to support the development of a strategy to optimally guide the Western Space Initiative and the Canadian Space Agency (CSA) within the matrix of priorities of the Space Systems Division of the Ministry of Industry, Science, and Technology Canada (ISTC), certain data regarding Canadian industrial capabilities and global market expectations are required.

Accordingly, ISTC recently issued bid documents for a project directed at the assimilation, analysis, and interpretation of such data. The successful contractor, F.G. Bercha and Associates Limited (Bercha) was tasked with such a project within the context of specific objectives and priorities.

In general, the work reported on in the present document consisted of doing a market, capability, and strategy study for earth observation and remote sensing satellite systems covering the

period from 1990 to the year 2000 focusing on existing and emerging Canadian industrial capabilities within the context of the global market.

1.2 Objectives of Work

The general objective of this work is the preparation of a market and capability study to serve as a basis for the development of a Canadian industrial strategy for earth observation and satellite system programs for the next decade. Specific objectives of the study include the following:

- (a) Definition of global market trends up to the year 2000, including the influence of foreign governments on their industry and the consequences for Canadian industry.
- (b) Definition of the size, structure, capability, and performance of the Canadian industrial sector in the space-based industry relative to foreign competitors.
- (c) Evaluation of the comparative advantages of using space-based as opposed to airborne remote sensing technologies to gather data to satisfy the market needs.
- (d) The impact of developing and emerging technologies and the provision of hardware and related space-based services on a global basis.
- (e) The development of optimal strategies for the positioning and development of Canadian industry to improve its competitiveness in domestic and international markets.

For the purposes of this work, the space-based remote sensing industry may be subdivided into three principal sectors as follows:

- (a) Companies involved in the supply of satellite systems, subsystems, hardware, software, and services for earth observation and remote sensing of conditions on earth or its surroundings.
- (b) Companies involved in the handling of data from earth observation satellites including data reception and processing systems, subsystems, hardware, software, and services.
- (c) Companies involved in providing value added services and systems.

The most important objective of the work relates to the definition and analysis of global markets. At least fifty percent of the consultant's effort was to be dedicated to the principal objective. The second most important one is the definition of industrial capabilities within the context of global competitive resources. Thirty-five percent of the consultant's effort was to be dedicated to this objective. The final objective, the assessment of an optimal strategy, is important but considered to merit only the remaining fifteen percent of the total effort.

1.3 Scope of Work

The scope of work designed for the achievement of the above objectives within the context of the resources and time frame available for the present project may be subdivided into three principal tasks as follows:

- (a) Task 1: Market Review;
- (b) Task 2: Industrial Capabilities Review;
- (c) Task 3: Strategic Assessment.

The first two of these three tasks were conducted concurrently due to the timing and methodology utilized. The final task was commenced as the first two tasks neared completion. Details on each task follow.

1.3.1 Market Review Scope of Work

The market review consisted of the identification of current and future international markets to the year 2000 encompassing the three industrial sectors of the space-based remote sensing industry on a global basis. Work consisted of the following principal subtasks:

- (a) Identification and quantification on a global basis of current and planned expenditures on remote sensing and earth observation satellite systems.
- (b) Definition of the industrial structure and composition of the international supply base in terms of existing technology and services and future trends in the development of remote sensing and earth observation technology and provision of services.
- (c) Definition of the structure and composition of international demand for earth observation and remote sensing data.
- (d) Identification of the specific types of remote sensing data currently being supplied and particular user markets to which these data are being supplied.
- (e) Identification of the types of remote sensing data planned for provision over the next decade, with details including sensitivity of the demand to factors such as timeliness of supply and alternative data sources; identification of future users and sources of funding for these planned programs.
- (f) Identification of any unique opportunities or new applications which Canada might optimally address in its industrial strategy.
- (g) Review of alternative methods such as airborne methods of collecting remote sensing data to serve the needs of global users.

- (h) Definition and projection of trends by foreign governments in their role as motivators and regulators affecting the space-based industry and identification of issues likely to impact on Canada's access to international markets in the space-based industrial sector.

1.3.2 Industrial Capabilities Review

The industrial capabilities review concentrated on the development of a profile of Canadian space-based industrial capabilities within the context of current and future user needs. Specific subtasks constituting this review may be summarized as follows:

- (a) Identification of Canadian companies competing in the three principal subsectors and their specific capabilities and potential capabilities.
- (b) Definition of the existing technology base in Canada for earth environment monitoring from space in the areas of development of earth observation instruments or sensors, deployment of small satellites and other types of platforms, and data reception, processing, information extraction, assimilation and dissemination systems.
- (c) Identification of deficiencies in the Canadian technology base and associated rectification measures required to bring Canadian technology to a level necessary to compete in global markets.

1.3.3 Strategic Assessment

This task consisted of the development of various options directed at optimizing Canadian resources in the space-based industrial sector for the next decade within the context of global markets and capabilities. Specifically, the following subtasks comprised this assessment:

- (a) Identification of potential market areas most compatible with Canadian technological and commercial competitive positions.
- (b) Development of a prediction of the market share for products and services that may be achieved by Canadian space-based industry together with an assessment of the steps necessary to realize this market share.
- (c) Identification of strategic steps to be taken by the federal government to assist Canadian industry in achieving its maximum potential world market share.
- (d) Recommendation of other mechanisms for exploiting the identified market opportunities.

- (e) Recommendations on areas for further study prior to development within the context of the study objectives.

1.4 Outline of Report

Following this brief introduction, Chapter 2 describes the methodology for each task of the study, Chapter 3 presents the results of the market review and analysis, Chapter 4 gives the results of the analysis of Canadian space-based industrial capabilities, Chapter 5 indicates the results of the strategy assessment, while Chapter 6 presents conclusions and recommendations and is followed by a list of References and a Glossary of Terms.

CHAPTER 2

METHODOLOGY

2.1 General Description of Methodology

The general methodology applied to the achievement of the study objectives consisted of data acquisition, analysis, and interpretation and planning activities. Data acquisition activities were directed at the assimilation of global market and capability data in each of the principal space-based industrial subsectors as well as domestic capability and potential capability data. Generally, the data acquisition approaches included a literature search, electronic communication questionnaires, and physical interviews. Analysis activities included sorting, cross-referencing, correlating, and statistically analyzing quantitative data, and sorting and conceptually correlating and reporting qualitative information. The interpretation and planning involved the correlation and interpolation of quantitative and qualitative data to form an integrated global and national description of markets and capabilities. Due to time constraints, it was necessary in some areas to utilize directly acquired data as a basis for interpolation points within the global picture developed through inquiry, expert opinion, and project team judgements. The strategy, similarly, was developed through a series of brainstorming and general interpretation sessions among project team members, working independently as well as interactively with other industrial performers. Details on each of the principal phases follow.

2.2 Data Acquisition

2.2.1 Data Acquisition Personnel

The study data acquisition team consisted of Bercha personnel and subcontractors providing optimal global coverage within the time and resource constraints of the present study. Bercha personnel operated from the Calgary head office and conducted field data acquisition activities as much as possible electronically from that base as well as through a number of national and international journeys. Bercha's principal subcontractors were both located in Washington, D.C., and conducted field trips both in their vicinity and internationally, as detailed later in this section. As indicated above, the principal data acquisition activities included literature assimilation and review, questionnaire implementation, and physical interviews with key authorities and individuals on a global basis.

2.2.2 Literature Assimilation and Review

Discussions with experts and ISTC recommendations and Bercha's extensive in-house files and library were utilized as a basis for the assimilation of literature to support the work.

A data base was compiled from references obtained from inhouse and local libraries as well as corporate and government publications. Specific references quoted in the work and used directly are given under the section entitled References at the conclusion of the present report.

Key references utilized in the work include the following:

- (a) An analysis of remote sensing market trends within the U.S. context performed by Kodak Remote Sensing for the U.S. Department of Commerce, cited under reference [1].
- (b) From Pattern to Process: The Strategy of the Earth Observing System, A NASA publication by the Eos Science Steering Committee, cited under reference [2].
- (c) Commercial Utilization of Space, A publication of the Battelle Institute of West Germany analyzing the existing framework conditions in the major western space nations, cited under reference [3].
- (d) The 1989 European Space Directory, published by Sevig Press, cited under reference [4].

In general, the references utilized assisted in the assimilation of a global picture but were generally found to be insufficiently specific and detailed, particularly with respect to Canadian capabilities, to be used directly in the work.

2.2.3 Questionnaire Implementation

A questionnaire was designed to serve for both the evaluation of global markets and users as well as Canadian capability. Accordingly, the questionnaire was in two parts: that pertaining to global market evaluation including Canadian market, and that pertaining to the evaluation of Canadian capability. As may be seen, the following principal areas of data gathering are reflected in the questionnaire:

- (a) Organization information;
- (b) Market definition;
- (c) Market trends;
- (d) Budgetary data;
- (e) Canadian capabilities (only sent to Canadian companies).

Organization information includes specific data such as address, contacts, and telephone numbers, which may be utilized for contacting the organization. The market definition undertakes to define the targeted organization activities in the appropriate industry sectors as well as provide general space-based data sources and applications within their field of endeavour. Market trends are direct questions relating to the important objectives of the present study. Budgetary data include quantitative data and form a basis for demand predictions as well as capabilities of a general global nature. Canadian capabilities relate to the specific objectives of the Canadian capability evaluation under the present project.

The questionnaire was distributed to 158 organizations throughout the world with 59 responses received at the time of writing of the present report.

2.2.4 Interview Program

Bercha personnel and subcontractors interviewed key individuals and organizations relating to the objectives of the present study. Generally, topics of discussion related to future remote sensing systems and opportunities, alternatives to space-based remote sensing techniques, the impact of government policies, perceived market inroads and competition, and any other information relative to the study volunteered by interviewees.

Travel by Bercha personnel covered strategic interview locations in Canada, the United States, and selected Asian locations including Thailand, Malaysia, and Indonesia. Bercha subcontractors conducted interviews in the Eastern United States, and Europe. Table 2.1 lists the organizations interviewed as part of this project.

2.3 Trends and Market Predictions

The determination of market trends and associated predictions was based on a series of information sources. The initial approach involved an extensive review of available literature. The primary sources of market data obtained from the literature were annual corporate reports, other market surveys covering mainly U.S. markets, government publications, industry directories and various other publications relevant to the subject matter.

The questionnaire distributed to a variety of corporate organizations and government agencies throughout the world was used for further market review. Data significant to the market survey which was available from the questionnaire database included corporate information such as annual expenditures, revenues and sales; information regarding the employee base and their associated qualifications; and information dealing with market trends and expectations. Although significant data were obtained through questionnaires, the information in these data represents only a partial cross-

TABLE 2.1
LIST OF ORGANIZATIONS INTERVIEWED

| ORGANIZATION | LOCATION |
|---|-------------------------------|
| Alberta Science and Technology | Edmonton, Alberta |
| Atmospheric Environment Service, Ice Centre | Ottawa, Ontario |
| Bakosurtanal | Jakarta, Indonesia |
| Bercha Group | Calgary, Alberta |
| Binary Image Corporation | Aldergrove, B.C. |
| Bristol Aerospace, Inc. | Winnipeg, Manitoba |
| Canada Centre for Remote Sensing, Applications Division | Ottawa, Ontario |
| Canadian Astronautics Ltd. | Ottawa, Ontario |
| Canadian Wheat Board | Winnipeg, Manitoba |
| Department of Energy and Natural Resources | Manila, Philippines |
| EOSAT Inc. | Lanham, Maryland |
| ESA | Paris, France |
| Intera Technologies Ltd. | Calgary, Alberta |
| Jet Propulsion Laboratory | Pasadena, California |
| Lapan | Jakarta, Indonesia |
| MacDonald Dettwiler and Associates | Richmond, B.C. |
| Malaysian National Remote Sensing Centre | Kuala Lumpur, Malaysia |
| Manitoba Remote Sensing Centre | Winnipeg, Manitoba |
| NASA | Washington, D.C. |
| National Research Council of Thailand | Bangkok, Thailand |
| Sabah Foundation | Kuala Lumpur, Malaysia |
| Saskatchewan Science and Technology | Saskatoon, Saskatchewan |
| SED Systems Inc. | Saskatoon, Saskatchewan |
| SPAR Aerospace Ltd. | Ste. Anne de Bellevue, Quebec |
| SPOT Image | Toulouse, France |

section of the global remote sensing earth observation market.

The most important data source for predictions involved interviews with companies and organizations and discussions with experts. The interviews were conducted with personnel involved in various sectors of the remote sensing and satellite based industry and in many instances were directly associated with corporate marketing, which proved beneficial to the market segment of the survey. To provide an additional perspective, end user companies and organizations were also interviewed in an attempt to establish viewpoints from all representatives of the market. These discussions provided corporate and capability data, information regarding requirements of the end user, as well as providing the opportunity to consider and expand upon market expectations, trends and predictions. The interviews were targeted primarily within the Canadian market, although foreign companies and organizations were also considered.

CHAPTER 3

MARKET ANALYSIS

3.1 General Description of Market Review

Following the data collection phase, as described in Chapter 2, an analysis of the remote sensing and earth observation market was conducted. The analysis involved determining existing market conditions and trends as well as predicting future conditions.

The first section in this chapter deals with current and planned expenditures on remote sensing satellite systems. Next, the market structure of the international supply base is described including consideration of the three primary sectors of the market. The analysis results of the present international demand for earth observation and remote sensing data, followed by those from an assessment of the current uses of the available data are then presented.

Section 3.6 describes future satellite remote sensing data acquisition programs presently in the developmental or planning stages. An identification of new potential markets within Canada and internationally is given in Section 3.7, identifying specific market opportunities for Canadian industry.

Section 3.8 provides a review of alternative data acquisition methods with identification of relative advantages. Finally, Section 3.9 discusses the impact of foreign government policies and issues affecting Canada's access to international markets.

3.2 Current and Planned Expenditures on Remote Sensing Satellite Systems

The technical description of both current and planned remote sensing and earth observation satellite systems can be provided in a detailed format based primarily on a review of available literature. The identification and quantification of planned expenditures on these same remote sensing systems is more difficult to assess primarily due to limitations in the availability and accessibility of quantifiable data. Global expenditure data were obtained from a number of literature sources with the most informative sources being the Commercial Utilization of Space³, the European Space Directory⁴ and the major data distribution organizations such as Canada Centre for Remote Sensing (CCRS), National Oceanic and Atmospheric Administration (NOAA), and the Earth Resource Observation System (EROS) Data Centre, as well as from trade publications and secondary references. These figures may not be totally reliable or indicative of actual plans. Expenditures were assembled on a

continental basis with individual breakdowns by country provided where data was available. Although a large number of countries are involved within the remote sensing satellite industry only those countries who act as major players within the market were considered. Throughout this report, monetary figures have been converted to U.S. dollars at 1990 rates.

3.2.1 North America

3.2.1.1 Canada

Canada's involvement in the remote sensing and earth observation satellite industry includes the development of spaceborne synthetic aperture radars (SAR) and high speed digital SAR processors, cooperative involvement in the European Remote Sensing Satellite Program (ERS-1) and, primarily, the development and implementation of Radarsat, Canada's independent satellite program. Originally planned for launch in 1988, Radarsat has been delayed to 1994. The federal government has committed a total of \$330 million in funding to the Radarsat project. The provinces of British Columbia, Ontario, Quebec and Saskatchewan have provided an additional \$52.9 million to be directed towards industrial work performed by companies in these provinces⁵. Launch costs will be borne by National Aeronautics and Space Administration (NASA) in exchange for data. Additional costs for applications and design studies have been supported by CCRS and the Canadian Space Agency (CSA) budgets.

As the Radarsat program demonstrates, Canada has extensive experience and commitment in the space satellite industry. Canada has been among the leaders in space science and technology from the launch of Alouette I, an ionospheric sounding satellite in 1962, through to Canada's involvement in the U.S. space shuttle program.

Historical expenditures by the Canadian Government since 1969 are depicted in Figure 3.1, and provide an indication of the distribution of the monies among contributions to the European Space Agency (ESA), Communications, Earth Observation and Science Programs⁴. Military expenditures are not included within the total. ESA expenditures are a result of Canada's affiliate member status in this organization. Expenditures in Science refer to space technology and research as well as space station projects. The Communications budget relates to the continuing development and operation of the nation's network of satellites, while budgetary information for earth observation studies include not only applications of remote

Figure 3.1: Annual Space Expenditures
Canada

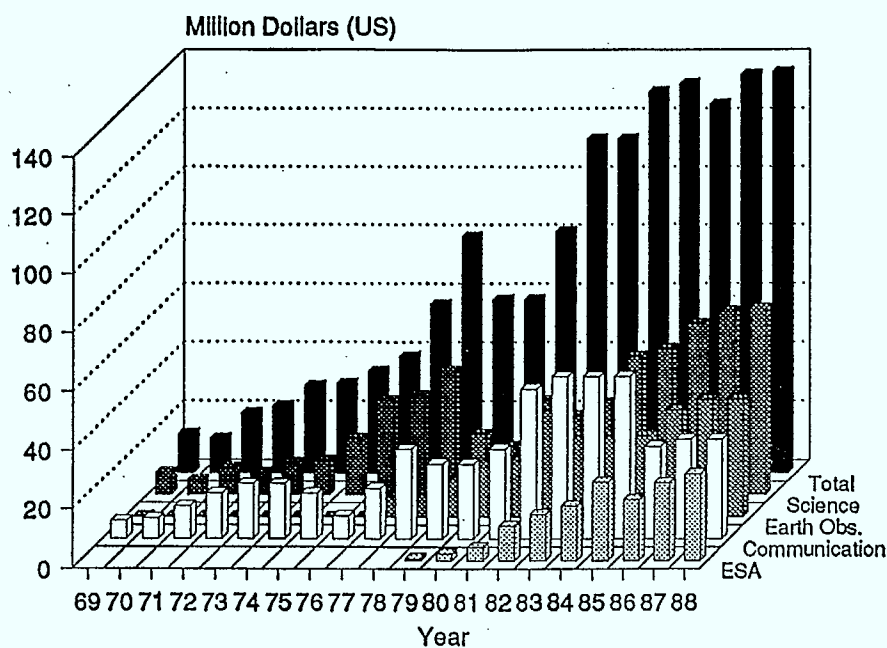
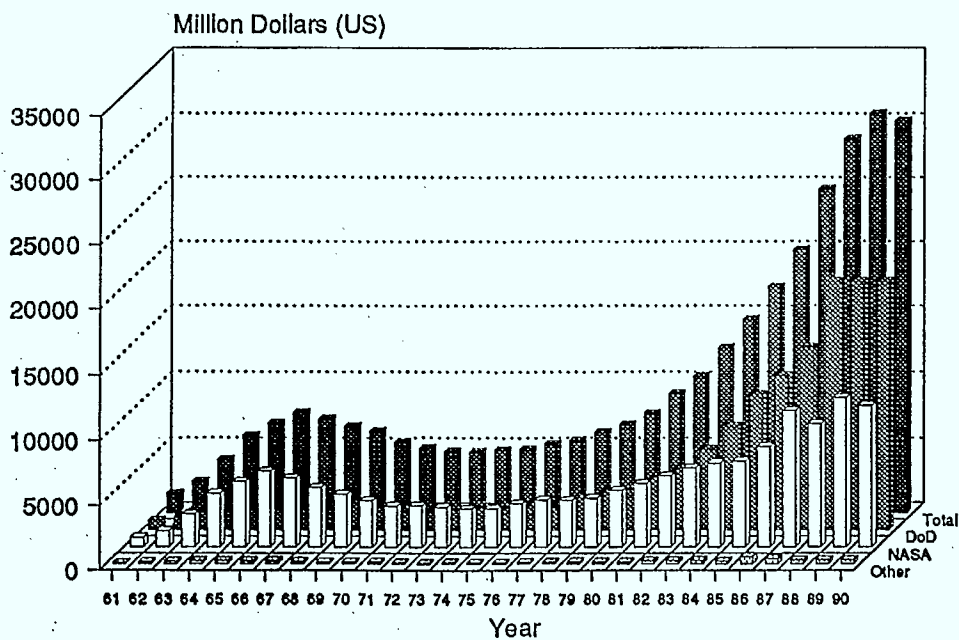


Figure 3.2: Annual Space Expenditures
United States



sensing data and CCRS operations but also the development of Radarsat.

The long-term Canadian space program encompasses several projects in addition to those already mentioned. These projects include a mobile servicing system contribution to the US space station "Freedom" including a user-development program, the continuation of the Canadian astronaut program, support for the Mobile Satellite (MSAT) communications system and further funding for space science research and continuous in-house research and development (R&D). These projects have led to an increase in funding from approximately \$80 million in 1981 to an estimated \$253 million by 1992. An average annual increase of over 10 per cent. The Government of Canada is committed to spending \$1.1 billion on the Canadian space program between 1989 and 1994 alone. Spending as a proportion of gross national product (GNP), on Canada's space program is just behind that of Japan, Germany, and Belgium and just ahead of Denmark and The Netherlands. To this point, the Canadian space program has emphasized both communications and remote sensing. As the year 2000 approaches, this communications/remote sensing balance will continue to shift so that the greater part of the Canadian Government's investment in space will involve the space station and primarily, remote sensing. This trend of increases is reflected in Figure 3.1 between the years 1981 and 1988.

3.2.1.2 United States of America

The predominant involvement in the remote sensing earth observation satellite programs within the United States is directed through National Aeronautic and Space Administration (NASA) for scientific missions, NOAA for meteorological operations, and Earth Observation Satellite Company (EOSAT), a private company, for the acquisition and distribution of Landsat remotely sensed imagery. Another prime player in the U.S.A. is the Department of Defence (DoD) although due to the lack of available data, the military budgets will be left undiscussed. Figure 3.2 illustrates the breakdown of U.S. space expenditures since 1961.

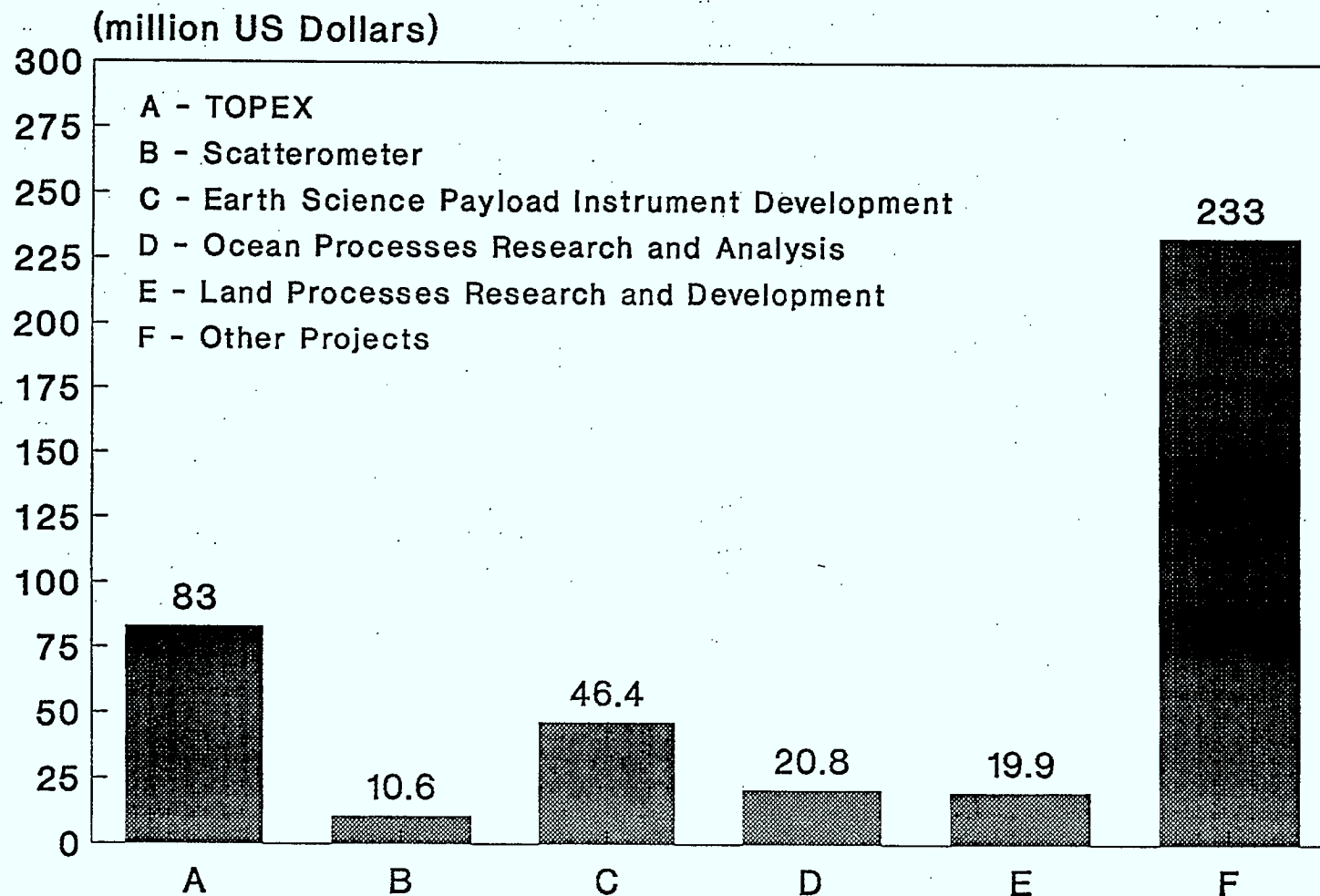
NASA, as the major research and development organization in remote sensing, plans, budgets, and coordinates all research and development in remote sensing including Metsat, Landsat, and ocean and ice observation systems. Aside from the primary NASA research centres, support research is also conducted through many universities, non-profit organizations, and various small and large companies.

To support this widespread distribution, NASA possesses a dominant proportion of the U.S. space program budget. The R&D budget for 1989 is \$4.266 billion which includes \$413.7 million for earth sciences³. A further funding breakdown, shown in Figure 3.3, includes \$83 million towards TOPEX, \$10.6 million for scatterometer, \$46.4 million for earth science payload instrument development, \$20.8 million for ocean processes research and analysis, and \$19.9 million for land processes research and development³. The remaining funding is for atmospheric research and analysis as well as for such non-commercial research topics as the geodynamics program and climate and radiation research. For the 1990 fiscal year, the NASA budget request is \$434.3 million for earth sciences which represents a 5% increase over 1989⁴. Even though an extensive need in the R&D budget for other activities such as planetary exploration exists, NASA's budget for earth sciences has remained stable relative to inflation since 1986, at which point the budget was \$365 million. Important to note is the fact that to support the major activities planned in the earth observation system (EOS) core program through the 1990s, NASA will have to maintain a funding level of at least \$250 million annually. It should be noted that predicted 1990 funding is below that of 1989.

NOAA holds the responsibility for the operation of remote sensing satellite systems including the Metsat and, formerly, the Landsat systems. The actual organization within NOAA which holds responsibility for satellite systems is the National Environmental Satellite Data and Information Services (NESDIS) situated in Suitland, Maryland. NOAA managed the Landsat program until 1985 at which point the transfer of this function to the private sector was announced. With this transfer, pressure to reduce overall spending initiated cutbacks in funding of \$67.5 million between 1986 and 1987 (\$263.5 million versus \$331 million). Although more current fiscal data is presently not available, these funding reductions will probably have an effect on future satellite systems for atmospheric and climatic research.

Although many private sector companies are either directly or indirectly involved in the U.S. space satellite industry, only EOSAT will be considered within this discussion. EOSAT was selected by the Department of Commerce (DoC) in May 1985 to take responsibility for the satellite program which to this point had been run by NOAA. EOSAT is a corporation formed by RCA and Hughes Aircraft

Figure 3.3: 1989 NASA Earth Sciences
Remote Sensing R & D Budget Breakdown



Corporation specifically to market Landsat data and construct, own, and operate additional Landsat satellites. The ownership structure changed when RCA sold its aerospace interest to General Electric while Hughes was purchased by General Motors. An agreement between the U.S. Department of Commerce and EOSAT as to the amount of subsidy and financial risk to EOSAT was established in 1985. The subsidy consisted of \$250 million plus launch costs of \$40 million. EOSAT agreed to build and launch two satellites regardless of whether the remote sensing satellite market has developed to become a profitable business. In the 1987 fiscal year, Congress approved \$72 million for the operation of the current Landsat program (i.e., Landsat 4 and 5). Developments between the Department of Commerce and EOSAT in 1988 have led to the signing of a \$220 million contract aimed at continuing the Landsat satellite program into the 1990s. Given expected launch and related satellite ancillary costs, the agreement provides for only partial funding of that required for the completion of Landsat 6 and related ground systems. The net cost to the U.S. Government for Landsat 6 is suggested to be \$209.2 million with EOSAT repaying \$10.8 million over approximately 5 years in revenue returns to the U.S. government beginning in 1988³. Estimated cost for completion of Landsat 6 is approximately \$300 million. Not included in this estimate are launch costs, development and experimental costs, or test costs. This estimate also disregards potential cost overruns. Aside from Landsat 6, EOSAT will continue worldwide market activities and operation of Landsats 4 and 5.

Limited information is available regarding military spending on earth observation, however, as Figure 3.2 clearly shows, DoD spending is significantly higher than all other American space expenditures. Certainly, the defence mapping satellite project (DMSP) and various military spy satellites are paid for from this budget, however, the percentage of total expenditures which these represent is unknown. In any case, military spending is expected to dominate total U.S. space budgets throughout the 1990s.

At this point the U.S.A. remains a leader in technology for earth observation. Planned expenditures for operational, meteorological, and surveillance satellites appears to be constant throughout the next decade. Financial commitments for commercial satellites remain limited to the Landsat 6 program, thus indicating a near

term decline in the market share for remotely sensed imagery held by U.S. firms. Experimental satellites remain a priority as is evidenced by the plans for the EOS system to be launched late in the decade.

3.2.2 Europe

3.2.2.1 European Space Agency (ESA)

The European Space Agency (ESA) was formed in the mid 1970's as a multinational space agency. Its goal is to integrate the individual European Space Programs to improve the worldwide competitiveness of European industry. Member countries and their respective participating agencies are listed in Table 3.1⁴.

ESA projects are supported by the member states through a combination of mandatory contributions and participation in optional projects. The size of the mandatory contribution by each member country is based directly on its GNP. The primary ESA remote sensing program is the Earthnet Program. The Earthnet program includes the receiving and processing of Landsat data, development of the Earth Resources Satellites, ERS-1 and the proposed ERS-2, and participation in joint experiment missions with other partners, for example, earth observation from Spacelab. ESA is heavily involved in the development of research satellites and sensors for remote sensing. The first of these is ERS-1 which is being built by a consortium of European companies, with some Canadian input.

The percentage of ESA expenditures devoted to earth observation over the long-term period from 1987 to 2000 is approximately 10%. Annual ESA space expenditures from 1961 to 1989 are provided in Figure 3.4⁴. Based on the increase presented in this figure, a determination of future trends is provided in Figure 3.5, which shows expected growth in expenditures on European satellite earth observation as well as mandatory ESA programs to the year 2000. Total expenditures from 1987 to 2000 on mandatory programs is expected to be \$5.8 billion. For specific science programs, the total is expected to be \$2.8 billion. Technology programs will total \$339 million and earth observation development will be \$3.1 billion. Costs for the completion of ERS-1 and ERS-2 have been estimated at approximately \$500 million per satellite. As with Landsat 6, discussed in the previous section, the completion cost estimates do not include launches, test, or development costs. The \$3.1 billion budget does not include the development of the Columbus Pressurized Module which,

TABLE 3.1

ESA MEMBER COUNTRIES AND THEIR PRIMARY AGENCIES OF PARTICIPATION

| COUNTRY | PRIMARY AGENCIES OF PARTICIPATION | % SHARE |
|-------------|--|---------|
| Austria | ASA - Austrian Space Agency | 0.9 |
| Belgium | SPO - Science Policy Office | 4.0 |
| Denmark | Danish Space Committee Danish Space Research Institute Ministry of Education | 1.2 |
| France | CNES - Centre National d'Etudes Spatiales | 25.9 |
| Germany | BMFT - Bundesministerium für Forschung und Technologie (Coordinating Ministry) DLR - Deutsche Forschungs und Versuchsanstalt für Luft und Raumfahrt (Science & Technology Branch) DARA - Deutsche Agentur für Raumfahrtangelegenheiten (German Space Agency) | 23.8 |
| Ireland | Department of Industry and Energy | 0.2 |
| Italy | CIPE - Interministerial Committee for Economic Planning MRST - Ministry for Scientific & Technological Research PSN - National Space Plan | 15.4 |
| Netherlands | NIVR - Nederlands Instituut voor Vliegtuigontwikkeling and Ruimtevaart SRON - Netherlands Space Research Organization | 3.9 |
| Norway | Royal Ministry of Industry Norwegian Space Policy Committee Norwegian Space Centre NTNF - Norwegian Council for Scientific and Industrial Research | 0.8 |
| Spain | CDTI - Centre for the Development of Industrial Technology INTA - National Institute of Aerospace Technology | 3.2 |
| Sweden | SBSA - Swedish Board for Space Activities SSC - Swedish Space Corporation | 2.8 |

TABLE 3.1 continued

ESA MEMBER COUNTRIES AND THEIR PRIMARY AGENCIES OF PARTICIPATION

| COUNTRY | PRIMARY AGENCIES OF PARTICIPATION | % SHARE |
|----------------------------|---|---------|
| Switzerland | Federal Consultative Commission for Space Affairs | 2.0 |
| United Kingdom | BNSC - British National Space Agency Interdepartmental Official Committee on Space Policy | 13.3 |
| Canada (associate member) | Canadian Space Agency Industry, Science and Technology, Canada Department of Energy, Mines and Resources | 2.3 |
| Finland (associate member) | Supported by a Group of Agencies Including: The University of Helsinki VTT - The Technical Research Centre of Finland The Hollming Company The Companies of the Nokia Group | 0.2 |

Figure 3.4: Annual Space Expenditures
European Space Agency (ESA)

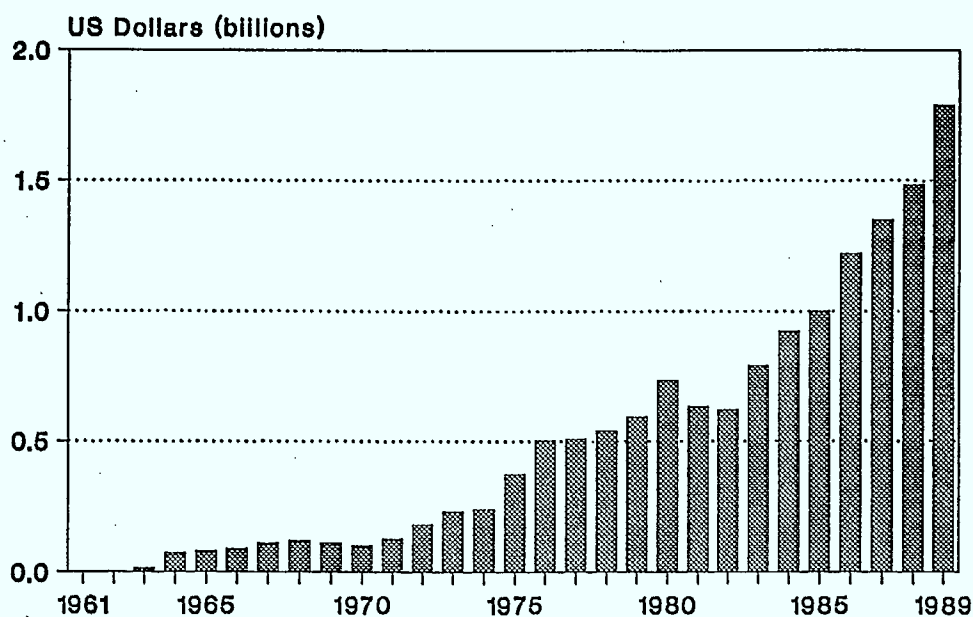
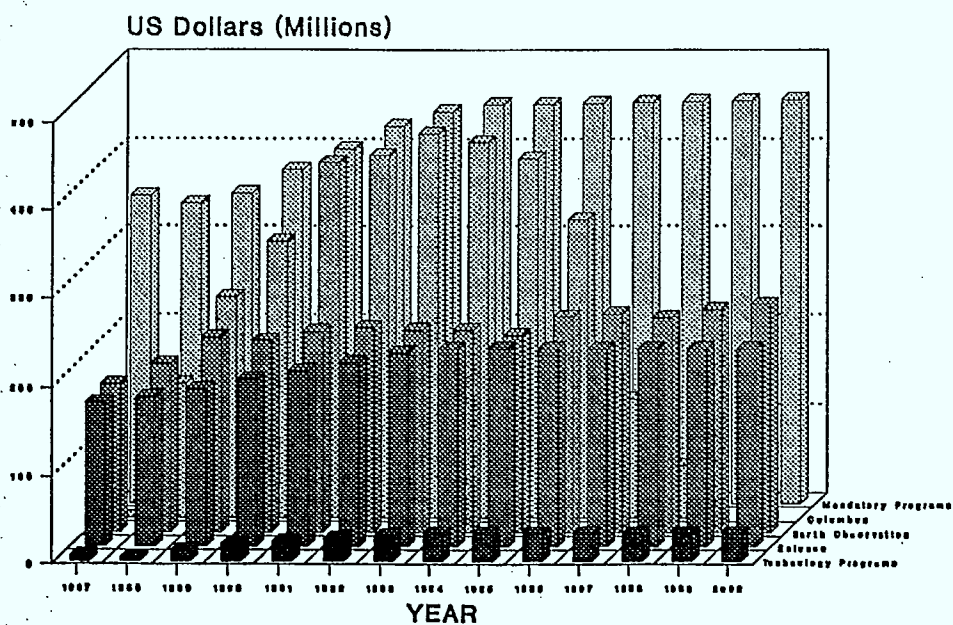


Figure 3.5: Planned ESA Expenditures
Remote Sensing And Science



from 1988 to 1998, is expected to cost \$3.3 billion³. In the satellite remote sensing field, Europe has established an excellent scientific base backed with heavy government research and development (R&D) funding and a mature aerospace industry. By providing the coordinating facility among European nations in space and launch facilities, the politically autonomous ESA network appears to have a positive commercial and economic future.

3.2.2.2 France

One of the primary competitors to the U.S. remote sensing satellite program is France with its series of SPOT (Système pour l'observation de la Terre) satellites. Within western Europe, France has the largest and most extensive national space program. The national agency which manages the bulk of the French space program and acts as distributor of the space budget is the Centre Nationale d'Études Spatiales (CNES). CNES proposes the annual space program budget which is generally funded through the Ministry of Industry and Research. Aside from remote sensing, CNES activities also involve the development of launch vehicles, telecommunications, and other varied endeavours including work on microgravity utilization. CNES has also initiated the formation of important commercially oriented ventures with specific emphasis on the French company SPOT Image. SPOT Image, with CNES as the largest shareholder possessing over one-third of the capital, is a semi-private corporation with a commercial structure. The French remote sensing earth observation program SPOT was initiated in 1978 in cooperation with Belgium and Sweden. The goal of SPOT Image as a commercial venture is to open new markets for satellite data on a much larger scale than is possible by a completely government owned organization. The initial capital of \$4.3 million was increased by \$4.2 million in 1984. Provided with this initial funding injection, SPOT Image is expected to be self-sustaining from the income from sales of remote sensing data from the first SPOT satellite, SPOT 1, and SPOT 2 launched in February, 1990. Sales from SPOT 1 imagery reached \$10.6 million in 1987 and \$13.9 million in 1988. The relatively good sales figures along with financial compensation received for the delayed launch of SPOT 1 should help finance the eventual launch of follow-on satellites. In these follow-on cases, SPOT Image will bear the costs of the basic operational payloads and its launch while all other developmental costs will be

financed by CNES. The estimated cost of each SPOT satellite is expected to be approximately \$300 million. This does not cover launch, development or test costs.

The overall French space budget in 1987, as shown in Figure 3.6, along with annual space expenditures from 1963 to 1989, was \$1 billion including \$400 million in payments to the European Space Agency (ESA). This leaves approximately 61% of the funds for use within France or for bilateral projects with countries outside ESA. This is quite different from the other western European countries who spend a higher percentage of their total budgets within ESA. Obviously, France places much greater emphasis on its national space programs and more importantly on its remote sensing earth observation industry primarily through SPOT Image and the SPOT series of earth observation satellites.

3.2.2.3 Federal Republic of Germany (FRG)

The Federal Republic of Germany (FRG), the prime contributor to the ERS projects with a cost involvement of up to 35 per cent, is privately involved in space programs designed to complement projects being carried out by ESA. There are three main areas which the FRG is presently pursuing and will continue to pursue over the coming decade. These projects include the development of launchers, recoverable platforms and microgravity experiments. To organize these efforts, plans are currently underway for the creation of a German Space Agency (DARA - Deutsche Agentur für Raumfahrtangelegenheiten). To emphasize Germany's commitment to space, one must only consider that the Germans have the second largest space budget in Europe, and spend more than 0.05% of its GNP on space. Figure 3.7 outlines Germany's annual space expenditures from 1962 to 1989, demonstrating the increase in its national space program, and, in turn, its contribution to ESA. Annual expenditures for 1988 were approximately \$842.2 million, with the present split being approximately 41% for national programs and 59% for European projects. Approval is presently being sought to increase space funding to \$1.345 billion during the 1990s, with an expenditure split of 35% for national and bilateral programs and 65% for ESA⁴. Germany also leads total ESA project contributions with a 25% share of the total budget costs.

Figure 3.6: Annual Space Expenditures
France

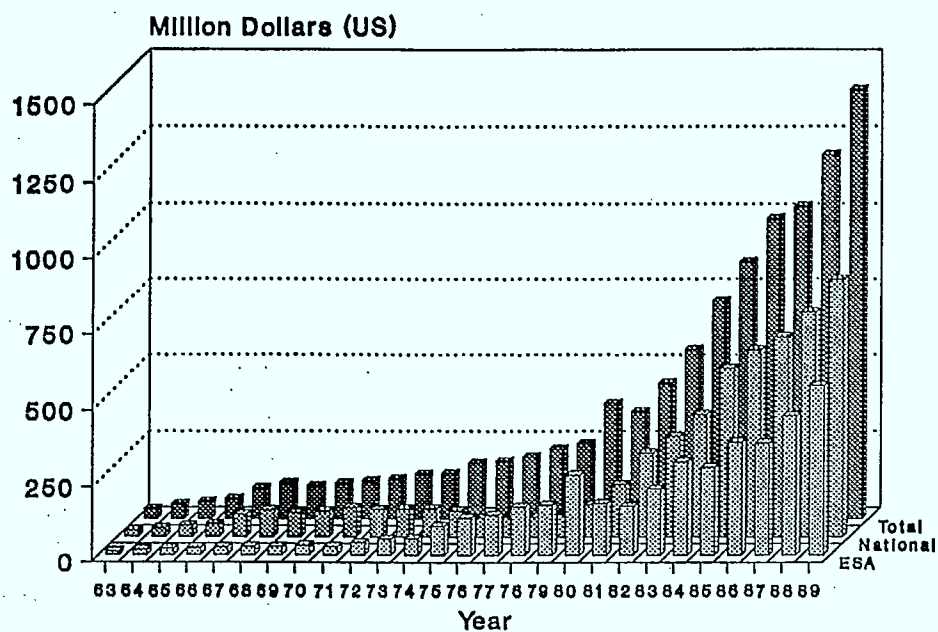
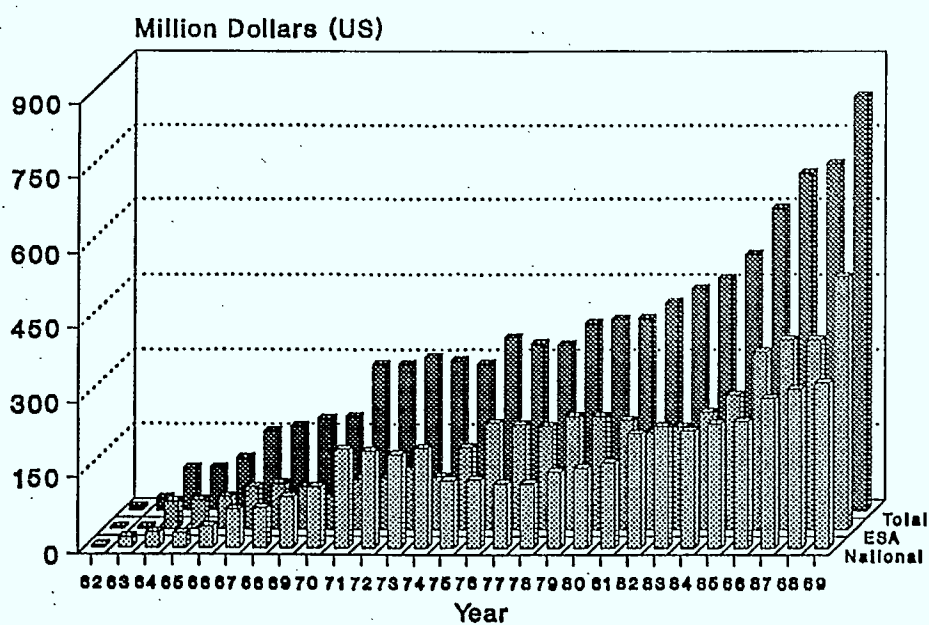


Figure 3.7: Annual Space Expenditures
Federal Rep. of Germany



3.2.2.4 Sweden

The Swedish Board for Space Activities (SBSA), which holds overall responsibility for space activities, delegates the executive tasks to the state-owned Swedish Space Corporation (SSC). The SSC oversees the remote sensing program which is one of four components of the national program; the other components being the space research program, the industrial development program and the management of the Esrange sounding rocket launch site. Along with these four components, the SSC also oversees programs involving international participation.

Swedish research groups are primarily focused on magnetospheric and ionospheric physics; the study of the upper atmosphere, astrophysics and the materials sciences. The largest program related to these research prerogatives was the scientific satellite Viking which was launched with the French SPOT satellite.

Remote sensing activities have concentrated on marine surveillance, ocean ice monitoring, atmospheric and water pollution monitoring, and vegetation mapping. Much of the SSC effort has been geared towards the use of SPOT information primarily as a result of Sweden's participation in the SPOT program.

Sweden's major remote sensing activity involves its association with ESA and SPOT. The Esrange Sounding Rocket Launch Site near Kiruna is managed by the SSC through an agreement with ESA, Germany, and France. Also at this same site is a Landsat/SPOT receiving ground station. The station is an integral part of ESA's Earthnet network.

Space program expenditures, shown in Figure 3.8, also reflect Sweden's involvement in ESA. National expenditures between 1985 and 1990 were approximately \$222.2 million which amounts to half of the Swedish space budget. The remaining expenditures of \$220.8 million between 1985 and 1990 were devoted to ESA activities. Future expenditure estimates are unavailable at this time.

Sweden also participates in Intelsat, Eutelsat, and Inmarsat. Although these programs are not reflected in the budgetary considerations above.

3.2.2.5 Italy and the United Kingdom

Of the remaining ESA members, Italy and the United Kingdom (UK) hold the next largest shares at 15.4% and 13.3% respectively (Table 3.1). Of the two countries, Italy has shown the greatest increase in space expenditures over the period

Figure 3.8: Annual Space Expenditures
Sweden

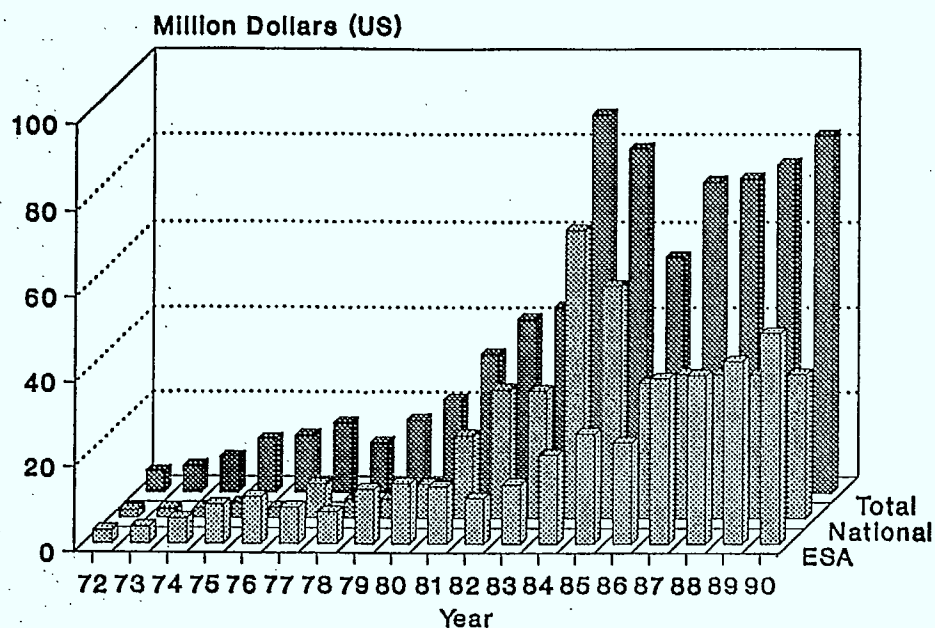
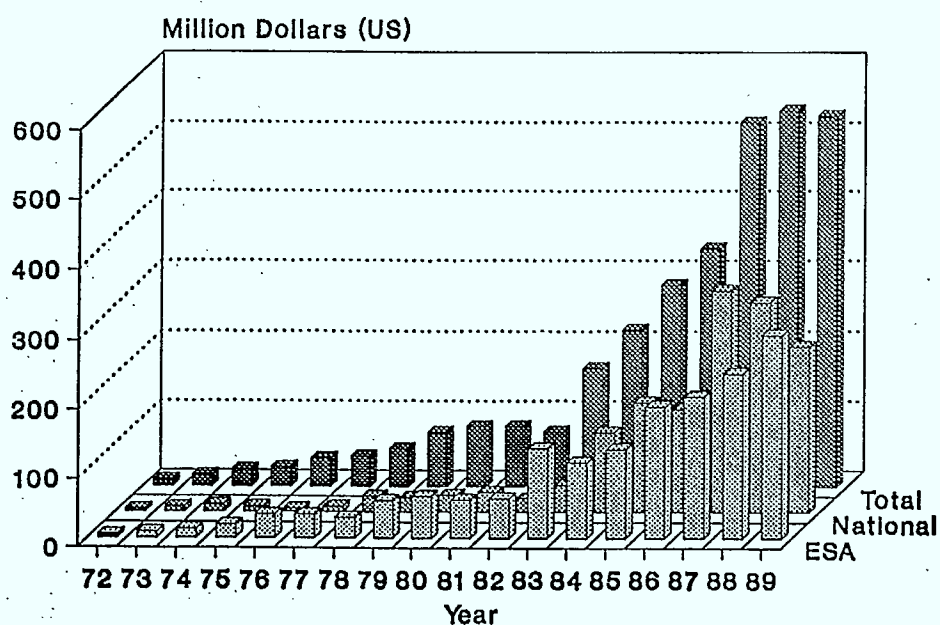


Figure 3.9: Annual Space Expenditures
Italy



of 1985 to 1989, as seen in Figure 3.9. The Italian National Space Plan (PSN), which was established by the government to provide a stimulus to industry and to establish a stronger Italian presence in ESA programs, has been subsequently replaced by the Italian Space Agency (ASI) formed in May of 1988. The present Italian five year plan, from 1987 to 1991, was provided a budget of \$1.28 billion, of which 9.1% was allocated to earth observation. Other Italian ESA involvement includes work on the Ariane, Columbus and Hermes programs.

The U.K., although a larger member of ESA, is more involved in the telecommunications satellite market and does not have an extensive impact on the remote sensing, earth observation satellite industry.

3.2.3 Japan

At present Japan must be viewed as one of the most rapidly growing remote sensing and earth observation industrial powers. Japan plans to approach the market via the launch of its own satellites as well as using foreign satellites for remote sensing applications. The future aim of the Japanese is to develop an internal space technology base which will be equally competitive with either U.S. or European industry. Over the next decade a significant increase is anticipated in Japanese capability in remote sensing.

Japan's initial space earth observation satellite, the Geostationary Meteorological Satellite (GMS), was launched in 1977, in cooperation with the U.S.A. Japan's first remote sensing satellite, developed by the Japanese National Aeronautics and Space Development Agency (NASDA), called the Marine Observation Satellite (MOS-1) was launched in February, 1987. It is the first of two planned MOS satellites. The second, MOS-1B, is scheduled for launch in late 1990.

NASDA is also developing the Japan Earth Resources Satellite (JERS-1). The intent of this satellite is to collect information on renewable and non-renewable earth resources. It is also planned for launch in 1990. The future Japanese plans are centred around the development of the Advanced Earth Observing Satellite (ADEOS) originally scheduled for launch in 1993 but current information indicates this program may be cancelled¹³. Its purpose was essentially to house several sensors including improved variations of those tested on JERS-1. In addition, Japan plans to launch the Japanese polar orbiting platform (JPOP) as part of the EOS system in 1998.

Japan also launched an Experimental Geodetic Satellite (EGS) in August, 1986. The satellite's purpose is to provide a variety of geodetic test services.

Expenditures on these projects will be considered as one value rather than as individual projects. Annual space expenditures by the Japanese from 1970 to 1988 are displayed in Figure 3.10. The total space activity budget in 1987 was \$850 million of which 12% or \$104 million was applied directly to remote sensing (i.e., the aforementioned projects)³. In 1988, the total budget dropped slightly to \$842 billion. Through the year 2000, the expected investment into space activities is \$48 billion. The percentage of the final figure devoted to remote sensing will likely increase slightly, possibly ranging up to 18 per cent.

3.2.4 Other Countries

3.2.4.1 India

The satellite remote sensing industry within India is directed by the Indian Space Research Organization (ISRO). This organization is the managing body responsible for the Indian remote sensing satellite (IRS) program which presently has one active satellite, the IRS-1 launched in March 1988 via Soviet launch facility. The predecessor to IRS-1 was a test vehicle called the SROSS-2 developed in conjunction with DLR, West Germany. Including the initial IRS satellite, six spacecraft are planned. The second satellite, IRS-2, is also to be launched from Soviet facilities while subsequent satellites will use the Indian PSLV, beginning in 1991. The PSLV launcher was developed for the primary purpose of placing remote sensing satellites in orbit. Two launch facilities are presently available in India with a third in the planning stages. India also possesses four tracking stations, three for telecommunications purposes and one which is a SPOT/Landsat tracking and receiving station.

Space remote sensing expenditures by the ISRO are at a level of over \$240 million per year. Total annual space expenditures are outlined in Figure 3.11. In summary, India must be considered as a valid competitor in the satellite remote sensing market, especially once the country establishes a broader market. However, this may take some time resulting in a market remaining localized within Indian/Soviet borders.

Figure 3.10: Annual Space Expenditures
Japan

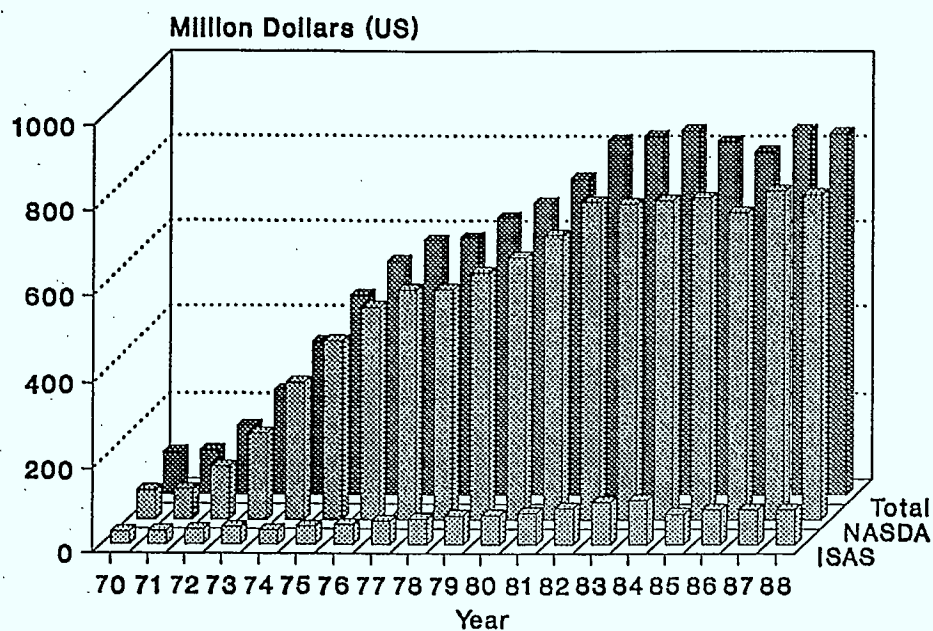
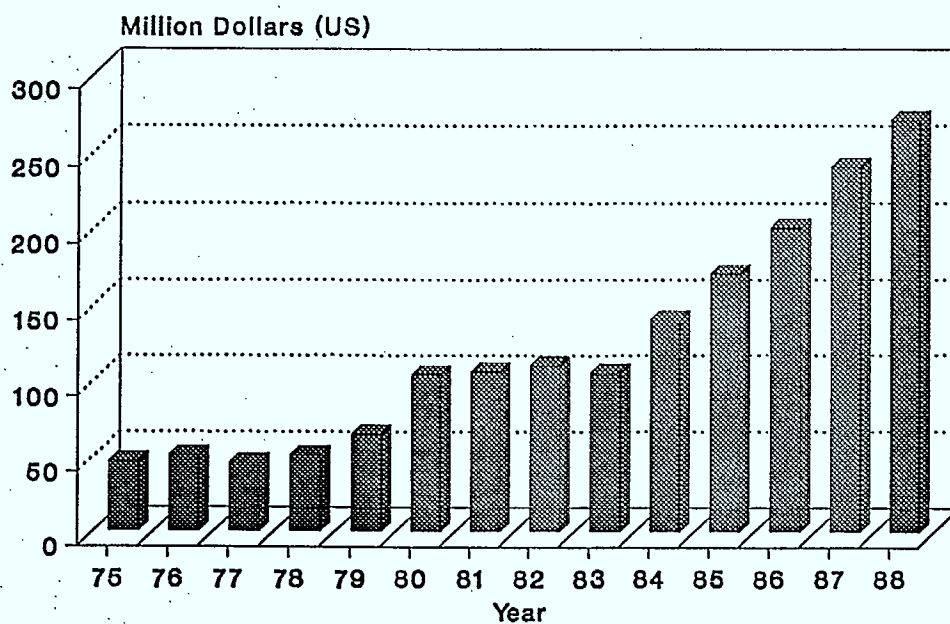


Figure 3.11: Total Space Expenditures
India



3.2.4.2 Brazil

Initiated in 1965, the Brazilian space program turned toward the remote sensing earth observation satellite industry in 1979 with the establishment of the full Brazilian space program, MECB (Missao Espacial Compelta Brasileira). Brazil presently has two primary launch facilities as well as a SPOT/Landsat receiving station in Cuiaba. These facilities will be directly linked to the development and implementation of two earth observation satellites which are being prepared for launch between 1989 and 1993. A Chinese/Brazilian remote sensing satellite is one of the earth observation projects in preparation for launch in 1993. The overall cost of the MECB space program for the 1983-1993 period is estimated at \$1 billion. Two-thirds of this is to be allocated to the development and construction of the VLS launcher and the Alcantera launch base. The remaining third is for the development of the two planned earth observation satellites and two satellites to be deployed for the purpose of collecting ARGOS type information. These expenditures are based on a constant expenditure of \$60 million per year based on 1981 values.

3.3 Structure of the International Supply Base for Remote Sensing Technology and Services

The international supply base for remote sensing and earth observation systems and services is primarily concentrated in the major space faring western nations; namely, U.S.A., Europe, and Japan. Other nations such as Canada, Australia, India, and Brazil have a smaller capacity. The U.S.S.R. and China do not represent a source of supply for this type of technology at this time. In spite of Japan's capability, the majority of its production is used internally. The following sections detail the composition of the supply base according to the three industrial sectors defined previously.

3.3.1 Satellite Systems

This sector of the industry is most heavily dominated by firms located in the United States such as Hughes, General Electric, Ball Aerospace, Martin Marietta, Boeing, Rockwell, Lockheed and TRW. This is a logical consequence of the extensive history of remote sensing missions funded by that country. To date the U.S.A. has launched the majority of all experimental and operational satellites for meteorological and earth remote sensing. By comparison, Europe and Japan have only recently begun to build and launch their own remote sensing systems. The early versions were based mainly on existing American designs. Except for the U.S.S.R. and possibly China, no other country or economic unit has demonstrated these specific capabilities. In Europe, the main firms are Dornier and MBB in West Germany,

Aerospatial and Matra in France, Fokker from The Netherlands, and Marconi and British Aerospace from the U.K. In Japan, the main companies involved in satellite systems are Toshiba, NEC, Mitsubishi and Hitachi.

Other countries have developed capabilities in building other types of satellites primarily for communications or experimental applications and these technologies can be applied to remote sensing systems. Nations such as Australia, Canada, Israel, and South Africa all have some form of capability in the production of space qualified systems which may be applied to earth remote sensing. In addition, some developing countries have progressed to the level of providing electronic and structural components such as integrated circuits. These countries, such as Thailand, Malaysia, Korea, Taiwan, Singapore, and Indonesia could potentially develop the infrastructure to supply complete subsystems.

Certain crucial technologies are only to be obtained in the three major centres; namely, the U.S.A., Europe, and Japan. These include attitude sensing systems such as horizon and sun sensors, reaction control systems, and platform or bus designs. The primary reason for this semi-monopoly is that these technologies are very expensive to develop and they are available at a relatively low cost from U.S., Japanese, and European firms. This situation acts as a disincentive for other countries to promote the development of these technologies. Instead the smaller nations have concentrated on communications, telemetry, primary sensors, and power supply systems to name a few.

3.3.2 Ground Receiving Systems and Data Distribution

This sector is divided into suppliers of ground based systems and owners of these systems. As a supplier of data reception systems, Canada competes with the U.S.A., Europe, and Japan. In fact, outside of the U.S.A., Canada is the major supplier of remote sensing ground receiving stations through MacDonald Dettwiler (MDA). A similar, although less dominant, situation exists in the supply of ground stations for non-remote sensing systems. The other leading suppliers for remote sensing ground stations are MS2i, in France, STX in the U.S.A. and Hitachi from Japan.

In terms of data supply from existing stations, a number of countries participate in this industry, usually through government-owned centres (Table 3.2). Figure 3.12 illustrates the location of these stations.

The two major suppliers of remote sensing data are EOSAT and SPOT Image Corporation. These firms allow the reception and distribution of their respective satellites'

TABLE 3.2: LOCATIONS OF MAJOR GROUND RECEIVING STATIONS

| Location | Country | Landsat | SPOT | Other |
|----------------------|--------------|---------|------|-------|
| Mar Chiquita | Argentina | x | | |
| Alice Springs | Australia | x | x | x |
| Cuiaba | Brazil | x | x | |
| Gatineau | Canada | x | x | x |
| Prince Albert | Canada | x | x | x |
| Beijing | China | x | | |
| Quito | Ecuador | x | x | |
| Fucino | Italy | x | x | x |
| Kiruna | Sweden | x | x | x |
| Maspalomas | Spain | x | x | x |
| Hyderabad | India | x | x | x |
| Jakarta | Indonesia | x | | |
| Tokyo | Japan | x | x | x |
| Islamabad | Pakistan | x | x | |
| Riyadh | Saudi Arabia | x | x | |
| Johannesburg | South Africa | x | x | |
| Bangkok | Thailand | x | x | x |
| Goddard Space Centre | USA | x | | x |

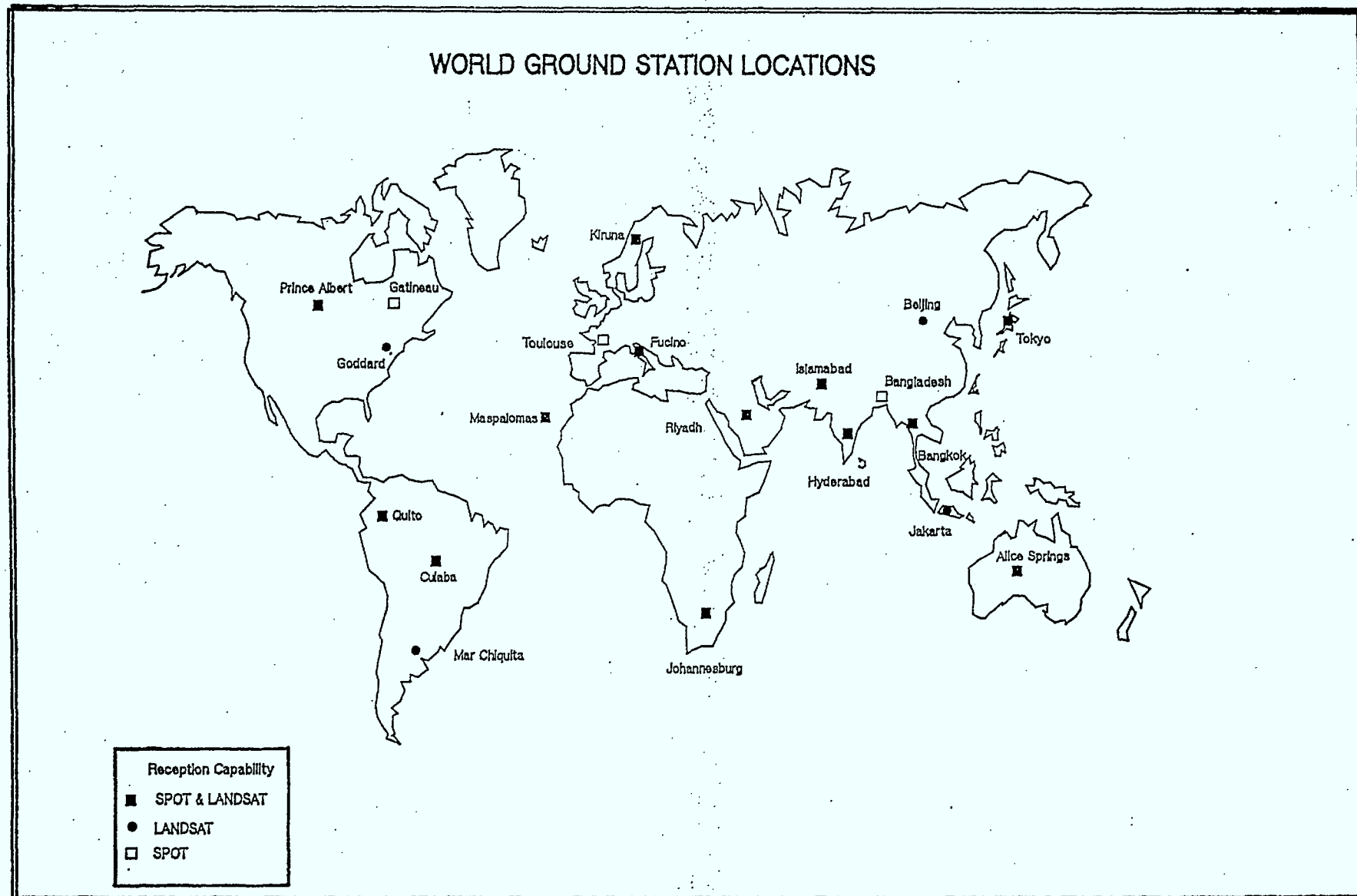


FIGURE 3.12

data by the national centres in return for a yearly licensing fee. The centres are limited to the distribution of imagery in their area of coverage only. For instance, CCRS can not distribute imagery of Africa.

One technology that may affect the supply structure is the use of data relay satellites such as the U.S. TDRSS system. This satellite allows EOSAT to receive Landsat data from most parts of the world directly rather than relying upon foreign ground stations. The system is not heavily used at present due to the cost of operation, however, if a remote sensing satellite was developed for which a heavy demand existed, exclusive downlinking of the imagery through the TDRSS or a similar system would allow the owner to control all sales and probably turn a healthy profit.

3.3.3 Value Added Services

The value added industry is divided into suppliers of equipment and software for the enhancement of remotely sensed imagery, and the firms which perform the actual image interpretation and enhancement who are usually customers of the first group.

Major equipment and software companies include Intergraph, PCI, I²S, and Erdas, while value added companies include Nigel Press of the U.K., Geospectra and Earthsat Corp. of the U.S.A., and GAF of the Federal Republic of Germany. France has GDTA and SPOT Image who act as Value Added Resellers (VARs). In Japan, Japex Geoscience provides services, equipment and software.

In these industries, Canada and Australia compete with the major players. Japan and the U.S. generally tend to service their internal markets with little attempt to generate foreign sales. In terms of the market for value added services, the U.S. is the largest and therefore, the majority of firms offering these services are concentrated there. Outside of the major countries, there are relatively few service companies although many national remote sensing or research centres have the capability to perform various levels of enhancement. In some countries, these centres perform all the value added work required by their governments.

3.4 International Demand for Earth Observation and Remote Sensing Data

From information on countries or groups most dominant within the remote sensing market (Section 3.2), international demand for the associated data can be evaluated. The data demand has increased as applications become more operational and the awareness of remote sensing technology increases. SPOT Image, for example, who are one of the primary market players, recorded sales in

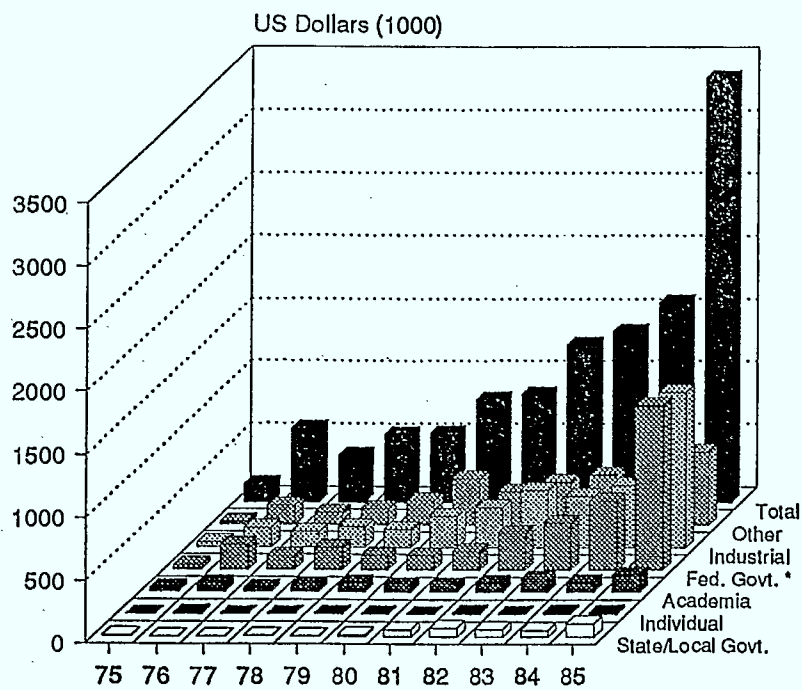
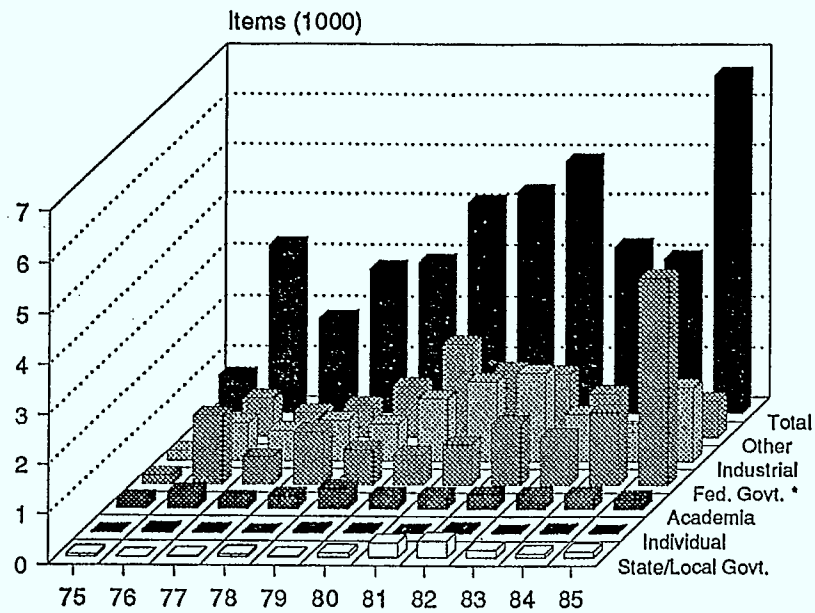
1987 of \$10.6 million and \$13.9 million in 1988³. Sales for 1989 have been reported at \$22 million. EOSAT, another prime player, recorded raw data sales of Landsat imagery of \$15 million in 1988. Figure 3.13 provides an example of digital imagery sales only for the US market⁶. Although only available to 1985, the sales of data, in terms of dollar values, have been increasing. Similar data for photographic image products sales (Figure 3.14) has been decreasing, while the number of digital imagery data items has begun to increase after a drop in 1983 and 1984 which was related to a price increase. This potentially suggests that the end user of the data is becoming more interested in obtaining variations of processed image data, as opposed to photographic data which do not allow for as much processing freedom. In addition, with the affordability and availability of personal computer (PC) based image processing systems, the increase in digital data sales versus a decrease in photographic products may be related to more companies purchasing and processing their own data. However, more recent data, as well as more of an international data set of the products sold would assist in the clarification of these interpretations.

It is estimated that EOSAT and SPOT Image dominate the remote sensing data market with shares of between 20 and 30%, while the other data suppliers; namely NOAA, IRS and MOS share the remaining market. Both SPOT and EOSAT regard information on sales volumes as commercially confidential, although they claim that total sales are growing at a rate of approximately 20% per year. IRS and MOS data are almost exclusively used domestically within India and Japan, respectively. Recent information available from EOSAT indicates that RESTEC had doubled the volume of Landsat imagery sales in Japan since the previous year⁶. Obviously, at the present time there is a strong market in Japan for remotely sensed imagery.

The primary difficulty in assessing the Japanese market and its associated potential is that at this time Japan has not published a policy regarding the commercial marketing of their data. It is expected that much of the Japanese market will remain domestic in the future, with data being provided for users at low prices or possibly cost free, simply for the internal promotion of the data. Expectations for the surrounding international market, at this time remain very unclear, although any market agreements emanating from Japan will be established solely for the purpose of Japan's own market potential. A current study by Geosat Committee Inc. is investigating the potential marketability of JERS data and providing recommendations to Japan. Therefore, the Japanese are considering marketing these data.

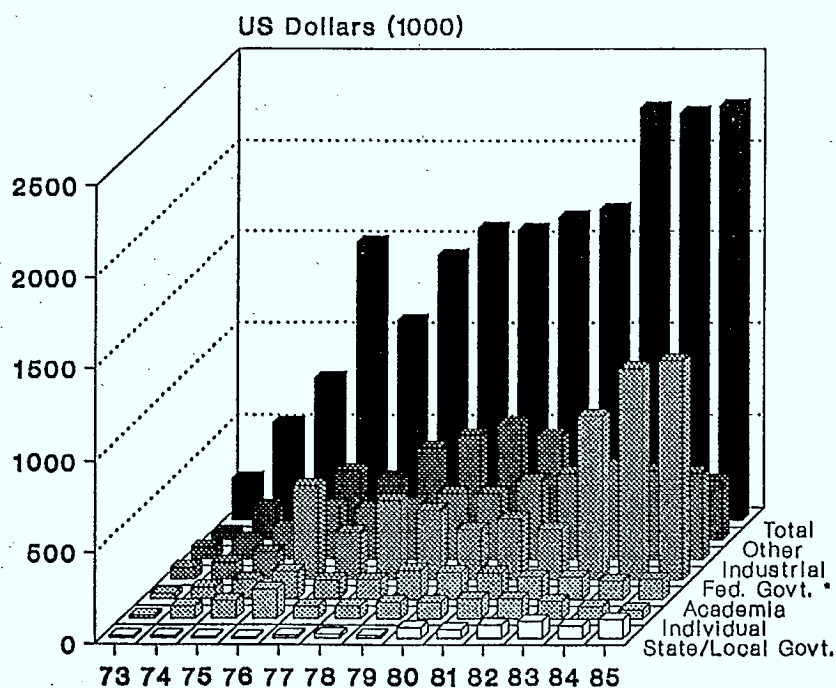
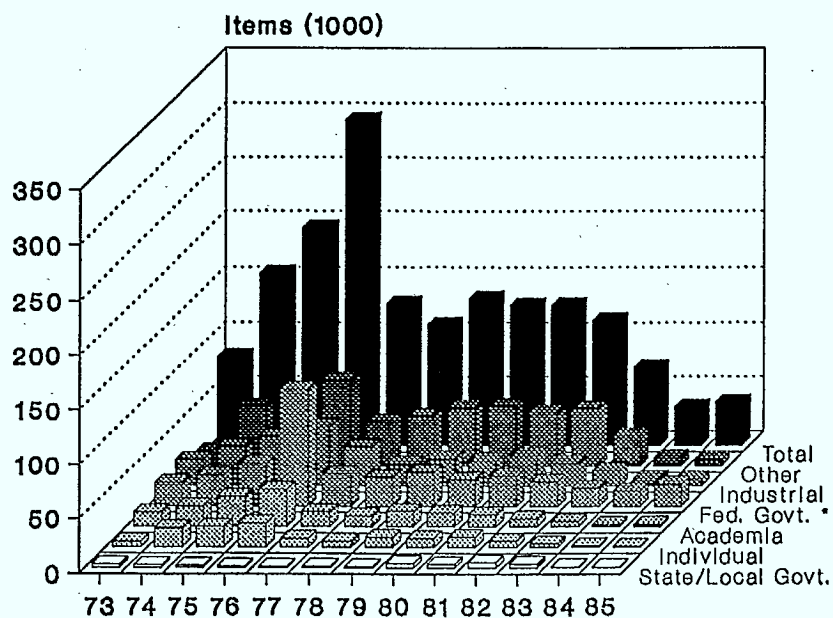
India, like Japan, uses IRS data exclusively for its own purposes. However, recently India announced that some of these data can be obtained for experimental purposes at a low cost⁹. If India

Figure 3.13: U.S. Digital Imagery
Data Sales 1975 - 1985



* Includes NASA Investigator (75 - 78)

Figure 3.14: U.S. Photographic Imagery
Data Sales 1973 - 1985



• Includes NASA Investigator (75 - 78)

did not have its own earth observation satellite, there is little doubt that SPOT and EOSAT sales would be higher in this country.

Overall, data are being purchased by a variety of organizations. Major purchasers are government agencies as is to be expected in a market which is predominantly run through government involvement and subsidies. A prime example of such an agency is the U.S. DoD, which also reflects the predominant and yet unpublicized, military component of the market. It is suspected that defence agencies in other countries are also major data purchasers.

In Canada, data were purchased through the CCRS until this year when Radarsat Inc. of Calgary began marketing this information. Data are still received at the Prince Albert, Saskatchewan, and Gatineau, Quebec, receiving stations.

3.5 Current Uses of Available Data

Satellite remote sensing data currently available for civilian use are listed in Table 3.3. Each of these data types is described in the following sections.

3.5.1 Space Photography

3.5.1.1 Mercury/Gemini/Apollo Photographs

The first spaceborne platform to acquire images of the earth for civilian purposes was implemented during the Mercury program. From 1961 to 1963, Mercury acquired over 400 photographs. This program was followed by the Gemini mission which acquired 2520 photographs between 1965 and 1966⁸ and used various films and lenses on a Hasselblad and Maurer 70 mm format cameras. The Apollo program permitted the testing of unmanned remote sensing systems in multispectral bands. During the Apollo flights 2138 photographs from hand-held cameras and an unmanned remote sensing system were acquired. These programs led to the realization that useful data about the earth's surface could be acquired from space. In particular, geological and meteorological information could be obtained and an assessment of the effects of human activities on earth could be made.

3.5.1.2 Skylab

One of the primary objectives of the Skylab program was to perform earth resource experiments. These experiments involved testing cameras, multispectral scanners, a pointable spectrometer, and microwave devices. A total of 40,767 photos were acquired during the Skylab missions⁸.

TABLE 3.3

SUMMARY OF AVAILABLE SATELLITE DATA

| SATELLITE | SENSOR | ORIGINATING COUNTRY | APPLICATION |
|---------------------------|--|---------------------|-------------------------------|
| Mercury/Gemini/Apollo | Hand Held Camera | USA | Earth |
| Skylab | Hand Held Camera, MSS | USA | Earth |
| Apollo/Soyuz | Hand Held Camera | USA/USSR | Earth Oceans Atmosphere |
| Space Shuttle Photography | Hand Held Camera Metric Camera Large Format Camera | USA | Earth Oceans |
| Soviet Photography | KFA 1000 + MK4 Camera | USSR | Earth |
| Landsat | RBV MSS TM | USA | Earth |
| SPOT | PLA MLA | France | Mapping Oceans Earth |
| MOS-1 | MESSR VTIR MSR | Japan | Earth Ocean Atmosphere |
| IRS | LISS 1 LISS 2 | India | Earth |
| Seasat | SAR | USA | Oceans Earth |
| Kosmos | RAR | USSR | Oceans |
| Space Shuttle | SIR-A + B MOMS SMIRR | USA FRG USA | Earth Oceans |
| HCMM | HCMR | USA | Earth Oceans |
| NOAA | IR | USA | Atmosphere |
| NIMBUS | CZCS | USA | Oceans |
| GOES/SMS | VISSR | USA | Atmosphere |
| Himawari | VISSR | Japan | Atmosphere |
| Meteosat | VISSR | Europe | Atmosphere |

3.5.1.3 Apollo/Soyuz

This mission was a joint U.S.A./U.S.S.R. project to improve relations and to establish policies and procedures for further cooperation. During the mission, 751 photos were taken⁸. Investigations performed included geology, land use mapping, land cover, coastal sedimentation, oceanography, and meteorology.

3.5.1.4 Space Shuttle Photography

During the space shuttle missions from 1981 to 1986, a total of 38,176 photographs were acquired⁸. The photographs were obtained using three types of cameras; a Hasselblad hand-held 70 mm, a 230 mm metric camera, and a large format camera. The Hasselblad camera uses three lens sizes; a 50 mm lens resulting in a spatial resolution of 150 metres, a 100 mm lens providing 80 metre resolution, and a 250 mm lens giving a resolution of 30 metres. The metric camera was flown for cartographic applications and provides a ground resolution of 3 metres. The large format camera was flown infrequently and provides products similar to the metric camera. With all three cameras, a variety of film types and filters have been used.

3.5.1.5 Soviet Photography

Not much information is available regarding Soviet photography, however, the Soviets are known to have used MKF-6M or Kate 140 multiband black and white camera systems. Unlike U.S. photography, these products are not available. In 1989, Soyuzkarta began marketing products from the KFA1000 and the MK4 cameras. The KFA1000 has a 5 metre spatial resolution and is recorded on panchromatic or spectrozonal colour film. The spectrozonal film records light in the 570-670 and 670-810 nm range. The MK4 is a multispectral cartographic camera with a 6 metre spatial resolution. It is available in black and white or false colour formats¹⁴. Unfortunately, it was reported that in January 1988 the satellite assigned to Soyuzkarta was detonated due to technical problems. Since that time the only photography available to Soyuzkarta has been obtained from the MIR Space Station⁹. Photography of any non-communist country is available for purchase from Soyuzkarta.

3.5.1.6 Photography Summary

The main advantages of U.S. photography are the easy access to the imagery if on a limited budget and the fact that it is in the public domain. The cost of these data is less than digitally produced hard copies of SPOT or Landsat images and it is surprising that it is used less frequently. In 1985, EROS Data Centre reported 90% of Landsat data purchases as photographic rather than digital products⁸.

3.5.2 Unmanned Satellite Data

3.5.2.1 Landsat

Since 1972, five Landsat satellites have been launched. Only Landsats 4 and 5 remain in operation at this time. The current orbiting parameters for Landsats 4 and 5 involve a near polar sun synchronous orbit which has a 9:30 a.m. descending equatorial crossing. They have an altitude of 705 km and complete 14.56 orbits per day at 98.9 minutes per orbit. The same area on the earth is covered once every 16 days for one satellite.

The first three versions of Landsat contained the Return Beam Vidicon sensor (RBV). The RBV was essentially a video camera which imaged a scene 185 x 185 km and captured a scene every 25 seconds to provide continuous imagery along the satellite track.

All five versions of Landsat have contained the multispectral scanner (MSS). This sensor is still functioning on Landsats 4 and 5. It has a spatial resolution of 80 m and records data in four spectral bands. Landsat 3 contained an additional thermal band with a spatial resolution of 237 x 237 metres.

The Thematic Mapper (TM) sensor was implemented on Landsat 4 and is also on Landsat 5. This sensor has seven spectral bands including one in the thermal infrared range. All bands have a spatial resolution of 30 m x 30 m with the exception of the thermal band which produces a resolution of 120 x 120 m. Data from the Landsat satellites are available from EOSAT in Maryland and the EROS Data Centre in South Dakota as well as from 16 nationally owned ground receiving stations located throughout the world (Table 3.2). In 1986, distribution of Landsat data was transferred to a private commercial organization called EOSAT which was created by a consortium consisting of Hughes Aircraft Company and General Electric. Landsat has been an important earth observation program and its data have been extensively

utilized in most of the earth study fields, particularly those dealing with natural resources.

3.5.2.2 SPOT

SPOT has been providing 10 m resolution panchromatic and 20 m resolution multispectral data since being launched in 1986. The sensors are composed of charge couple devices (CCDs) operating in a pushbroom fashion. The ground swath width is 60 km and may be acquired in a stereo mode because of the system's ability to steer the reflecting mirror, thus providing imagery to either side of the satellite track. The satellite is in a sun synchronous orbit and crosses the equator at 10:30 a.m. Repeat coverage occurs every 26 days although because of the ability for off nadir viewing, repeat cycles as little as 5 days can be obtained. Presently two SPOT satellites are operational the second having been launched in February, 1990. Data are presently received in France, and a number of other countries. In order to receive SPOT imagery, upgrades to existing Landsat stations are being conducted in several countries.

SPOT has been used for a variety of earth studies. Because of its resolution, it is primarily used for urban planning, mapping, and engineering. The stereo capability of the imaging sensor is useful for the creation of digital elevation models (DEM). Due to the limited spectral resolution of the multispectral linear array, SPOT is not an ideal sensor for vegetation studies, hydrology, or the other earth science applications, although some geological studies have been completed using SPOT data.

3.5.2.3 MOS-1

Japan launched the marine observation satellite (MOS-1) in 1987. This system is currently being used to monitor water and air pollution, agriculture, marine and water resource use, and forestry. The MOS-1 satellite is equipped with the following sensors:

1. Multispectral electronic self-scanning radiometer (MESSR) which is similar to the Landsat MSS sensor.
2. Visible and thermal infrared radiometer (VTIR).
3. Microwave scanning radiometer (MSR).

In addition to Japan, there are several ground stations that receive these data. These stations are located in the U.S.A., Sweden, France, Thailand, and Canada.

3.5.2.4 Indian Remote Sensing (IRS) Satellite

The IRS satellite provides agricultural, geological, and hydrological data and is used for surveying and managing India's resources. This satellite serves as a direct competitor to SPOT and EOSAT in India. The satellite has two sensors; the linear imaging self-scanning sensor 1 and 2 (LISS-1 and LISS-2). These data are limited to domestic use, but current information indicates plans to make some imagery available to other countries⁹. Both LISS-1 and -2 have four channels with a spectral range of from 0.45 to 0.86 micrometers. LISS 1 has a 73 metre spatial resolution, while LISS 2 provides 36 metre pixels. The swath for both sensors is 148 km.

3.5.2.5 Seasat

Seasat was an imaging radar system. It was launched in 1978 and failed after a short three month operation. Imagery was acquired over 125,000,000 km² of the earth's surface. The synthetic aperture radar had an L-Band Horizontal Transmit and Horizontal Receive (L-HH) configuration and acquired imagery with a resolution of 25 metres. Seasat was primarily used for ocean and ice applications but monitoring of vegetation changes and geology was also performed. Seasat data are available from NOAA in the U.S.A. and CCRS in Canada.

3.5.2.6 Kosmos

The Soviet Union launched Kosmos 1500 in 1983 and Kosmos 1870 in 1987. Kosmos 1500 was the first Soviet satellite equipped with all weather radar. Both satellites carry a real aperture X-band imaging radar although Kosmos 1870 has a much more improved version of the sensor flying on Kosmos 1500. These data were used primarily for ice reconnaissance. Data were distributed to a combined total of 500 ships and earth stations. Recent reports indicate the U.S.S.R. may be intending to market Kosmos data internationally⁹.

3.5.2.7 Heat Capacity Mapping Mission (HCMM)

This system was designed to acquire data on surface temperatures and was operational from 1978 to 1980. It had a sun synchronous orbit ascending across the equator at 2 o'clock p.m. and descending at 2 o'clock a.m. Image spatial resolution varied from 0.6 to 1 km and the spectral resolution was 0.5 to 1.1 and 10.5 to 12.5 micrometers. The acquired data were applied to geological and vegetation mapping, snow and ice melt prediction, and monitoring of industrial pollution. Although these

data are still available from NOAA, their usefulness may be limited due to a lack of available ground data to relate to the conditions at the time of acquisition.

3.5.3 Space Shuttle Sensors

3.5.3.1 Space Shuttle MOMS

The West German built modular opto-electronic multispectral scanner (MOMS) was tested aboard an early 1984 shuttle mission. It uses an array of charge coupled devices (CCDs) operated as a pushbroom sensor. This sensor was used experimentally and has not been marketed commercially.

3.5.3.2 Shuttle Multispectral Infrared Radiometer (SMIRR)

SMIRR was a non-imaging spectral radiometer. This sensor provided useful information to geologists. It measured 10 wavelengths of reflected radiation over the range of 0.5 to 2.4 μm with the experimental objective being to determine if it was possible to discriminate between various rocks and minerals from space.

3.5.3.3 Shuttle Imaging Radar - A (SIR-A)

The SIR-A sensor was flown on the second flight of the space shuttle in 1981. This synthetic aperture radar provided active microwave imagery covering 10 million km^2 . The imagery was optically recorded on film and none was acquired over Canada. SAR imagery was recorded in an L-HH configuration providing a 50 km wide swath with a resolution of approximately 40 meters. One of the more notable applications of this imagery was the detection of buried stream channels in the Sahara desert. Other applications included forest mapping in cloud covered tropical regions and various geological studies.

3.5.3.4 Shuttle Imaging Radar B (SIR-B)

The SIR-B mission flown in 1984 was similar to the SIR-A experiment. The imagery was also acquired in L-HH configuration but was recorded with a digital data system and processing facility onboard the space shuttle. Swath widths varied between 20 and 50 km. The image resolution was 25 metres in azimuth and 17 to 58 metres in range. A total of 65,000,000 km^2 was imaged including portions of Canada. Applications for SIR-B imagery included the demonstration of the ability of radar stereo imagery to observe ocean dynamics as well as similar applications to those of the SIR-A imagery. Access to SIR-B imagery is generally restricted to federally funded/cooperative researchers¹⁰.

3.5.4 Meteorological Satellites

The study of atmospheric processes and the prediction of severe weather anomalies were the first applications of spaceborne remote sensing. At present a number of operational satellites provide weather data for the majority of the world.

3.5.4.1 Polar Orbiting Satellites

The polar orbiting satellites used for meteorology are usually in low orbit from 800-1500 km above the earth's surface. At this altitude, they cover the globe 12 to 14 times each day. Typical examples of these satellites include the NOAA series and the earlier TIROS and ITOS. TIROS was a Television InfraRed Observation Satellite. ITOS was an improved version of TIROS. It was developed to monitor night and day weather conditions on a global scale. ITOS contained a very high resolution scanning radiometer to record cloud cover data and a vertical temperature profile radiometer to collect data above and below clouds.

Later, Nimbus satellites were used to test meteorological and remote sensing sensors. The coastal zone colour scanner (CZCS) was included on the Nimbus series. The CZCS on Nimbus 7 was used to measure chlorophyll concentration, sediment distribution, and general ocean dynamics including sea surface temperature. The NOAA advanced very high resolution radiometer (AVHRR) was designed to provide data for hydrologic oceanographic and meteorological studies. However, the data has also been used to monitor the earth's surface conditions. These data are available from NOAA.

3.5.4.2 Geostationary Satellites

These satellites have been launched by the U.S.A., U.S.S.R., ESA, and Japan for global atmospheric monitoring. The primary sensor is a visible and infrared spin scan radiometer (VISSR). These satellites include the GOES/SMS (Geostationary Operational Environmental Satellite/Synchronous Meteorological Satellite) that orbits at 35,800 km. Japan operates a GMS (Geostationary Meteorological Satellite) known as Himawari. Europe operates the Meteosat system, while the U.S.S.R. operates the METEOR system. All satellite data with the exception of the Soviet data are available. Recent literature indicates the Soviet Union will market METEOR data in the near future⁹.

3.5.4.3 Summary

Generally all of the data described are available with the exception of early polar orbiting meteorological satellites. Nimbus CZCS data are still available. The quality of data may not be of scientific use due to the archive media life span of 10 years. This is a critical problem at present with the concern of global warming since an important data base may be lost. Efforts are presently being conducted in order to preserve some of these data. It is possible these data will be transferred to optical disks for future preservation.

3.6 Future Remote Sensing Satellite Data Acquisition Programs

3.6.1 General Introduction to Future Remote Sensing Programs

The 1990s appears to be a productive decade if all of the scheduled programs, as shown in Figure 3.15 are successful. In the following sections, the future commercial, experimental and domestic programs are discussed.

Commercial satellites refer to those systems in which data can be purchased from data distributors such as EOSAT or SPOT Image. In this section the U.S.A., France, ESA and Canada are primary players who will be involved over the next decade.

The U.S.A. plans to launch Landsat 6 in 1991, France has launched SPOT 2 and has plans for SPOT 3, 4, and 5 during the 1990s. ESA will be launching ERS-1 in late 1990 providing the first commercially available satellite radar imagery since Seasat. Canada will be completing in this market in 1994 when Radarsat will be launched. The U.S.S.R. has announced intentions of marketing their radar imagery, and Japan is presently investigating commercial aspects for JERS imagery. Brazil may also be involved in the commercial distribution of data.

Experimental imaging programs include SIR-C and EOS. Experimental geophysical remote sensing programs include TOPEX/Poseidon, Geopotential Research Mission, Aristoteles, Magnetic Field Explorer and Laser Geodynamics Satellite. An atmospheric satellite experiment is the Tropical Rain Explorer Mission. The countries involved include Italy, France, the U.S.A. and Japan. Data from experimental programs are not likely to be available since these missions are designed primarily for research.

Domestic satellites are used primarily within a country. For example, MOS-1B, JERS and ADEOS are all systems which will be used primarily by Japan. India will use IRS-1B although some data may be available to external research organizations.

FUTURE EARTH OBSERVATION PROGRAMS AND THEIR EXPECTED PERIOD OF ACTIVITY

| COUNTRY/ GROUP | FIELD | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|-------------------|------------|--------------------|----------------------|--------------|-------------------------------|---------------------------|-------------|---------------------------------|----------------------------|-------------|-----------------------|
| ESA | Atmosphere | x MOP 2 | | | x MOP 3 | | | | | MSG * ? | |
| | Land | ERS 1 x | | | | Aristoteles * ? | | | * EPOP 1 | | |
| | Ocean | * ? MFE | | | | ERS 2 * ? | | | | | EPOP 2* (MID 2000) |
| FRANCE | Land | o SPOT 2 | | SPOT 3 x | | | SPOT 4 * | | | | SPOT 5 * |
| | Ocean | | Posidon (TOPEX) x | (France/USA) | | | | | | | |
| INDIA | | IRS 1B x | | IRS 1C x ? | | | | | | | |
| JAPAN | Atmosphere | | | | | GMS 5 x ? | | | * ? TREM (USA/Japan) | | |
| | Land | | | JERS 1 x | | ? | | | | | |
| | Ocean | MOS 1b x | | | | * ADEOS | | | | JPOP 1 * | |
| U.S.A. | Atmosphere | GOES I x | GOES J x | x GOES K | NOAA K x | | | GOES L x ? | GOES M x ? | | |
| | | NOAA I | UARS x | x NOAA J | | | NOAA L x | NOAA M * | | | |
| | Land | | Landsat 6 x | | SIR C x | GRM SIR C x * ? | | | | | |
| | Ocean | | TOPEX (Posidon) x | (France/USA) | | * ? Landsat 7 | x SIR C | * ? TREM ↓ (USA/Japan) | * NPOP 1 | * NPOP 2 | |
| | | | | | | | | | | | |
| OTHERS | Atmosphere | | | | (China/Brazil) BRESEX x | | | | | | |
| | Land | | | | x | | | | | | |
| | Ocean | x SAR (USSR) | ? | | LGS (Italy) | x Radarsat (Canada) | | | | | |

NOTE: o operational x under development * planned ? period of activity unknown

FIGURE 3.15

Within the meteorological program, Japan, the U.S.S.R. and the U.S.A. are all planning satellites. One of the more complex and interesting programs is the Upper Atmospheric Research Satellite (UARS) which is set for launch in 1991.

Each of these satellite programs is described in the following sections.

3.6.2 Commercial Satellites

3.6.2.1 Landsat

Two Landsat satellites, numbers 6 and 7, have been proposed. These satellites are intended as a continuation of the existing Landsat program and are expected to carry a variety of sensors. Landsat 6 is currently planned to be launched in 1991. In addition to the thematic mapper sensor which provides 30 metre spatial resolution over 7 spectral bands, an enhanced thematic mapper (ETM) sensor is also to be included in the sensor payload. This sensor will provide panchromatic imagery in the spectral range of 0.5 to 0.9 μm with 12 x 15 metre spatial resolution. Although this sensor will not provide as high a resolution as the panchromatic sensor onboard the SPOT satellite, it is seen as an attempt to compete with the French system. In the original proposal, a wide field of view, low resolution scanner for ocean applications called Seawifs was also to be flown on Landsat 6. However, recent information suggests it will not be included in the payload under the revised plan.

Landsat 7 is less certain. There is the possibility of transferring control of the Landsat program to the US DoD. An investigation has also been done to look into a joint venture between NOAA and CNES following the Landsat 6 program. All of these plans are still in the formulative stages.

3.6.2.2 SPOT

Three additional SPOT satellites have been approved for the 1990s. SPOT 2 was recently launched in February, 1990 and should be fully operational before middle of the year. SPOT 3 proposed for launch in 1992 is intended to provide dual satellite coverage for several years in conjunction with SPOT 2. These satellites are similar to SPOT 1 except that they will both carry receivers for search and rescue operations.

SPOT 4 funding has recently been approved. In addition to a short wave infrared (SWIR) sensor, CNES is considering a wide field of view multispectral

instrument for monitoring large regions of the earth with high temporal frequency. This sensor would be similar to the advanced very high resolution radiometer (AVHRR) currently available on NOAA satellites. A launch date for SPOT 4 has been proposed for the mid-1990s and for SPOT 5 in 1999.

3.6.2.3 Bresex (Brazil)

Brazil plans to develop an earth observational satellite in conjunction with China. This satellite is to be launched in 1997 by a Chinese rocket. The sensor configuration for this system is similar to those of SPOT and Landsat but no detailed information is available.

This program is part of the Brazilian complete space mission (MECB) which was initiated in 1983. The program involves four satellites and is expected to cost over \$1,000 million¹¹.

3.6.2.4 Radarsat

The Canadian Radarsat program was announced in the early 1980s with the objective of launching a synthetic aperture radar satellite into orbit by 1988. For various reasons, this program has been delayed and a launch is not planned until 1994.

The satellite will be launched on a Delta II rocket and put into a circular sun synchronous polar orbit. The synthetic aperture radar will be configured for a horizontal polarization C-band system. The primary fields of application for which this system is intended are the study of ice and oceans followed by geology and forestry. Spatial resolution will vary from 10 to 55 metres with a variety of scanning options.

3.6.2.5 Earth Resources Satellite (ERS)

The European Space Agency (ESA) is planning to launch the first ERS satellite in late 1990 to early 1991. This satellite is designed to increase understanding of coastal zones, global ocean processes and sea ice. The satellite will carry a C-band SAR with a spatial resolution of 30 x 30 metres and operate in a variety of modes including one designed to measure wave frequencies on the ocean. Altimetry to 10 m accuracy will be obtainable.

Other functions will include measurements of wind fields above the earth's surface, the determination of ocean surface temperatures to 1°C accuracy, mapping of ocean and polar ice cap topography and also to provide radar imagery of the earth.

There have been recommendations by ESA member states to proceed with ERS 2 although final decisions have not been made.

3.6.2.6 Soviet SAR

Not much information is available regarding this program. It has been reported that the Soviet Union intends to launch a synthetic aperture radar satellite in July 1990. This system will have a resolution of approximately 15 metres. The resulting data may be commercially available outside the U.S.S.R.⁹

3.6.3 Experimental Satellites

3.6.3.1 SIR-C

SIR-C will be an X-band SAR sensor flown in 1993, 1994, and 1995 space shuttle missions. This system will provide multi-date SAR imagery over selected test areas at 30 metre resolution. Applications include geology, forestry, and ocean processes. Canada is also planning to experiment with these data for agricultural applications.

3.6.3.2 European Polar Orbiting Platform (Columbus)

This system proposed by ESA is designed for long-term earth observations and is directed at global monitoring. A list of proposed payload sensors is given in Table 3.4. This platform will be launched in 1995 and will be included as part of the international EOS program.

3.6.3.3 U.S. Space Station/EOS

The proposed earth observing system (EOS) is a major scientific and technological undertaking. The concept of the space station is to perform scientific experiments in a manned space environment and to provide servicing to various instruments related to the earth observation system. EOS involves geosynchronous and polar orbiters, special purpose orbiters, data relay satellites, ocean drift instruments, pop-up buoys, tethered buoys, ocean bottom instruments and other earth based sensors. It is an integrated set of experiments that form the basis of the planned Mission to Planet Earth.

TABLE 3.4
CONFIGURATION OF EUROPEAN POLAR-ORBITING PLATFORM
1995 LAUNCH

| SENSOR | NO. OF CHANNELS/ FREQUENCIES | SPECTRAL RANGE/ FREQUENCY RANGE | RESOLUTION | SWATH WIDTH |
|---|---------------------------------|--|--|--------------------------|
| AMSU-A (Advanced Microwave Sounding Unit-A) | 15 | 23 - 89 GHz | 50 km | 2,250 km |
| AMSU-B (Advanced Microwave Sounding Unit-B) | 5 | 89-183 GHz | 15 km | 2,250 km |
| AOCM (Advanced Ocean Colour Monitor) | 8 | Visible and near infrared | 250 m | 1,140 km |
| ARA (Advanced Radar Altimeter) | TBD | 13.8 GHz | 20 km (Nadir) | TBD |
| ARGOS | N/A | 401 MHz | N/A | N/A |
| ATLID (Atmospheric Lidar) | TBD | 1.06 or 1.53 μ m | 10 - 50 km (Horizontal) 0.5 km (Vertical) | TBD |
| AVHRR (Advanced Very High Resolution Radiometer) | 6 | 0.63 and 12.0 μ m | 1.1 km | 2,900 km (Crosstrack) |
| CCR (Corner Cube Reflector) | N/A | N/A | N/A | N/A |
| DF SAR (Dual Frequency SAR) | 2 | 5.3 GHz and L or X band | TBD | 200 km |
| HIRS-2 (High Resolution Infrared Radiation Sounder) | 20 | 3.8 - 14.5 μ m | 10 km | 2,300 km (Crosstrack) |
| HRIS (High Resolution Imaging Spectrometer) | 10 | 0.4 - 1.0 μ m | 20 m | 60 km |
| HROI (High Resolution Optical Imager) | 4 | 0.45 - 0.90 μ m 1.6 and 2.1 μ m | 25 m | 200 km |
| PPS (Precise Positioning Systems) | TBD | TBD | N/A | N/A |
| WINDSCAT (Wind Scatterometer) | 2 | 14 GHz 5.3 GHz | 25 km | 1,000 km |

Some of the candidate instruments to be flown on the EOS platform are listed in Table 3.5. The complementary nature of these sensors will provide information synergisms that can only be dimly perceived at the present time.

There will be three components comprising the American EOS system. The first component is scheduled for launch in 1997, the second in 1998, and the third in 1999. Once in orbit, these components will be assembled into a single orbiting platform. The system is designed to be serviceable in orbit and be capable of utilizing replaceable sensors for a multitude of tasks.

3.6.3.4 TOPEX/Poseidon

The TOPEX/Poseidon program is designed to measure ocean topography and ocean current signatures. The mission is a cooperative venture between the U.S.A. and France and is the \$270 million successor to Seasat. The expected launch date is 1991.

3.6.3.5 Geopotential Research Mission (GRM)

The objective of this mission is to measure gravity and magnetic fields at the earth's surface. This U.S. system may involve cooperative efforts with ESA. While a 1994 launch date is planned, this program appears to be the same as Aristoteles.

3.6.3.6 Magnetic Field Explorer (MFE)

This U.S. mission will involve the measurement of the earth's magnetic field that would hopefully yield new insights into the earth's interior. NASA is leading this joint venture in association with ESA. A mid-1990 launch date is planned.

This mission is the last in a sequence of satellites which includes UARS, NSCATT (was to have been carried on the US Navy N-ROSS mission which was cancelled in 1986) and TOPEX/Poseidon. This program, MFE, would be follow up with a Gravity Gradient Mission (GGM) (Aristoteles/GRM) to measure the earth's gravitational field.

3.6.3.7 Laser Geodynamics Satellite (LGS)

Italy is planning the launch of a laser geodynamic satellite in 1993. The objective of this mission is to measure plate tectonic motions. This system is a follow-on to the American Lageos satellite which was a high density, small diameter

TABLE 3.5

PROPOSED EOS INSTRUMENTS

| NAME | INSTRUMENT |
|--|--|
| SISP - Surface Imaging and Sounding Package | |
| • Moderate-Resolution Imaging Spectrometer (MODIS) | Surface and cloud imaging in the visible and infrared 0.4 to 2.2 μm . Surface and cloud imaging in the visible and infrared 0.4 to 2.2 μm , 3 to 5 μm , 8 to 14 μm resolution varying from .01 μm to .5 μm . |
| • High-Resolution Imaging Spectrometer (HRIS) | Surface imaging 0.4 to 2.5 μm , .01 to .02 μm spectral resolution |
| • High-Resolution Multifrequency Microwave Radiometer (HMMR) | 1 to 94 GHz passive microwave images in several bands |
| • Lidar Atmospheric Sounder and Altimeter (LASA) | Visible and near-infrared laser backscattering to measure atmospheric water vapor, surface topography, atmospheric scattering properties |
| SAM - Sensing with Active Microwaves | |
| • Synthetic Aperture Radar (SAR) | L-, C-, and X-band radar images of land, ocean, and ice surfaces at multiple incidence angles and polarizations |
| • Radar Altimeter | Surface topography of oceans and ice, significant wave height |
| • Scatterometer | Sea surface wind stress to 1 m/s 10° in direction K_u band radar |
| APACM - Atmospheric Physical and Chemical Monitor | |
| • Doppler Lidar | Tropospheric winds to 1 m/s doppler shift in laser backscatter |
| • Upper Atmosphere Wind Interferometers | Upper atmospheric winds to 5 m/s doppler shift in O_2 thermal emissions |
| • Tropospheric Composition Monitors | Trace chemical constituents of the troposphere |
| • Upper Atmosphere Composition Monitors | Trace chemical composition passive emission detectors at wavelengths from UV to microwave |
| • Energy and Particle Monitors | Solar emissions from .150 to .4 μm , .001 μm spectral resolution, Earth radiation budget, total solar irradiance, particles and fields environment |

object in a high orbit covered with passive corner-cube reflectors for lasers ranging with high accuracy from earth stations.

3.6.3.8 Tropical Rainfall Explorer Mission (TREM)

The purpose of the TREM program is to measure tropical precipitation. These measurements would be obtained through a sensor package which includes a multichannel passive microwave radiometer, a visible infrared radiometer and a dual frequency radar. The projected initiation of the program is 1991, with a potential launch scheduled for 1994. This program is a joint venture between the U.S.A. and Japan. Japan refers to this mission as the Tropical Rainfall Mapping Mission (TRMM).

3.6.3.9 Aristoteles

This program is designed to determine the Earth's gravity field based on an areal resolution of 100 x 100 km. Aristoteles will be moving along a heliosynchronous orbit (crossing the equator in a northerly direction at 6 am) at an altitude of 200 km. This mission has an expected launch date in late 1994 and will provide useful information on areas such as geophysics, i.e., plate tectonics and earthquake areas, as well as oceanography [12].

3.6.4 Domestic Satellites

3.6.4.1 MOS-1b

MOS-1b was built in Japan as the prototype for testing of the current MOS-1 satellite technology. As such, this instrument contains the same sensors as the currently operational MOS-1. MOS-1b was launched in 1990 in order to provide follow-on data for the successful MOS-1 program.

3.6.4.2 IRS-1b

India's IRS-1b satellite will be identical to the IRS-1 which is currently in operation. The launch is proposed for 1991 and will be performed by a launcher provided by the Soviet Union. A third IRS is planned for 1993-94. A second generation of IRS will likely involve international cooperation and may include microwave sensors to be developed during the late 1990s.

3.6.4.3 Japanese Earth Resources Satellite (JERS)

This satellite will combine an L-band SAR operating in horizontal polarization with an optical sensor. The spatial resolution of both sensors will be 25

metres, allowing an integrated data set to be produced. The objectives of the JERS-1 mission, to be launched in 1991, are primarily global exploration for mineral and energy resources with additional applications for agricultural and forestry assessments, environmental monitoring, and land use planning.

3.6.4.4 Advanced Earth Observation System (ADEOS)

The Japanese ADEOS is an environmental observation satellite for earth and ocean resource investigations. It will have visible and near infrared radiometers as well as an ocean colour and temperature measurement payload. Launch is planned for 1994. There have been unconfirmed reports that this mission has been cancelled but these could not be verified¹³.

3.6.5 Meteorological Satellites

As previously described, a number of nations are currently operating geosynchronous meteorological satellites while the U.S. operates polar orbiting, high resolution satellites.

The Japanese National Space Agency (NASDA) plans to launch another geosynchronous meteorological satellite (GMS-5) in 1994. This satellite will include a visible and infrared radiometer as well as potential new advanced sensors which have yet to be announced.

The Soviet Union is presently developing new sensors for the next generation METEOR satellite. No information is available at this time regarding the configuration of this new system.

In the U.S.A., NASA and the DoD in conjunction with NOAA are preparing improved meteorological satellites. Among the plans are new NOAA and GOES series platforms. Geostationary satellites are used primarily for weather data, cloud information, temperature profiles, real time storm monitoring, severe storm warning systems and for measuring sea surface temperatures.

Several TIROS weather satellites are planned for the 1990s. These satellites are designed specifically for weather observations from a Polar orbit.

In addition to weather satellites, there are other atmospheric missions planned. One mission known as the upper atmospheric research satellite (UARS) is the most complexly designed space investigations ever attempted to measure major upper atmospheric parameters. The Wind Imaging Interferometer (WINDII) was built by Canadian Astronautics Ltd. of Ottawa, Ontario, in conjunction with Advanced Information Technologies of Ottawa, Ontario.

Launch of UARS is expected to be performed by the space shuttle in late 1991. The earth observation system (EOS) contains a number of meteorological sensors and is described in a previous section. Another ongoing project that will continue into the 1990s is the defence meteorological satellite program (DMSP). This satellite provides operational weather data for the U.S. Department of Defence.

3.6.6 Summary

The 1990s represent the most ambitious decade for the planning, development, acquisition and analysis of satellite based remote sensing data. Obviously, the number of programs and their payloads may be changed or delayed depending on a variety of factors. A common theme running through the majority of these proposed programs is the focus on global monitoring, particularly atmospheric, ice, and ocean properties which are a major concern in view of recent discoveries regarding global warming trends. The numerous variety of sensors planned for launch will complement each other in the hope of better understanding our planet.

3.7 Specific Opportunities

Based upon the current market review, several specific opportunities which may be capitalized upon by Canadian Industry have presented themselves. In all cases, these opportunities would require a medium to high level of government involvement.

The first opportunity relates to the distribution of remotely sensed data on an international scale. The current system is fragmented and highly unreliable, consisting of numerous government agencies and companies in various countries. The level of service provided by these various organizations ranges from excellent to non-existent. The difficulties which arise from this disorganization include inability of potential users to locate data which may be suitable for their purposes and secondly, slow delivery times of the ordered imagery which sometimes leads to the data being unusable for the purpose specified. The opportunity clearly exists for an international organization which would provide search services of all the major remote sensing data bases to all users worldwide. This organization would be based upon international agreements between the major governments which operate remote sensing satellites. Canada could take a leading role in this organization by offering Radarsat data. In addition, Canada's worldwide reputation for efficiency in data processing and distribution could be used to promote such an operation as a Canadian organization. A further step would be for this organization to actually distribute the data, although

it is unlikely that commercial organizations such as SPOT Image and EOSAT would readily grant international distribution rights.

A second opportunity appears in the so-called "announcement of opportunity" sensors proposed for the EOS and EPOP polar platforms to be launched later this decade. By taking advantage of these space allocations on the large polar orbiters, Canadian companies could potentially orbit commercial remote sensing instruments at a low cost. It should be recognized, however, that while the logistical problems of launching and satellite control are eliminated through this method, the commercial operator would also lose control over the actual positioning of his sensor.

The third opportunity presents itself in the opening of previously untapped markets, specifically the Soviet Union. Radarsat is intended to support Canadian Arctic activities such as resource exploration and shipping. Due to the similarity in geographic position, Soviet needs are undoubtedly similar if not greater than Canadian requirements for this type of data. The opportunity therefore exists to supply the Soviet Union with one or more Radarsat ground stations and thereby collect revenues on a yearly basis for the licensing of such stations. Furthermore, the Soviet Union currently plans to launch a similar synthetic aperture radar satellite in the near future. A cooperative agreement to jointly market Radarsat and the Soviet SAR satellite imagery would provide international users with double the coverage of a single satellite from one source. Such a cooperative venture may be well received by the Soviets in light of their current economic policies.

3.8 Review of Alternative Methods

For each of the following major application areas for which remote sensing data are used, there exist one or more alternative methods of data collection including aircraft, suborbital rocketry, balloons, and of course, ground measurements. Accepting that ground data collection is both expensive and limited in scope, the alternative airborne data collection methodologies may be compared in terms of the application area. A summary of relative benefits for space based and alternative collection techniques for each of the application areas is given in Table 3.6.

3.8.1 Atmospheric Studies

The study of the earth's weather patterns on a large scale is best performed using the synoptic overview afforded by high altitude satellites. This has been proven by the successful use of the TIROS, Nimbus, and GOES satellites which have been in use since the 1960s. However, certain measurements are still performed using aircraft and balloons mostly because they are easier to perform for such measurements as wind speed, air temperature, and humidity. Some operational and proposed spacecraft instruments may replace these

TABLE 3.6

SUMMARY OF SPACEBORNE AND ALTERNATIVE COLLECTION TECHNIQUES FOR VARIOUS APPLICATIONS

| APPLICATION | SPACE | AIRBORNE |
|---------------------------------|--|--|
| AGRICULTURE | <p>Sensors: MSS,TM,SPOT,AVHRR</p> <p>Ability to identify cropped versus uncropped fields, estimation of crop yields, plus in some cases crop health. Low resolution is a disadvantage.</p> | <p>Sensors: Camera, MEIS, Radar</p> <p>Permits identification of crops and conditions, diseased areas, and soil moisture. Expense of these sensors is a disadvantage.</p> |
| ATMOSPHERE | <p>Sensors: Radiometer, AVHRR, Scatt, Lidar, MS</p> <p>Provides synoptic views of the earth, measurements of wind speed, surface temperatures. A disadvantage is that local temperatures and conditions cannot be measured.</p> | <p>Sensors: Balloons, Aircraft</p> <p>Measurements such as wind speed, temperature and humidity at various altitudes are available. Cannot provide synoptic coverage.</p> |
| ENGINEERING, SURVEY AND MAPPING | <p>Sensors: MSS,TM,SPOT</p> <p>Ability to study regional conditions which might affect large structures. Stereo SPOT imagery can provide elevation data. Some nations use SPOT for small scale mapping. Stereo SPOT is not of sufficient accuracy for topographic mapping and satellite imagery does not permit detail identification of construction materials.</p> | <p>Sensors: Camera, MEIS, Radar</p> <p>Airborne data provide best information for topographic mapping, and local site conditions for construction. Best for studying local environmental conditions. Radar is useful for studies of ice dynamics as they relate to ocean structures that will encounter ice conditions. Expense of data is a major disadvantage.</p> |
| FORESTRY | <p>Sensors: MSS,TM,SPOT,AVHRR</p> <p>Useful for monitoring clear cut areas, diseased forests over large regions. Disadvantage is that tree species, local environmental impact cannot be assessed and often imagery can be cloud covered.</p> | <p>Sensors: Camera, MEIS, Radar</p> <p>Useful for tree species identification, diseased forests, and various densities of forest cover.</p> |

TABLE 3.6 - Continued

SUMMARY OF SPACEBORNE AND ALTERNATIVE COLLECTION TECHNIQUES FOR VARIOUS APPLICATIONS

| APPLICATION | SPACE | AIRBORNE |
|---------------------------|--|---|
| GEOLOGY AND GEOMORPHOLOGY | <p>Sensors: MSS,TM,SPOT,Seasat,SIR</p> <p>The imagery is useful for delineation of structure and geobotanical studies. Radar (Seasat - SIR) have been used for this purpose and provide a side view highlighting topography. Satellite multispectral data presents a planar view and does not highlight topography. Multispectral imagery is susceptible to cloud cover.</p> | <p>Sensors: Camera, MEIS, Radar, TIR,Magnetometers,Gravity</p> <p>Imagery has been used extensively in geomorphological and geological interpretations as well as geobotany and mapping. Radar has been more useful for structural mapping. Geophysical instruments provide data which can be used to support and assist interpretations from airborne imagery. Multispectral imagery has been used in Geobotany. These types of data are expensive to acquire.</p> |
| HYDROLOGY | <p>Sensors: MSS,TM,SPOT,Seasat,SIR</p> <p>Imagery has been used for study of regional hydrologic processes but not local processes. Problems occur on multispectral data where clouds and snow are similar in reflectance.</p> | <p>Sensors: Cameras, MEIS, Radar, TIR</p> <p>Useful for determination of sedimentation, algae, shallow aquifers and soil moisture. Imagery is expensive to acquire but confusion between snow and clouds does not exist.</p> |
| OCEANOGRAPHY | <p>Sensors: MSS,TM,SPOT,SIR,Seasat,AVHRR</p> <p>Useful for study of ocean processes, currents, wave patterns, plankton and surface temperature are all measured from satellites. Clouds present problems by obscuring ocean.</p> | <p>Sensors: Camera,TIR,MEIS,Spectrometers,Radar,FLI</p> <p>Sensors are useful for studying oceanic processes, identifying ships and oil spills. This imagery is only capable of covering small areas. Few geographic reference locations available in open ocean.</p> |
| LAND USE | <p>Sensors: MSS,TM,SPOT,SIR,Seasat</p> <p>Imagery can be used to identify land use practices more frequently over regional areas and updating road networks. Clouds are the greatest problem for multispectral data sets.</p> | <p>Sensors: Camera, MEIS, Radar</p> <p>Imagery is most valuable for updating urban land use changes. The expense is high for this imagery.</p> |

TABLE 3.6 - Continued

SUMMARY OF SPACEBORNE AND ALTERNATIVE COLLECTION TECHNIQUES FOR VARIOUS APPLICATIONS

| APPLICATION | SPACE | AIRBORNE |
|----------------------|--|--|
| GLACIOLOGY | <p>Sensors: MSS,TM,SPOT,SIR,Seasat,AVHRR</p> <p>Used to monitor glacial environments such as polar ice caps and glacial movement. Orbital paths are not advantageous for monitoring polar caps in the case of some satellites and there is difficulty in separating snow from cloud in multispectral images.</p> | <p>Sensors: Camera, MEIS, Radar</p> <p>Imagery is used to study ice. Radar penetrates the snow to produce surficial glacier features. Ice penetrating radar provides information on ice thickness. Cost is the most prohibitive aspect of this imagery.</p> |
| ICE SURVEILLANCE | <p>Sensors: TM,MSS,AVHRR,SPOT,Seasat,SIR</p> <p>Imagery is used to monitor ice conditions. Radar is best for this surveillance because of the all weather and light conditions sensing capabilities. However, there are no active satellite radar sensors at present. Multispectral sensors can be used when light conditions improve.</p> | <p>Sensors: Camera,Radar,MEIS</p> <p>Radar is the most usable form of ice surveillance data. Low northern light conditions in winter months permit the acquisition of multispectral data. Radar also provides information about the ice type not available from multispectral sensors.</p> |
| GENERAL SURVEILLANCE | <p>Sensors: None</p> <p>Events such as forest fires, erosion, and flooding require continuous coverage in near real time which is not available from satellites.</p> | <p>Sensors: Camera,MEIS,Radar</p> <p>These images provide data on events which are not covered using satellites. Although costly, this information is required for planning strategies prior to the occurrence of severe damage.</p> |

measurements on a global basis such as Lidar, Microwave Sounders and Scatterometers.

There will need to be considerable improvement in satellite sensors before programs such as flying aircraft into hurricanes to measure windspeeds can be stopped.

3.8.2 Agriculture

Aside from ground data collection techniques, very few airborne data acquisition surveys are done for agricultural purposes except on an experimental basis. Depending upon the application, satellites are indispensable for monitoring agricultural trends, particularly when monitoring agricultural planting practices in foreign countries such as the U.S.S.R. or for monitoring large areas such as all of the western provinces. The use of Landsat was demonstrated in a project called LACIE which ended in 1978. This program estimated the total Soviet wheat crop using Landsat MSS data to 1% less than the official Soviet figure. A less successful LACIE project was attempted in the US and Canada where the long narrow wheat fields could be confused with young crops¹¹. This demonstrated the problem with multispectral data applications in that they are generally site specific and an application technique can not be necessarily used in a new region.

Budgets for agricultural data collection are low and therefore the majority of remote sensing data used are in the form of meteorological satellite information such as from the AVHRR sensor, although Landsat data are also used extensively.

3.8.3 Engineering, Surveying and Mapping

Airborne data are widely used in the mapping industry because aerial photography supplies the resolution required for detailed mapping studies and is well understood, having been in common use for over 40 years. In addition, aerial photography is an valuable tool for engineering studies related to such areas as construction and reservoir engineering. Radar has been useful for studying ice dynamics and the potential impacts on structures that encounter ice. Alternatively, high resolution satellite imagery sufficient for such detailed studies is not available at this time and the processes required to generate topographic maps from the satellite data are not widely understood. Satellite imagery from the SPOT and Landsat systems is presently used for small scale mapping in developing countries where there are problems of inaccessibility and for update revisions to existing maps.

3.8.4 Forestry

As in the mapping industry, aerial photography and ground truth are still the primary data sources used for this industry. Space-based imagery is primarily used for experimental

work, mapping of tropical forests, and mapping at small scales. Space based imagery also has been proven as a useful tool for clear cut mapping and diseased forests. This balance in data usage could change in the near future with the advent of high resolution satellites and SAR imagery from space although SAR has been used experimentally in many areas for forestry studies.

3.8.5 Geology and Geomorphology

While some satellite imagery and photography has been used for mapping of structure, and geomorphological features airborne photography and SAR data are the most widely used remote sensing tools for these purposes. Other airborne remote sensing tools which are widely used for geological applications are magnetometers and gravity instruments which are unlikely to be available at the resolution required in a space configuration in the near future. Experimental studies with multispectral scanners may lead to some space applications in the field of geobotany in the near future.

3.8.6 Hydrology

While spaceborne data has been successfully used to map fluvial processes over large areas, very few proven results have been determined for such applications as soil moisture and water table detection. In addition, snow and clouds appear the same on spaceborne imagery. The majority of data collection for soil moisture and water table detection is performed on the ground, with airborne infrared imagery, using SAR or any combination of the three methods. Sedimentation and algae content in water is typically studied by multispectral imagery in the visible region although infrared is also used to study algae. Shallow aquifers are studied using thermal infrared imaging in combination with other data sets such as infrared and visible bands.

3.8.7 Oceanography

As with meteorology, oceanography requires the wide overview which satellites are uniquely capable of providing. Landsat data are being used to map current patterns. Monitoring of a number of oceanic processes such as chlorophyll content, surface temperature, plankton, and wave patterns requires a frequent revisit schedule. For this reason, airborne data collection is still in very wide use. It is unlikely that satellite imagery will completely replace the use of airborne data collection, however, with the launch of multiple polar platforms in the late 1990s, a considerable amount of oceanographic work will be performed from space-based remote sensing platforms.

3.8.8 Land Use

In urban areas where high resolution is required for mapping of land use, both ground data acquisition and aerial photography are the common sources of data. However, SPOT panchromatic 10 m imagery has been successfully used for road network mapping and other similar purposes. In rural areas, satellite imagery is most satisfactory for these applications, however, aerial photography is still widely used in a number of areas for the same reasons that it is used in the mapping industry, that is, wide acceptance from the user community due to the familiarity of the data product. Satellite imagery allows the user to update regional landuse changes in a much more frequent time frame than if using aerial photography.

3.8.9 Glaciology

As the study of glaciology is primarily a research topic, satellite imagery is widely used due to its lower costs. Satellite imagery has been used to study glacial movement using Landsat data. However, for major projects such as the studies ongoing in Antarctica, a number of airborne data acquisition techniques have been utilized including high altitude airphotos, partially as a result of the satellites orbital path, and ice penetrating radar to measure thicknesses. Radar can be used to provide information about glacial features. Many of these applications could be replaced with spaceborne data provided the information is readily available to the researchers at a reasonable cost.

3.8.10 Sea Ice Surveillance

This area of application accounts for \$10 million per year to Canadian airborne radar data acquisition companies. In the past, aerial photographs were acquired but radar has proven to be much more effective for ice management. The ability of radar to be acquired regardless of light conditions makes radar a powerful imaging tool for ice surveillance, especially since there is a lot of offshore drilling and shipping activities in the Arctic. In addition, this sensor penetrates the snow cover allowing the discrimination of sea ice types. Ice type discrimination is important because older ice can damage drilling vessels which may result in an environmental disaster. If these ice types can be identified then ice breakers can be dispatched to deflect the ice floe.

Once radar satellites have been launched, continuous coverage of the Arctic will provide a more comprehensive data set in which ice can be monitored and its motion modelled. In addition, direct downlinks to the Atmospheric Environment Service are being planned for the acquisition of Radarsat data.

3.8.11 General Surveillance

Landslides, soil erosion, flooding, forest fires and subsidence are application areas which require continuous update. As a result, satellite imagery does not provide a suitable source of data due to its return cycle as well as its resolution. Soil erosion often occurs over a period of time and therefore a well documented collection of aerial photographs provides a useful data set. Flooding, which in Canada occurs most frequently in Spring, can not be monitored because the skies are often cloud covered at the time the satellite returns. Radar satellites will alleviate this situation but will not provide the flexibility in return periods as would airborne data. Similarly, forest fires require that near real time TIR imagery is provided to fire fighters to be used in planning attack strategies.

3.9 Trends and Impact of Foreign Government Policies

As motivators and regulators of the remote sensing industry, governments use their research and development agencies as well as taxation and other financial tools to promote their internal business interests in the remote sensing sector. Accordingly, some foreign countries present a good business potential for Canadian industries whereas others are highly competitive and do not represent a favourable external potential. In the following sections, several of the major countries are reviewed.

3.9.1 U.S.A.

American policy appears to be aimed at maintaining its dominance of the remote sensing industry in terms of space capability and variety of data types available. However, the American government does not appear willing to support a comprehensive system for distribution of the various data. This is evidenced by the high level of funding support for research and production of the earth observation system (EOS) as a component of the space station Freedom. On the other hand, considerable debate and negotiation is ongoing regarding the status of government funding for EOSAT which is the primary distribution channel for American remote sensing data.

The U.S.A. allows Canadian participation in its space programs mainly by accepting Canadian Government funded systems on an approval basis such as the SPAR Canadarm system. In other sectors of the industry, such as ground receiving stations and value added systems and services, Canadian companies compete on a fairly level playing field. However, due to the high level of internal competition within the American industry most Canadian firms are content to look elsewhere for this business. However, the requirements for Radarsat data by the U.S. are likely to be extensive, partially due to their interest in Arctic.

3.9.2 Europe

The European Space Agency has shown a generally high commitment to remote sensing on an experimental basis as indicated by the planned launch of ERS-1 and ERS-2 as well as the initial commitments for the European Polar Orbiting Platform (EPOP) to be included as part of the earth observing system. ESA allows Canadian participation as a member of the association but requires upfront financing for specific projects which results in a lower general return on the Canadian investment. In terms of ground receiving stations, Canada has been successful in providing the SAR processor for ERS-1 and other associated equipment related to Landsat and SPOT reception, however, for value added services and other remote sensing systems, Canada is not generally competitive because of the favoured status of many local European firms. Even though Canada does not have great potential in Europe, it is likely that some European nations, such as Norway and the UK, will represent a potential market for Radarsat data.

3.9.3 France

French companies are competitive in all sectors of the remote sensing industry. France has a strong commercial presence in the data supply sector through the SPOT Image Corporation which is heavily subsidized by the French Government. SPOT's aggressive marketing and technology development policies will probably lead to parity or even dominance over the United States remote sensing program until the EOS system is operational. This market balance may continue if SPOT's distribution system is superior. In general, France does not present a favourable market for any sector of the Canadian remote sensing industry.

3.9.4 Japan

Similar to France, Japan has an aggressive remote sensing program including the MOS-1 and MOS-1b satellites for oceanography as well as the planned JERS-1 radar satellite and the Advanced Earth Observing Satellite (ADEOS) planned for late in the 1990s. The Japanese space agency is not committed at this point to international access to the data from these satellites although Canada currently down-links data from the MOS-1 satellite and is negotiating an agreement to download satellite data from MOS-1b. With these satellites, Japan has a constant source of remotely sensed imagery. Historically, Japan has not contracted out work to Canadian firms for satellite technology or ground receiving stations. In addition, very few value added firms have made any inroads into the Japanese market. In

general then, Japan represents an internal market which is not a good prospect for Canadian industries.

3.9.5 U.S.S.R.

Although undergoing major changes in the last several years, the Russian market for remote sensing data and technology is limited by inefficient organization and over regulation. In spite of this, the Soviet space organizations could become a buyer of Canadian technology both for satellite instrumentation and ground receiving stations. At this time, the Soviet Union is a supplier of satellite remote sensing data through the Soyuzkarta Organization, however, the data supplies are somewhat unreliable and of limited coverage. Soviet plans for future satellites include a SAR, but, it is uncertain if data supplies will be available or reliable. In general, the Soviet Union could become a good market for Canadian industries.

3.9.6 China

While little is known of Chinese plans for the remote sensing sector, based upon past dealings, it would seem that China is a potential purchaser of Canadian equipment and technology. At the same time it is unlikely to become a data supplier or purchaser of value added information but may represent a potential market for Radarsat data.

3.9.7 India

By operating its own remote sensing satellites, India represents a unique situation in the Third World. At present the usage of IRS-1 data is primarily internal, however, India plans to supply this information to other nations on a commercial basis in the near future. Because of this successful remote sensing program and the limited budgets of the Indian Government, India is an unlikely market for multispectral remotely sensed data but could be a potential market for Radarsat data. However, for space technology, ground receiving stations, and value added systems and services, India is a likely prospect because of the high interest and the extensive need for these types of data.

3.9.8 Other Countries

The majority of the remaining countries do not have sufficient budgets or political intentions to support a space remote sensing system. Notable exceptions are Israel and South Africa who have highly militarized technology bases but are unlikely to present a good market for Canadian technology. For ground receiving stations and remotely sensed data, most Third World nations provide a good market potential especially for Radarsat data. In fact, a number of countries have already purchased Canadian ground receiving stations. The same situation

holds true for value added systems and services. This is especially true in equatorial rain forest and Savannah regions such as South America, Africa, and Asia which urgently require remote sensing data in order to manage their vanishing natural resources.

CHAPTER 4

CANADIAN INDUSTRIAL CAPABILITIES

4.1 Introduction

Canada has demonstrated expertise in several key areas of the aerospace industry. This expertise has been clearly illustrated in the development of communication systems and satellites. As a result of this work and the world's focus on earth observation and global monitoring, Canadian industry has advanced into the area of developing earth observation satellites. Radarsat will be Canada's first remote sensing satellite. Its primary objective is to monitor ice conditions in the Canadian Arctic, but it has other capabilities which will be exploited by the value added community.

The following sections describe various capabilities contained within Canadian companies in the remote sensing industry as well as the nation's existing technology base with specific application to the design of earth observation sensors, small satellites, and data reception systems. A discussion of the various deficiencies in the Canadian technology base is included along with potential areas for development and improvement in international markets.

4.2 Canadian Companies and Capabilities

Canadian companies are actively involved in most facets of the earth observational field. The capabilities embodied in these companies include advanced antenna design and construction, computer systems and software, sensor development and a host of other high technology items such as the development of thin film semiconductors.

Many of the companies identified are involved in the provision of products for military applications and therefore the capability definition of these companies is difficult to assess due to their reluctance to provide information on the specific products they produce. In general, the Canadian industrial capabilities described, in the three sectors of the remote sensing industry, are available for commercial and scientific usage.

4.2.1 Satellite Systems and Subsystems

While the Canadian industry has gained a world-class reputation for the design and construction of communication satellites, there is no similar track record for earth observation

satellites. The only earth observational satellite program upon which Canada has embarked is Radarsat which is planned for launch in 1994. Despite this lack of national programs, a number of Canadian companies have contributed subsystems and components to foreign earth observational systems.

The majority of the Canadian firms with a capability to produce components for earth observation satellites are listed in Appendix A and the various capabilities offered by these companies are given along the top of the table. These capabilities have been grouped into general categories; namely, platform, attitude control, reaction control, tracking and telemetry, power, sensors, and other.

The platform group includes structural components, thermal control, and system design and integration. These are the capabilities required to assemble the basic satellite body and perform final testing. The remaining groups represent specialized subsystems which are added to the basic platform.

Attitude control systems are used to maintain the spacecraft in a precise orientation relative to the earth surface. These systems monitor the actual attitude by sensing the relative location of the earth's horizon. Sun sensors are used to correct the position of the solar arrays. Attitude modification is generally achieved using electromagnetic torque rods, which use the earth's magnetic field for leverage, or momentum wheels which provide precise angular control. Other mechanical stabilization systems are also possible. Overall control of these systems is performed by programmable microcontrollers.

Reaction control systems are used to modify and maintain the satellites' orbit. These systems work in concert with the attitude control system and include small liquid propellant rocket engines which are used to boost the satellite to the desired velocity and altitude. Restrictions in the amount of fuel which may be carried by these systems are a common reason for the limited lifespan of many satellites.

Telemetry, Tracking and Control (TTC) systems provide the link between the ground segment and the spacecraft. These systems include the central computer, which monitors and directs onboard activities such as orbit corrections, and the radio system which allows the earth based tracking station to supervise the satellite's health and upload commands to be carried out.

Power systems include solar arrays, batteries, converters, invertors and distribution control systems. Fuel cells and nuclear reactors are also potential power sources but are not

in common use for earth observation satellites. An exception is the Soviet RORSAT system which is powered by a nuclear reactor.

Sensor packages are specific to earth observation satellites. These systems must include the sensor itself, a control system to operate the sensor, and a data transmission system to send the acquired data to earth. Most of the more sophisticated systems also include a data storage device for recording the data during periods when downlinking is not possible. The two major imaging sensor types are optical and radar systems. The special requirements of these sensor types are represented by the headings labelled optics, optical coatings, and SAR antennae.

The other category includes companies with specialized capabilities in fabrication of mechanical components and materials. Composites and plastics are included here. For the sake of completeness, rocket technology has been included.

Table 4.1: Major Canadian Companies, Satellite Systems

| Company | Location | General Capability |
|------------------------------|------------------|--|
| Spar Aerospace | Quebec | Prime Contractor, Radar Systems, TTC, Structure, Optical Systems, Solar Arrays |
| Com Dev | Ontario | Microwave Components |
| Canadian Astronautics Ltd. | Ontario | Radar Systems, Optical Sensors, TTC |
| SED Systems | Saskatchewan | TTC, Optical Sensors, Microwave Components |
| Bristol Aerospace | Manitoba | Rockets, Structure |
| MacDonald, Dettwiler & Assoc | British Columbia | Dedicated Processors, Radar Systems, Software |

There are many Canadian aerospace companies involved in the satellite industry as shown in Appendix A. However, only six companies as shown in Table 4.1, may be considered as the major players.

Several of the major foreign suppliers are also represented in Canada such as Lockheed Aerospace, Aerospatiale and Hughes Aerospace. However, the presence of these companies' sales offices does not represent a Canadian capability and therefore is not discussed further.

The six major companies listed above are capable of providing a number of the components as well as integration and testing for the construction of an earth observational satellite. At the present time, only Spar Aerospace maintains a complete testing facility. Because it is owned by the Government of Canada, this test facility is available to other Canadian companies. Presently, Spar Aerospace is the prime contractor for Radarsat, while the remaining companies, CAL, SED, MDA and Com Dev are all involved as subcontractors.

Spar Aerospace is the largest company involved in the satellite industry in Canada. Its primary capability is in system integration and design. It possesses cleanroom facilities and antenna testing facilities large enough for the Radarsat program. In addition, Spar has extensive experience in tracking, telemetry and control systems (TTC), power supplies; namely batteries, converters, and solar arrays, structural components, thermal control, sensor development, and communication systems. Spar Aerospace currently operates the David Florida test facilities near Ottawa, where satellites and components may be exposed to space-like conditions prior to launch.

Canadian Astronautics Limited's areas of expertise are TTC, power supplies, sensor design and development, structure and antenna design. This company has also been involved in the integration of major systems such as the radar system they developed for monitoring the Aurora Borealis. CAL has a specific research commitment to synthetic aperture radar applications and has supplied both airborne and satellite systems and components.

SED systems of Saskatoon has experience in sensor development and TTC. This company specializes in construction of sensor and communication components from existing or foreign designs.

MacDonald Dettwiler and Associates, in addition to their extensive ground station industry, has designed and built several remote sensing instruments notably the IRIS SAR and the Multispectral Electro-optical Imaging Scanner (MEIS). These instruments are currently offered in an airborne configuration, however, the technology could potentially be modified for space applications.

Com Dev Industries is primarily involved in telecommunications and microwave technology. While not specifically involved in sensor technology, Com Dev represents a considerable capability for construction of space-borne instruments. They have been involved in the supply of components or subsystems for EXOS-D, Anik A through E and Brazilsat to name few projects.

Bristol Aerospace operates predominantly in the aviation sector, but has been involved in the space industry through the supply of Black Brandt rockets and launch support for upper atmosphere research studies. Bristol, a subsidiary of Rolls Royce PLC of the U.K., commands a considerable array of technologies and potentially could become a prime contractor for small satellites.

The remaining companies shown in Appendix A are generally involved in the development of electric components, precision machining and other subsidiary services as subcontractors to the major companies previously described. As stated previously, Canadian industry is fairly well established in the areas of sensor technology, power supplies, TTC and communications. However, several of the space specific technologies such as orbital control, launch capabilities, and spacecraft bus technology are notably lacking. This issue will be further elaborated in Section 4.4.1.

4.2.2 Data Reception and Handling

In this sector of the industry, Canada possesses a fairly complete capability. There are several companies which design and build ground receiving stations for the reception, processing, and distribution of remote sensing satellite data. The four main companies that have these capabilities are listed in Table 4.2.

Table 4.2: Major Canadian Companies, Ground Receiving Systems

| Company | Location | General Capability |
|-------------------------------|------------------|--|
| MacDonald, Dettwiler & Assoc. | British Columbia | Prime Contractor: Landsat, SPOT, Radar, GOES, NOAA |
| Canadian Astronautics Ltd. | Ontario | Communications, Radar, MSAT |
| SED Systems Ltd. | Saskatchewan | Components, MSAT, Maintenance |
| Array Computing Systems Ltd. | Ontario | GOES Earth Stations |

In addition, there are several companies as shown in Appendix B which provide additional products which are integrated into the earth stations built by the four main companies.

MDA is probably the most widely known company in this sector. It has participated in the development of 15 Landsat receiving stations around the world, including acting as prime contractor for five such systems. In addition, it provides station upgrades for reception of data from new satellites such as SPOT, ERS-1, and in the future Radarsat. Other activities include the supply of turnkey meteorological satellite ground stations to several foreign governments. MDA possesses an excellent reputation in the area of processing of spaceborne SAR imagery. This company was the first to process Seasat SAR signals into an image format. As a result of this effort, the company became recognized around the world as a leader in the data processing field, leading to a number of lucrative military and commercial contracts such as the provision of the SAR processor for the ERS-1 satellite.

Another company which has experience in earth station design, construction, and operation is SED of Saskatoon. This company was the original operator of the Prince Albert receiving station for the Canada Centre for Remote Sensing (CCRS). Due to the fairly limited market for remote sensing ground stations and the requirement for heavy international marketing, SED along with the other companies has concentrated mostly on communications ground stations. SED also has the capability to build earth station antennas. This statement also applied to Canadian Astronautics Limited, however, both of these companies should theoretically be capable of duplicating a good portion of MacDonald Dettwiler's work. Essentially, the design and construction of a remote sensing earth ground station involves the integration of a number of off-the-shelf components such as mainframe computers, tape drives, and image display systems. Most of these components are not Canadian products. The key to MacDonald Dettwiler's success in this field has been the supply of the crucial technologies specifically related to earth remote sensing such as SAR processors, software and colour image output products.

A smaller player in this sector is Array Computing Systems (ACS). This company concentrates on meteorological ground stations which receive data from the geosynchronous weather satellites operated by the United States, ESA and Japan. These systems are generally of a simpler design due to the lower volumes of data handled and the fact that the antenna does not need to track the satellite as it passes overhead. However, the implication of a company possessing this technology is considered significant for the purposes of this report.

Several other companies in Canada possess experience in data processing and reception of data from satellites, notably Spar Aerospace, however, to date these companies have not pursued the earth remote sensing ground station business.

4.2.3 Value Added Systems and Services

Canadian representation in this sector of the industry is quite high probably because of the great need in Canada for remote sensing and airborne surveillance. This need is a direct consequence of Canada's vast size and sparse population. The main companies supplying value added systems and services are listed in Appendix C. Of the firms listed, six companies represent major powers in the international market, as shown in Table 4.3, while the remainder are mainly concerned with local work in specific niches. Not shown in this list is a large number of end-user organizations which possess their own capabilities for image processing and interpretation in-house. For example, Gulf Canada Resources possesses the capability to process satellite imagery for geological applications.

All of these companies have been involved in remote sensing for a number of years and it represents a large portion of their business. Most of these companies entered the remote sensing industry because of a particular need for data that could be applied to a

Table 4.3: Major Canadian Companies, Value Added Services

| Company | Location | General Capability |
|--|--------------|--|
| The Bercha Group | Alberta | Radar, Ice Surveillance, Geology, Forestry, Agriculture, Landuse |
| Dendron Resource Surveys | Ontario | Forestry, Agriculture, Geology, Landuse |
| Electromagnetic Sensing and Interpretation | Manitoba | Agriculture, Ice surveillance, Geology, Forestry |
| Horler Information | Ontario | Agriculture, Landuse, Forestry, Geology |
| Intera Technologies | Alberta | Radar, Ice Surveillance, Meteorology, Forestry, Geology, Landuse |
| Nordco | Newfoundland | Forestry, Ice Surveillance, Oceans, Geology |

specific business interest. For instance, Intera Technologies developed from an environmental monitoring company specializing in meteorology and weather control, Dendron Resources Surveys originated as a forestry consulting firm while the Bercha Group entered the remote sensing field with the gathering of ice data in the Beaufort Sea in support of offshore exploration.

In the value added sector of the remote sensing industry, the difference between airborne and satellite data is negligible. A number of the companies listed in Appendix C also supply airborne data acquisition services with a variety of instruments including side-looking radar (SLAR), synthetic aperture radar (SAR), optical imaging sensors, and lasers, to name a few.

While the majority of the companies and institutions listed in Appendix C apply their expertise to a specific client's needs, two companies are taking an alternative approach. Advanced Satellite Productions and Binary Image Corporation are marketing satellite imagery to the general public in the form of poster art. It is probably too early to judge the size of this potential market. However, the capabilities which these companies are currently developing could prove useful in other aspects of the value added industry such as raising public awareness thereby potentially expanding the market.

A number of so-called non-profit agencies are also involved in the value added sector. These include universities and government agencies, both provincial and federal. Foremost among these is the Canada Centre for Remote Sensing (CCRS) which concentrates primarily on the development of new applications for remotely sensed data but also offers data acquisition, distribution and consulting services. The Universities of Alberta, British Columbia, Calgary, Laval, Manitoba, Sherbrooke, Waterloo, and York are among the other institutions which have at times offered consulting and data processing in addition to remote sensing training. The majority of the work done through the universities relates to the advanced applications which generally do not represent a large proportion of the value added industry.

Provincial government agencies such as the Ontario Centre for Remote Sensing (OCRS), the Manitoba Remote Sensing Centre (MRSC) and the Saskatchewan Research Council (SRC) represent a different case. The original mandate of these agencies was to investigate provincial applications for remote sensing technology and to promote the transfer of this technology to local organizations. In addition to technology transfer and basic

research, some of these organizations have conducted major projects for other government agencies and private industry in the interests of cost recovery. As a result, these agencies have become competitors with private industry. Because of the provincial organizations' ability to compete on cost, the growth of local private industry has been suppressed in some areas, notably Saskatchewan and Manitoba. There is also a spill over effect on companies operating in other provinces. Current information indicates that OCSR will not solicit private business in the future.

In terms of the supply of image processing systems, the principal Canadian companies are shown in Table 4.4.

Table 4.4: Major Canadian Companies Supplying Value Added Systems

| Company | Location | Software Capability |
|-------------------------------------|------------------|---|
| MacDonald Detwiler Associates (MDA) | British Columbia | Meteorological and Earth RS Systems, Radar processing, Stereo DEM |
| PCI Inc | Ontario | Multispectral Analysis |
| Dipix Technologies | Ontario | Multispectral Analysis |
| Applied Terravision Systems | Alberta | Multispectral Analysis |

It should be noted that Intergraph Canada, a wholly-owned subsidiary of Intergraph Corporation headquartered in the USA, is also a major supplier to the local market.

MDA provides a variety of hardware and software systems ranging from the Meridian image analysis system and Fire image scanners to the low-cost PC based Earth-probe image analysis system marketed by a subsidiary company. In addition, MDA has displayed the capability to develop custom high end image analysis and processing systems such as the Ice Display and Image Analysis System (IDIAS) which was developed for the Atmospheric Environment Service (AES) Ice Centre.

PCI image analysis software was initially developed for the personal computer, however, they have expanded their software capability to run on various technical work stations, mainframes and even supercomputers. As with MDA, PCI is distributing their systems world-wide including sales to Europe and has had recent sales to the medical profession.

Intergraph Canada has recently begun marketing the Tigress Imager System. This system has been on the market approximately one year. Its major strength is the fact that the image files are interchangeable between the imaging system and the very popular GIS software produced by Intergraph.

Dipix Technologies Limited was formed after the collapse of the original Dipix Corporation which enjoyed world-wide sales of its dedicated image processing systems throughout the 1980's. The focus of the new company is to provide user support service and upgrades to existing Dipix systems. Although the potential exists for a resurgence of this company, they are not currently at the forefront of their sector of the remote sensing industry mainly as a result of the poor reputation acquired by the original company for providing user support.

Applied Terravision is a new entry into the image processing field. Although their sales have been small, their software, called Landscan, has a powerful user interface and is optimized for processing of SPOT imagery. Due to the fairly limited size of the local Canadian market, this company, as with all others, will be dependent for its growth upon the success of its international marketing effort.

In addition to the aforementioned companies, there are several other firms providing image processing capability, as shown in Table 4.5.

Table 4.5: Other Canadian Companies, Value Added Systems

| Company | Location | Software Capability |
|---------------------|------------------|--------------------------------------|
| Eidetic Image Corp. | British Columbia | Low Cost Image Analysis Software |
| Pamap Graphics | British Columbia | GIS, Digital Mapping, Image Analysis |
| Imago | Ontario | Image Analysis |
| Nucor | Ontario | GIS, Image Analysis |

These systems have specific applications, such as GIS, but could be likely expanded to general purpose image processing systems given sufficient development effort.

4.3 The Existing Technology Base

The existing Canadian technology base is diverse but still relies on imported technologies as will be outlined in Section 4.4. Within this section, the available technologies possessed by Canadian industry will be examined in relationship to the design, development, and building of earth observation instruments and sensors. Potential applications of small satellites and other platforms as well as data reception, information, extraction, dissemination, and assimilation systems will be also considered.

4.3.1 Design Development and Construction of Earth Observation Instruments or Sensors

Canadian industry has a number of proven accomplishments in the building of earth observation instruments. These instruments include synthetic aperture radar (SAR), electro-optical imaging sensors, and instrumentation for monitoring of the upper atmosphere. These products have been developed for both airborne and space-borne systems.

In the case of SAR, the current technology has been primarily developed by MDA, Spar, and CAL, with assistance from a number of smaller companies which supply microwave components. In terms of airborne systems, MDA has developed the IRIS radar which is flown on military aircraft as well as the CCRS Convair-580 and the Star II airborne SAR system currently operated by Intera Technologies. CAL has supplied side-looking real aperture radars to the Atmospheric Environment Service and is currently offering an upgraded version with synthetic aperture capabilities and further potential to be used as a multipolarization system.

In terms of space-borne SARs, Canadian capability is equally advanced. The Radarsat active radar instrument, to be flown in 1994, has been virtually entirely designed and developed by Canadian companies. The construction to follow will also be Canadian. In addition, several Canadian companies have been consulted and provided design work for the ERS-1 SAR sensor and potentially could offer their services for the EOS SAR and ERS-2.

In terms of electro-optical systems development, a number of instruments have been developed by Canadian companies using Canadian designs, however, to date only one sensor of note has been flown on a spacecraft, that instrument being a far ultraviolet camera developed by the National Research Council and built by CAL. A number of airborne sensors, however, have been designed and built in Canada and show good potential for spacecraft applications. Among these is the Multi-spectral Electro-optical Imaging Scanner (MEIS) built by MDA. This multi-detector optical system which offers a high degree of flexibility in an airborne mode. A new MEIS sensor is presently under development and will

permit a wider swath width and stereoscopic capabilities possibly offering an economical alternative to aerial photography.

Two imaging spectrometer systems have been developed in Canada. One, the Fluorescent Line Imager (FLI) developed by Moniteq of Ontario, the other being the Compact Airborne Spectrographic Imager (CASI) developed by Itres Research of Calgary. Both of these instruments provide high spectral and spatial resolution in the visible and near infrared portions of the electromagnetic spectrum. Future developments are aimed at widening the spectral bandwidth of these instruments. This current technology is imminently applicable to spaceborne sensors due to their solid state nature. This is evidenced by American plans to fly two such sensors on the proposed Earth Observation System (EOS).

Canadian firms such as Spar Aerospace, AEG Bailey Incorporated, and MPB Technologies possess some capability in the production of infrared sensors, although probably not to the same extent as British or American technologies. The majority of these instruments are sold for military purposes and thus the exact specifications are difficult to ascertain. However, commercial systems consisting of Forward-Looking Infrared Radiometers (FLIR) are available. These systems are primarily used for forest fire detection, and other such surveillance work and are not suitable for spacecraft applications although similar technologies could be used for a nadir looking instrument. The primary difficulty with the development of infrared spacecraft instruments is the need for large, high quality optics requiring a large, expensive spacecraft which is unlikely to be launched in the near future.

A number of non-imaging type sensors are also within the capability of Canadian industry. These include microwave scatterometers (MPB Technologies), radio interferometers (CAL), ion mass spectrometers (SED), and laser instruments (Optech and Barringer). Instruments such as these play an important role in the quantitative analysis of the earth's meteorological system as well as studies of the factors influencing the total earth's climate. Research on instruments, such as the those listed above, is ongoing world-wide. However, local expertise to design and built such instruments is quite good. One example of such capability is the Supra-thermal-ion Mass Spectrometer (SMS) which was designed by the Canadian National Research Council, built by SED systems in Saskatoon, and has been flown on the Japanese EXOS-D satellite.

In general, the Canadian technology base for the development of instrumentation technology is quite complete, however, it should be pointed out that the rate of progress in

these technology areas is quite high and in order to keep abreast of current developments, basic research into a number of key technologies must be continued. These technologies include radar antennas, transmitters and receivers, optical components, and hybrid materials for detection of specific electromagnetic wavelengths.

4.3.2 Small Satellites and Other Platforms

The technology required to design and build the basic spacecraft platform for a large satellite does not appear to be present in Canada at this time. Due to the high cost of such development, and the availability from a number of foreign sources, it is unlikely that such technology will be developed in the near future without a significant initiative on the part of the Canadian government. On the other hand, the small satellite concept is an open field. To date no actual small satellites have been launched, however, interest in this technology is high for a number of reasons. From the users' point-of-view for earth remote sensing, small satellites in their stated concept would provide the ability to launch numerous earth observation systems thus increasing the chances of obtaining cloud-free imagery of a particular area and potentially lowering the cost of data acquisition. From the systems suppliers' point-of-view, small satellites are attractive because by their very concept a small satellite system would imply a large number of these spacecraft, thus allowing contractors to level their personnel and equipment requirements over an extended period of time and improve their general management systems.

A small satellite would not require the large general purpose satellite bus which is found on most systems currently in use, rather the small satellite would be based on a single purpose design where the structure would integrate the sensor, telemetry and control systems power and other ancillary systems into a single framework. Due to the basic simplicity of this concept and the implied benefits of such a technology, a number of Canadian companies are eager to develop such a platform. Foremost among these companies are Spar Aerospace, Bristol Aerospace, SED systems, and Canadian Astronautics Limited. If such a concept were to be funded, other potential entrants into this field could be Oerlikon Aerospace, Edo Corporation, and MPB Technologies. While these companies possess the majority of the necessary requirements for such an undertaking primarily the knowledge required for design and construction of these systems, what appears to be lacking in Canada are the key technologies involving reaction control, attitude control, and advanced materials development. Finally, it should be noted that the entire premise of the small satellite system would be

dependent upon the parallel development of a national launch capability without which the inherent economy of these systems would be lost.

4.3.3 Data Reception, Information Extraction, Dissemination and Assimilation Systems

As stated previously, the Canadian technology base for data reception is well developed and Canada competes successfully on the international market through several leading firms. The supply of components for these systems, however, is primarily non-Canadian. Key components include computer systems, antennas, and data storage systems. The strength of the Canadian companies appears to lie in their abilities for systems integration and the provision of crucial components such as dedicated processors, software and colour image printers.

One of the challenges for the future will be the efficient extraction and dissemination of the increasing volume of data gathered by remote sensing satellites, both present and future. This will require high speed computer systems coupled with efficient software and image processing capabilities and backed-up with high speed, large capacity data storage facilities. Several Canadian companies are addressing these needs in various areas. For instance, Myrias Research in Edmonton is building a large parallel processing supercomputer which may provide suitable capability for high speed image processing. Research into improvement of software applications for data assimilation and information extraction is ongoing both at the government research centre level and also in a number of private companies. The value added products which result from information extraction are limited both by computer technology and by the algorithms available. These limitations change as new approaches and technologies become available. For example, the concept of using texture in digital processing was developed in the 1970s but the amount of processing time required was in the order of weeks which limited the use of this algorithm. This algorithm is presently being investigated for a variety of applications which would not have been possible without the improved computing technology. Shape algorithms will be one of the next techniques to have an impact on digital image processing. The problems of high capacity data storage are being addressed by a B.C. firm, CREO Electronics, which is developing an optical tape drive which could potentially be applied to remote sensing data storage.

4.4 Deficiencies in the Canadian Technology Base

As discussed in the previous section, the Canadian technology base for earth observation covers the entire spectrum from space systems through to applications of the acquired data. However, several gaps exist in the existing technology base. These deficiencies are discussed according to the three primary industrial sectors.

4.4.1 Satellite Systems and Subsystems

In spite of Canada's long history of involvement in satellite development, the deficiencies still evident today are in the areas of attitude control systems, reaction control systems, solar cells, the basic spacecraft bus, and launch capability.

Presently, there is no Canadian company which currently possesses the technology to build a multipurpose spacecraft bus. These systems, while providing the general structure for the spacecraft, also integrate electrical power distribution, thermal control, and other necessary requirements. The basic problem with developing this technology is in the amount of experimental development which would be necessary for the final design of a production spacecraft. Such a program would have very high costs and would be prohibitively expensive for a private company to embark upon.

Attitude control systems allow the spacecraft to be accurately positioned relative to the earth and as such are an absolute necessity for most remote sensing satellites. These systems consist of sun and horizon sensors, momentum wheels and electromagnetic torquing rods. The primary reason why these technologies have not been developed in Canada is their ready availability from foreign suppliers and the associated experimental costs involved in developing proprietary systems.

Reaction control is another capability which Canadian industry lacks. Reaction control systems consist primarily of thruster devices which allow the spacecraft orbit to be modified, thus prolonging the usable lifetime of a satellite. The primary problem with development with these systems is the need for a greater technological base in liquid fuel rocket technology which is currently lacking in Canada.

The basic component of solar arrays, which are an essential supplier of power for satellite systems, is the solar cell. These semiconductor based devices are not currently produced in Canada, however, the integration of the entire solar array is completed domestically. This is a key technology which could easily be developed in Canada depending upon economic factors.

A final area in which Canadian industry is deficient in the space sector is in the ability to launch satellites. This hampers Canada's ability to fully control its Radarsat program and telecommunications satellites. On the other hand, with the growing availability of foreign launchers from such countries as the US, France, China, Japan, and recently the USSR, it seems unlikely that economic necessity will force the Canadian industry to develop such a launch capability for major payloads.

4.4.2 Data Reception and Handling

In this area Canadian industry does not demonstrate any outright weaknesses except perhaps in the provision of Canadian-made telemetry antennas. Changes in the Canadian data distribution system are anticipated in the near future with the formation of Radarsat International (RSI). This consortium of Spar Aerospace, MDA, Com Dev and Intera Technologies offers the potential to improve an already excellent system of data distribution. However, with one of the consortium members in the value added segment, care should be taken to ensure that there is no access to commercially confidential information supplied by its customers for the purposes of unfair competition. In addition, the possibility exists for the image processing to be monopolized by this consortium thereby hampering the competitive environment, in Canada and Internationally, for other value added industries.

4.4.3 Value Added Services and Systems

In the value added services segment, Canadian companies are competing in international markets against U.S.A. based companies and primarily government owned European companies from countries such as France. France's value added segment is in most cases entrenched into the national space program. This results in a government subsidized system which gives France the edge in obtaining international contracts for image analysis and processing. With the market likely to significantly expand in the next decade, more of the market share will go to foreign governments. A particular example is the continued development of enhanced products by SPOT Image Corporation which essentially removes competition since an end-use of the analysis will simply purchase the enhanced SPOT data directly from the French company.

In the U.S. market, Canadian companies are not heavily involved due to the competitive market in this country and the large number of value added suppliers.

The following deficiencies in the Canadian value added segment have been identified. Firstly, there is a lack of coherent technology transfer policy for applications between federal,

provincial agencies and private industry. As mentioned earlier, several provincial research agencies have completed pilot projects and then moved directly to providing value added services. This technology would be more useful if it were transferred to the private sector, thus allowing an expansion of private industry rather than government bureaucracy. Secondly, Canada lacks the ability to process stereo SPOT and radar data. If this we could develop capability and successfully transfer the technology to the value added sector, a potentially large untapped portion of the market could be available to Canadian companies. Applications areas for this technology include geology, hydrology, forestry, engineering and mapping. The automated production of DEMs would permit the integration of these data in image classifications and rectifications to name just two areas of use in the previously named fields.

In general, Canada can not consider itself deficient in the technological base in relation to other countries. However, if Canada developed the following technological capabilities prior to other nations, it could capture a large segment of the remote sensing market. The first technology is a low cost plotting system in which hardware and software would be far more accessible and economical than the current plotting systems. A second technology involves developing direct link between remote sensing and GIS systems. Some companies have claimed to be successful in this area but they must exit one operating system and then import the file to the next system. A third advance could be made in the integration of geophysical data with image processing systems. This integration has not been clearly define or transferred to the value added community at this time.

4.5 Areas for Development and Improvement in International Markets

In order to expand international markets for Canadian remote sensing technology, the industry must offer superior products and service at a competitive price, or apply innovative thinking and concepts in order to create new markets. The following discussion covers a number of good potential concepts and products which could potentially expand the Canadian share of the international market.

One of the prime products for which Canadian industry is known is synthetic aperture radar. By continuous improvement of these radar system components including antennas, receivers, transmitters, and processors, Canadian companies stand to benefit from the growing international market for radar systems. It is anticipated that as the utility of spaceborne radar imagery is realized, continuations to such programs as Radarsat, ERS, and JERS will be funded. As well, the Earth Observation System could potentially launch as many as three synthetic aperture radars for which Canada could become a supplier.

In the market for ground receiving stations for remote sensing satellites, Canada is a leading nation. A problem with market growth in this area is the high costs associated with the ground receiving stations in addition to the rising licence fees charged by SPOT, EOSAT, and other potential satellite operators. One concept for reduction of the cost and expansion of the market which may prove feasible is the idea of designing and building modular, mass produced ground receiving stations. By offering the highest quality product at the lowest price, Canadian firms could be fairly certain of receiving most of the future contracts for ground receiving stations throughout the world. By building these systems in a modular fashion, upgrades would be simplified for reception of new satellites such as Radarsat and as well, the Canadian company would be favoured for performing this upgrade because the systems would be compatible by design.

The various users of remotely sensed data are by and large concerned with information about geographic locations. For this reason, the use of geographic information systems has proliferated throughout the world over the past several years. One of the primary problems for suppliers of value added interpretation services has been the integration of image processing systems with GIS. Were this capability to be realized in an efficient and cost-effective manner, the applications of remote sensing would almost certainly increase thereby increasing the market for value added services. The amount of research being done on this topic is high throughout the world at this time. Almost certainly no nation will hold the lead for any significant period of time but, to be the first country to accomplish a useful linkage between image processing and GIS would be a significant publicity factor and could contribute to a general strengthening of the Canadian value added remote sensing industry.

Another area which would benefit the Canadian Remote Sensing Industry is in the processing of radar data. By developing the best technology for analysis and interpretation of radar imagery, Canadian firms will be able to actively expand their international markets for such services as well as market the available software. The ability of Radarsat to provide a continual and reliable data set will have a positive effect on operational monitoring systems. The same is true for ERS and JERS data. While operational systems will make use of a variety of data sets, relationships between vegetation condition illustrated on multispectral and radar sets are necessary to make inferences about vegetation condition when multispectral data sets are unavailable. This in turn will have a positive effect on the overall Canadian industry by increasing the demand for Radarsat imagery.

On a more general theme, a Canadian initiative to develop an environmental monitoring capability covering a wide variety of sensors and a holistic approach to the analysis of the data and the modelling of environmental processes would be a highly marketable capability for third world

countries as a total service. Such a system would be modelled after the proposed EOS system but on an operational as opposed to experimental basis and yield results or observations about the Earth that have not been previously noticed. This would imply the use of numerous spaceborne and airborne sensors coupled with ground data collection systems and a multivariate data processing procedure.

4.6 Summary

Canada has a major interest in earth observational technology and applications. Since it is the second largest country in the world by land mass and is sparsely populated, monitoring resources is a primary reason that Canada has entered the remote sensing field.

As has been mentioned in this chapter, Canadian capabilities are extensive in various areas of the remote sensing industry primarily through previous experience with the production of communications satellites and in the application of airborne remote sensing. Through the development of these satellites, Canada has obtained expertise in providing a variety of systems specifically sensors TTC and power systems. It also has a firm capability for system integration and testing. However, Canadian industry is deficient in the areas of attitude and reaction control as well as in the lack of technology for the construction of the complex satellite bus. For Canada to pursue these areas, the economic benefits versus the R & D costs will need to be carefully considered.

In terms of ground stations, Canada is at the forefront of this technology. As a systems integrator, the deficiencies in this sector are evident in the supply of basic components such as computer systems, displays, and antennas.

The value added sector is presently hampered by the lack of technology transfer from government agencies and the current provincial centres conducting value added services. It is imperative that the technology being developed within government research agencies is released to the private sector. In so doing, the Canadian value added sector will improve upon its capabilities and therefore be able to pursue new markets. However, the Canadian Government will need to assist Canadian industries by implementing a National Strategy to benefit the remote sensing industry.

CHAPTER 5

STRATEGY ASSESSMENT

5.1 Description of Strategy Assessment

The purpose of this section is to develop optional strategies for the optimal application of Canadian capabilities to the international remote sensing market. Development of such strategies will be achieved by identifying growing market areas which match existing Canadian capabilities and identifying areas in which Canadian capabilities can be effectively enhanced. A prediction is also made of the future market share attainable by Canadian companies in the three industrial sectors of the earth observation market. Central to the strategic plan is the proposal for a series of federal government policies to further the Canadian remote sensing industry. Finally, a recommendation is made for continued monitoring of market conditions in order to ensure that the proposed strategies are having their desired effect.

5.2 Areas of Potential Market Growth

The earth observation and remote sensing industry is currently in a position of early development and thus has a large capacity for potential growth. Actual growth over the next decade, however, is difficult to predict due to the high cost and associated difficulties of budget mobilization for the realization of technological advances in this field. Based upon current funding planned by the various space agencies, a number of specific subsectors of the industry can be expected to grow over the next ten years.

Clearly, the market for complete satellite systems for earth observation may be expected to increase in the short-term based simply upon announcements of future earth observation satellites by the various space-faring nations. In fact, there is already a certain amount of competition among existing systems. Unfortunately for Canada, the complete satellite system market is protected by the nations which supply the funding; therefore, any major benefits to Canadian industry will be dependent upon Canadian government funding and initiatives such as contributions to NASA or ESA. It is likely that the best hope for Canadian satellite producers would be a Canadian government

commitment to a follow-on to Radarsat, and possibly a long-term, small satellite based earth observation system.

Unlike satellite system prime contractors, manufacturers of satellite components and various subsystems may see significant expansion in their sector in the coming decade. This growth potential applies particularly to makers of sensors, specifically those of radar antennae and associated components as well as custom optical components, power systems, telemetry and control systems and solar arrays. In order to secure these contracts, Canadian industry must work to ensure the superior quality of its products while the federal government must maintain close cooperative links with the other space industry nations.

The market for complete new ground receiving stations for earth observation will likely see small to medium growth over the next decade. The potential construction of between two and six new ground stations in order to provide complete Landsat and SPOT coverage of the Earth's land mass is likely. Also, political considerations may prompt the construction of several more receiving stations in areas where the level of political cooperation between nations is low. Such a situation currently exists between Pakistan, Bangladesh, and India, for example. Canadian industry is well positioned to benefit from this general market growth, except possibly in the Soviet Union and areas of strong U.S. influence such as Latin America.

The potential market for upgrading of existing ground stations appears to be quite promising. If the assumption is made that commitments to ensure the continuous availability of data such as that which will be provided by Radarsat, ERS-1, and JERS-1 are made, then it seems likely that a number of existing ground stations will be chosen to upgrade their equipment to receive and process radar data. The Canadian industry is at the forefront of this technology at this time and having built a number of the ground stations worldwide, stands to gain a significant proportion of the upcoming contracts with this type of work.

Growth in the value added sector of the earth observation industry is difficult to predict as it presupposes an increase in the number of end users or the scope of their requirements. Such an expansion will require significant progress in end user educational programs and marketing. At the present time, the market is characterized by a small number of capable firms marketing to a large body of relatively uneducated and sceptical potential end users. Because of this, the market will exhibit a positive feedback response to successful project completions; that is, a successful application of the technology on a project basis may lead to much greater market growth than might otherwise be anticipated in a more mature market. A prime candidate for this type of scenario is the large body

of potential end users who are also GIS users, such as the forestry industry. If remote sensing applications can be demonstrated to be an efficient and cost-effective means for supplying reliable data to GIS users, the heavy demands for data which GIS systems generate will ensure a large market for the value added industry both in software and services. In spite of the obvious applicability of remote sensing technology to the supply of data to GIS, the growth of this market is not guaranteed to occur while end users employ alternative methods of data collection. In addition to a lack of proven applications and user education, two other factors are impediments to the growth of this industry; namely, cloud cover obliterating optical imagery and slow delivery times for data.

More optimistically, a number of applications of remote sensing technology have been shown to be feasible on an operational scale; namely, agriculture, forestry, mapping, and surveillance. A number of Canadian firms are well positioned to take advantage of this market potential. Also, with the expanding data base of available imagery and the expected increase in demand for processing of imagery, a number of service applications should see some growth over the next decade. These include stereo processing of satellite imagery for elevation determination, image geocorrection and colour printing.

In summary, the areas which represent potential market growth for Canadian companies are as follows:

- (a) Minor growth for satellite prime contractors.
- (b) Moderate to significant growth for manufacturers of satellite components and subsystems, specifically those related to radar sensors.
- (c) Small to medium growth for suppliers of ground receiving stations.
- (d) Moderate to significant growth for suppliers of upgrades to existing ground stations, specifically for radar and other high resolution sensors.
- (e) Potentially significant growth for suppliers of value added services and systems.

5.3 Prediction of Market Share

Canadian industry currently possesses a small, but relatively stable portion of the international markets in each of the sectors of the remote sensing industry. As the markets and competition levels change, the market shares held by Canadian firms will also fluctuate. Factors which affect market share in these sectors include the following:

- (a) Level of technology relative to competitors;
- (b) Pricing;

- (c) Type and level of government support;
- (d) Quality of marketing effort;
- (e) International perception of Canadian capability.

In the satellite and ground station market segments, government support is extremely important. Major contracts in these fields are often apportioned according to the amount of contributions made by the contractor's government, as is the case with ESA. In dealings with developing countries, contracts are generally financed through foreign aid programs. In such cases, companies from the country which makes the greatest donation generally win the largest share. Even contracts which are open to international bids are subject to the influence of participant governments promoting their national space industry. An example of such influence is Canada's commitment to supply an upgrade to the Brazilian ground station for the reception of ERS-1 data partially resulting in Spar Aerospace being awarded the contract for the Brazilsat communications satellites.

In the value added sector, government support is somewhat less of a controlling factor although it is still significant. Foreign aid policies such as CIDA Inc. allow Canadian firms to export their products with government funding. The U.S.A., Japan, and many European nations have similar programs, however, the sum total of all government funding represents only a small proportion of the value added market. For the most part, free market forces, pricing and product value control this sector. This is particularly true in the service portion of the sector where government support is noticeably lacking.

The following sections discuss the percentage of the international market which may be captured by Canadian firms for the supply of products and services in each of the three industry sectors. The technological improvements necessary to achieve this level of performance are also discussed.

5.3.1 Market Share: Products

As mentioned above, the market for satellite systems and components is heavily influenced by government policy. Canadian companies are generally successful when competing for the supply of minor components and raw materials, such as microwave devices, aluminum and plastics. This success is due to procurement decisions being made on the basis of price, quality and availability for such low cost items. However, in the market for complete satellites and major sub-systems, selective procurement policies are dominant. In general, Canadian companies do not obtain these major contracts unless they have a

considerable technological advantage over competing firms or funding is supplied by the Canadian government under a cooperation agreement.

Over the next decade, roughly thirty earth observation satellites are planned for launch. These programs represent between \$10 and \$30 billion in contracts for the provision of systems, materials and assembly. Keeping in mind that not all of these proposed satellites will ultimately be launched, it seems likely that Canadian firms may capture up to 7% of this expected \$20 billion market, assuming that;

- a) current procurement trends of relevant foreign governments remain stable;
- b) Canadian involvement in NASA and ESA remote sensing programs is maintained or slightly increased.

This market share represents up to \$1.4 billion total over ten years and does not include possible future Canadian earth observation satellites such as Radarsat 2. It is estimated that Canada presently holds about 5% of the international market for satellite systems and components. In order to realise this potential 2% increase, Canada will be required to commit substantial funds to specific optional ESA programs such as ERS-2 and EPOP and maintain a high contribution level to the various NASA projects. Contracts which may be procured based upon technological superiority, pricing, or available capacity will be primarily related to microwave technology, testing facilities, data transmission and processing.

In the data reception and distribution sector, the market share held by Canadian firms is already high, estimated at roughly 40-50%. This share could very likely increase as the market shifts to upgrades to existing stations for the processing of radar data. Canada will probably capture 60% of these upgrades due to the technological lead in the field held by companies, such as MDA, who have a solid reputation for quality and service.

There is a potential for the construction of up to six new ground receiving stations at various locations during the coming decade. Of these, Canadian firms will likely participate in four or five, however, similar to the situation for satellite systems the selection of the prime contractor is generally determined by government support. This implies that the actual market share which will be captured will depend heavily on Canadian initiatives. It is not unreasonable to assume that a Canadian firm will be chosen as prime contractor for at least one station with major participation in three or four others. After including subcontracts, particularly for software and colour image printers, a total market share of roughly 55% of

the six new ground stations may be predicted. This gives a dollar value to Canada of from \$40-50 million.

In the value added industry, the primary products are image processing systems and software. In this market, Canadian firms are experiencing healthy growth. The size and potential of this market are extremely difficult to determine because they are dependent upon user acceptance of an infant technology. Therefore, the potential market for image processing systems over the next ten years could range on the very broad spectrum from \$75 million to \$1 billion. Canadian systems enjoy a good reputation for quality and are competitively priced. As well, there are nearly as many Canadian companies offering products as there are in the U.S.A. These factors lead to the conclusion that, regardless of the rate of market growth, a share of between 10% and 30% of all sales may be attained by existing and future Canadian firms.

One factor which will have a significant bearing on the market is the growth of GIS software to perform image processing tasks. Since end user requirements are not generally to acquire image data, but rather to obtain the information which can be extracted from them, hybrid GIS packages can be expected to capture a large share of the image processing market. For this reason the current status of existing GIS firms must be considered. In this field, Canadian firms are not as well represented as in the image processing field, however, the level of expertise is equivalent. One disadvantage currently experienced by Canada is that the major market for GIS systems is in the U.S.A. This demand for software and systems is driving development efforts which may lead to significant technological superiority in competing GIS systems.

5.3.2 Market Prediction: Services

The market for services in the satellite systems sector includes engineering design, simulation, feasibility studies, integration and testing. The demand for these services is expected to increase as other countries attempt to tap into Canadian expertise in the design and application of microwave technology. Canadian membership in ESA allows aerospace design firms to compete for feasibility and design studies for most proposed programs. Historically, Canada has been successful in obtaining a share of ESA contracts. Contracts for U.S. programs are generally dependent on the competing firm having unique expertise or funding by the Canadian government. Such qualifying programs are generally inexpensive,

compared with construction and launch costs, and thus are less prone to scrutiny by national spending control authorities. The total market for feasibility and design studies is roughly 10% of the satellite systems market, giving a total dollar estimate of between \$1 billion and \$3 billion over the period 1990-2000. Canadian firms may capture between 2% and 8% of this total market, depending upon how well the requirements of the studies match Canadian expertise and on the availability of sufficient personnel to perform the work.

In the data reception and distribution sector, service generally entails software upgrades, system maintenance and training. The software market is relatively captive, that is, the original supplier does not have to compete for upgrade projects. As a leading supplier of ground stations, this works in Canada's favour. System maintenance is generally performed by local contractors with expertise in supporting major data processing systems. Aside from supply of operational personnel, these two requirements represent the only portion of ground station operating budgets which may be captured by private firms. For a typical ground station, the requirements for software upgrades and system maintenance would translate into about \$100,000 to \$250,000 per year, assuming major software upgrades are not anticipated.

Training and technology transfer programs are often included in the original contract for the supply of a ground station. Follow-on programs are generally required but are not always performed under a commercial contract. Staff upgrades through the sponsorship of university courses and hiring of qualified personnel are often used alternatives to a formal technology transfer contract. Similar to software upgrades, the original supplier is often favoured with any in-house training contracts. Other technology transfer programs are funded on an intermittent basis. Overall, the present technology transfer market outside of universities and technical institutes is less than \$10 million per year. This market could grow significantly over the next ten years as the need for training in remote sensing technology becomes more widely recognized. Expectations of a three to five fold increase in the number of contracts let are not unreasonable. In technology transfer, Canada will command less than 5% of the total market unless major initiatives are begun to increase world awareness of Canadian capabilities in this area. The European, American and Japanese governments have already targeted this market as having important spin-off benefits for other sectors of the remote sensing industry as well as being a potential profit centre per se.

Service contracts are the basic source of income for the value added sector of the earth observation industry. The services provided include environmental monitoring, resource

mapping, surveillance and weather prediction. The size of this market is extremely difficult to estimate due to the large number of companies and subcontractors involved and their reluctance or inability to divulge the ultimate source and volume of their business. However, by taking a similar approach to that used to estimate the market share held by Canadian companies for the sale of image processing systems, the current situation may be assessed. The number of value added remote sensing companies in Canada represents roughly 10% of the total number world-wide. Although the size and capability of these firms vary widely, the overall market share held by these firms is roughly that stated above. Several factors are important to note in this market. The Canadian firms competing internationally are at or near the forefront of their respective fields. For this reason, the Canadian firms compete successfully for a large proportion of all international contracts. The markets in Europe and the U.S.A. are partially closed to these firms either because of political barriers to trade or an inability to compete with local competitors who can offer personal service at a lower cost. Therefore, it can be concluded that as the market matures and expands, particularly in developing countries, Canadian firms stand an excellent chance of increasing their total market share to roughly 15% of the overall market. Depending upon the rate at which the overall market expands, this could lead to dollar values ranging from \$70 million for a growth rate of 8% to \$110 million for a growth rate of 15% over ten years.

5.3.3 Technology Enhancements Required To Achieve Market Share

From the foregoing discussion, it is clear that in addition to government support for the export of Canadian technology, certain technical advances will be necessary to maintain and increase the portion of the international market held by Canadian firms. Foremost among these is maintenance and continued advancement in the technology base relating to synthetic aperture radar systems. Significant advances have been made in the design and construction of advanced antennae, transmitters, receivers and processors through the development of the Radarsat sensor and experience in the airborne experimental program. As competing nations strive to duplicate this technology, a continuing effort must be devoted to maintaining Canada's lead in this field. This can be achieved through research initiatives by the CSA and CCRS; however the best results will stem from actual design and construction of operational space and airborne radar systems. Specific technologies which must be addressed include steerable beam antennas, multipolarization and multifrequency systems, high speed array processors and the reduction of transmitter power requirements.

With the increasing interest in the concept of the small satellite, Canadian research efforts should be directed towards the development of efficient, lightweight optical, power, and communication components for integration into these satellites. For instance, solar arrays and their deployment mechanisms which make up a major component of the bulk and mass of a satellite will need to be lighter and more compact in order to allow the use of small launch vehicles. This is an area which Canadian industry may concentrate upon and thus gain a measure of input into future small satellite programs.

The technology used in ground receiving stations is constantly being upgraded, primarily as a result of the high rate of advance in the field of computer technology. The challenge for Canadian suppliers is to keep abreast of these changes in order to offer their prospective clients the most efficient and economical hardware/software combinations available. Key technologies which will require continued development are software systems for maximum utilization of array processors, high capacity storage systems and data management techniques.

The value added sector of the industry will be the driving force behind the expansion of the earth observation market. As the developers and implementors of new applications for remotely sensed data, value added organizations will be responsible for any growth in demand for data and services which will stem from the introduction of new users to this technology. Naturally, those companies which develop new markets will capture the largest share over the short term. For this reason, continuing technology development for the applications of remotely sensed data is essential to the prosperity of the Canadian value added industry. Specific areas which warrant attention are as follows:

(a) The Integration of GIS and Image Processing Software

As mentioned previously, satellite imagery offers an optimal source of raw data for users of GIS such as resource managers and land use planners. The difficulty at this point is the transfer of the processed image data in a useful form from the image processing software to the target GIS systems. Conversely, data which resides in existing GIS systems may be useful in the interpretation and analysis of satellite imagery. Clearly, the development of GIS systems which allows the efficient use of satellite imagery for data capture will open large new markets for such imagery.

(b) Extraction of Digital Elevation Models (DEMs) from Satellite Imagery

At present only a small percentage of the total land surface of the world is mapped with large or medium scale topographic maps. The advent of high resolution pointable satellite sensors such as the SPOT HRV and the Radarsat SAR sensor will allow topographic mapping at moderate scales to be performed with satellite imagery. This concept has already been proven through the use of SPOT and other stereo imagery.

(c) Integration of Multisensor Data Sets, Particularly Geophysical and Geochemical Data

Satellite data has seen increasing usage in the exploration for minerals and petroleum, however, satellite images reflect only the surface features of the earth. By incorporating subsurface information in the form of geophysical and geochemical measurements, more advanced techniques may be applied to the search for these valuable resources. In addition, the integration of various remotely sensed data sets may yield important insights into the interrelationships of the earth's environmental parameters. There is little doubt that man's impact on his environment over the past few centuries will be revealed.

(d) Use of Shape and Texture in the Analysis of High Resolution Data Sets

High resolution images such as are provided by the SPOT HRV, Landsat ETM, and Radarsat sensors exhibit higher local variability than those obtained from previous satellite sensors. These images are more difficult to classify using established multispectral analysis techniques, however the improved resolution offers additional data qualities which may be interpreted using the shape and texture shown on the images. The demand for reliable and efficient software products to perform these analyses is expected to increase.

(e) Efficient Analysis of Imaging Spectrometer Data

Imaging spectrometers are currently used in airborne experimental configurations and are expected to be used on satellite platforms towards the end of this decade. These instruments provide extremely high spectral resolution offering an order of magnitude more bands than currently existing multispectral scanners. The "image cube" data generated by imaging spectrometers represent a challenge to existing multispectral analysis software to provide efficient throughput and data management techniques.

5.3.4 Summary of Market Share Predictions

The median values of the anticipated total market and potential Canadian share over the ten year period, 1990 to 2000, are shown in Table 5.1. As can be seen, the expected total market is conservatively estimated to exceed U.S. \$22 billion. Of this market, Canadian firms may be expected to capture roughly 7%, totalling \$1.6 billion.

5.4 Recommended Government Strategies to Enhance Canadian Competitiveness

The Canadian Government and private industry have been active participants in the remote sensing market for several decades. As a result, Canada has a strength and presence in the international field of remote sensing that is unique especially given the small population of Canada. The technology developed and applied in Canada holds great promise as an exportable product of ideal characteristics. Such characteristics include:

- (a) low resource requirements;
- (b) efficient utilization of brain power;
- (c) no negative residual effects;
- (d) applicability to many of the new and growing industrial sectors of the twenty-first century;
- (e) provides a renewable and expanding revenue stream;
- (f) provides a world-wide showcase of Canadian engineering and technical talent;
- (g) contribution to the solution of many of the most pressing environmental problems.

With the impending launch of Radarsat, Canada is moving into a leading role among nations. The opportunity exists at this time for Canada to solidify its position as a world player in the earth observation field. This opportunity, however, demands close cooperation between both the provincial and federal governments and private industry.

The cornerstone upon which a significant Canadian industrial base can be built is a strong, clear, consistent, and long-term commitment by the federal government that embraces remote sensing as a field that Canada has chosen as one of great importance to Canada's international business strategy. This commitment will provide a strong framework within which private industry may expand. Such an expansion will require visible policies that can be referred to constantly, both domestically and internationally, in order to generate the greatest possible confidence in Canada's commitment to the remote sensing industrial sector.

Long-term export opportunities, in terms of revenue producing products and service as well as world-wide leadership and aid to developing nations, can be created by a series of industry

TABLE 5.1
SUMMARY OF PREDICTED CANADIAN MARKET SHARE

| MARKET | ANTICIPATED 10 YEAR TOTAL | POTENTIAL CANADIAN SHARE | |
|-------------------|------------------------------|-----------------------------|---------------------|
| | \$ US | % | \$ US |
| PRODUCTS: | | | |
| Satellite Systems | 20×10^9 | 7 | 14×10^9 |
| Ground Stations | 82×10^6 | 55 | 45×10^6 |
| Value Added | 100×10^6 | 20 | 20×10^6 |
| SERVICES: | | | |
| Satellite Systems | 2×10^9 | 4.5 | 90×10^6 |
| Ground Stations | 40×10^6 | 25 | 10×10^6 |
| Value Added | 600×10^6 | 10 | 60×10^6 |
| TOTAL | 22.822×10^9 | 7.1 | 1.625×10^9 |

sustaining support programs with long-term supervision to be administered by the federal government. The strategic recommendations which follow are based upon an assumption that Canada has accepted remote sensing as an essential element of its economic strategy. These recommendations can be treated in terms of policy development and funding commitments. The highlights of these recommendations are summarized in Table 5.2 and detailed in the following subsections.

5.4.1 Policy

In terms of policy, three items should be addressed at both the federal and provincial levels; namely, government requirements for environmental and resource monitoring, standards and procedures for such monitoring, and private sector input to government policies regarding remote sensing technology.

First, requirements for environmental monitoring by resource users and regulatory agencies should be increased. This policy will have a two-fold impact of improving Canada's environmental awareness as well as increasing the demand for remote sensing data and value added services. At present, monitoring of Canadian environmental conditions is performed on an ad hoc basis, generally in reaction to situations of massive ecological damage or issues which have captured popular interest. Examples of these types of issues are the effects of acid rain and the public outcry over the depletion of British Columbia's coastal rain forests. It has become clear however, that environmental processes and the factors that influence them cannot be completely understood as discrete phenomena. For this reason, a successful environmental monitoring program will be required to track a wide array of parameters in order to detect significant adverse changes before they reach critical proportions. An understanding of the extent and severity of man-made changes to the environment implies a quantitative data base covering issues such as soil erosion due to clear cutting and agricultural activities, industrial emissions, the side effects of resource extraction, and other activities. Such an understanding is required by policy makers and their advisers in order to realise the oft-stated, but somewhat incompatible goals of environmental protection, sustainable development and economic growth. By enacting legislation which requires industry to determine and report on its effects on the natural environment and increasing regulatory activities in the same area, this data base will begin to take shape. The benefit to the remote sensing industry will be in the increased demand for its products as users choose the most cost-effective approach for data acquisition.

HIGHLIGHTS OF STRATEGIC ASSESSMENT

POLICY

1. **Environmental Monitoring:**
Increase requirements for environmental monitoring by resource users and regulatory agencies.
Upgrade provincial and federal environmental monitoring programs.
2. **Use of Remotely Sensed Data:**
Enact legislation requiring the use of remotely sensed data for above environmental monitoring regulations.
3. **Industry Input:**
Government should actively seek private industry input on establishment of research and international market development priorities.

FUNDING

1. **Radarsat 2:**
Commitment should be made prior to launch of Radarsat 1.
 2. **Promotion of Canadian Industry:**
The export of Canadian expertise should be promoted through the provision of technically literature trade officers in key market areas. A catalogue of Canadian companies and their capabilities should be published to aid in this endeavour.
 3. **Research and Development:**
R&D efforts should address:
 - Advanced SAR sensors and Applications of SAR Data;
 - Imaging spectrometer;
 - Wide field of view V/IR scanner;
 - Microwave scatterometer;
 - Atmospheric lidar sensors.
 4. **Education and Technology Transfer:**
Canadian Technical expertise should be marketed internationally through the supply of professors and instructors to key international institutions to teach remote sensing theory and practise. Support for the training of international students at Canadian institutions should be supplied.
 5. **International Cooperation:**
Canada should actively pursue cooperative efforts with other countries in remote sensing programs. Specific programs which should be considered include:
 - EoS;
 - ERS-2;
 - SPOT 5;
 - NOAA.
-

To amplify this effect, a second policy of ensuring that remote sensing technology is used wherever applicable can be applied to all federal and provincial regulation programs. These operational programs should be subcontracted to private industry, not government agencies. Additionally, industrial regulations for environmental monitoring could be rewritten so as to require industry to use satellite data wherever possible. The result of this policy will be to develop a highly experienced value added environmental monitoring industry within Canada which could potentially export its expertise internationally. The Earth Environment Space Initiative (EESI) could contribute to the development of the above two policies by providing technical assistance to government agencies and resource industries for the development of remote sensing data acquisition programs as well as development of sensors specifically designed for environmental monitoring under Canadian conditions.

The third policy recommendation calls for the federal government to actively pursue private industry input for advice on research and market development priorities. This function is partially fulfilled by the Canadian Advisory Committee on Remote Sensing (CACRS). An expanded role for this Committee may be what is required in order to ensure that the needs of the remote sensing industry for new research and in opening international markets are addressed by government funding policies.

5.4.2 Funding

While the policy recommendations given above will be generally beneficial for the Canadian earth observation industry, they will not ensure the growth that will be necessary for Canadian industry to remain competitive in this sector through the coming decade. Historically, the space industry has been primarily government funded due to the high risk levels associated with these types of endeavours. The need for government funding is not expected to change significantly over the coming decade. Consequently, funding recommendations are given in five major areas, generally according to priority:

- (a) A commitment for a follow-on satellite to Radarsat, i.e. Radarsat 2, should be made prior to the launch of the first spacecraft.
- (b) Government support for the export of Canadian technology, specifically value added services and systems, and ground stations.
- (c) Research and development initiatives for applications of imaging radar data, sensor research, and small satellite programs.
- (d) Education and technology transfer.

- (e) International cooperation through participation in foreign governments earth observation programs.

The first recommendation is for a firm commitment to a follow-on satellite to Radarsat which is expected to be launched in 1994. This commitment, if not the actual funds, should be made prior to the launch of the first satellite and will ensure that the Canadian Radarsat program is perceived as a serious operational system worldwide. This perception will stimulate the purchase of ground stations and the allocation of funds by foreign governments for licensing fees. Because of the major costs associated with the upgrading of ground stations, yearly licensing fees and maintaining archives of the acquired data, foreign governments are unlikely to commit major funding to a program which is seen as experimental in nature. Through to the year 2000, the potential financial returns to Canada resulting from a commitment to Radarsat 2 will likely exceed \$100 million from the sales of ground station upgrades and yearly licensing fees.

The second funding recommendation calls for the federal government to actively support the export of Canadian technology to other countries. Such support should focus on small Canadian firms providing value added systems and services with secondary support being provided for the export of satellite ground receiving stations. This could be done by providing technically literate trade officers to key international markets such as south-east Asia, South America, and Africa. These officers would augment the current trade support programs. To support this operation, the federal government could publish a catalogue listing all Canadian space remote sensing companies cross-referenced with their capabilities in remote sensing and environmental monitoring.

While the foregoing proposals will serve to support the stability of the Canadian space industry and promote the exports of Canadian technology, specific research and development initiatives must be taken in order to expand the Canadian technology base which is necessary for maintaining the competitiveness of Canadian industry. Three specific research programs are recommended relative to earth observation and remote sensing:

- (a) Continued development of imaging radar technology and applications;
- (b) Advanced sensor research; and
- (c) Small satellite systems.

The first program recommended under the research and development proposal is a short-term program specifically aimed at having well defined operational applications available

at the time of the Radarsat launch. These applications should include software and hardware for the processing of radar data to allow efficient ice monitoring, forest inventory, agricultural assessment and topographic mapping. The authors recognize that such a program is already in place in the form of the Radar Data Development Program (RDDP) and suggest that this recommendation may be taken as affirmation of the importance of this program. The success of the RDDP will stimulate demand for Radarsat data and increase the competitiveness of the Canadian value added industry. It is recommended that the results of these application developments be publicized through the use of a demonstration program similar to the PEP program performed by SPOT Image prior to the launch of SPOT 1. The results of the RDDP program may indicate that Radarsat data is a reliable information source for operational situations. This result should indicate to potential users the reliability and value of these data in their field of application.

The second research and development program is for an advanced sensor development initiative which should be controlled by the Canadian Space Agency. A number of Canadian firms as well as the National Research Council have developed expertise in the design and construction of optical and other types of space sensors. This progress must continue. The capability thus developed will allow Canada the option to participate as a contributor to the space programs of foreign governments under arrangements similar to those made for the remote manipulator system (Canadarm) contribution to the U.S. space shuttle. A recommendation for specific sensors to be developed is the subject for separate studies, however, consideration should be given to the following:

- Imaging spectrometer;
- Wide field of view visible/infrared scanner;
- Microwave scatterometer;
- Atmospheric Lidar sensors.

Naturally, research into advanced SAR sensors such as multipolarization, multifrequency radars should be continued.

The third research initiative should consider a made-in-Canada small satellite program. This would include feasibility studies for the development of a prototype system platform and launch capability in addition to refinement of existing Canadian capabilities for these systems. One potential application of a small satellite system would be to launch sensors which are specifically designed to complement Radarsat imagery into an orbit which gives near

simultaneous imaging of the same area of the earth. This earth observation system would allow highly accurate calibrations to be performed on the recorded data, potentially leading to improved results. It seems likely that early in the next century, small satellite technology will reach maturity and begin to dominate the earth observation industry due to the economies inherent in the small satellite concept. In order to maintain its current position in the space industry, Canada must commit to maintaining its technological base through research and development programs.

The fourth funding proposal involves support for education and technology transfer programs. A commitment to the promotion of education on the application of remote sensing data and the technologies involved in spaceborne systems and sensors will provide good returns in a number of ways. First, a strong research community will supply Canadian industry with a continuous source of new and innovative technologies and ideas. Second, a local supply of highly qualified young scientists, engineers, and technicians is required by all sectors of the remote sensing community in order to maintain growth. Only by ensuring that the courses and training needed to obtain these qualifications are offered in Canada will we be able to avoid importing skilled labour. Also, by promoting the strength of the Canadian educational system, the international profile of Canadian companies will be raised through association. Two programs are recommended for government support for the remote sensing educational proposal.

The first proposal involves placing Canadian professors and instructors to teach remote sensing applications at key international institutions such as the Asian Institute of Technology in Bangkok, and the International Institute for Aerospace Survey and Earth Sciences (ITC) in the Netherlands. Such a program will have the positive effect of exposing many future users of remote sensing to the wealth of Canadian expertise in this area. The benefits of such a program will accrue as graduates of these institutions go on to positions of power in their respective countries. Canadian proposals will be given equal consideration relative to competing European, American, and Japanese bids. In addition, the program will effectively be placing highly qualified sales personnel for the promotion of Radarsat data in key market locations. As respected academics, readily available for consultation, these persons will be able to demonstrate the local applications of Radarsat imagery much more effectively than foreign sales personnel. Such a program is working very well for the promotion of SPOT imagery at the present time.

The second education and technology transfer program would provide support for foreign students studying in Canada. This program would provide partial funding for students studying at universities, technical institutions, or private institutions for remote sensing applications courses. The benefits of such a program are similar to the first, that is, to raise the profile of the Canadian technology sector among foreign nationals. At the same time, such a program would be of immense help to small Canadian firms marketing their services internationally. Often, proposals for remote sensing data acquisition and analysis are amended by the potential client to include a technology transfer component. By making this program available, administration and organization costs could be significantly lowered, thus allowing a more acceptable proposal. Long-term benefits from these technology transfer programs will come from the increased number of knowledgeable users who will stimulate demand for remotely sensed images, thus increasing the total market size.

The above educational programs are similar to the now defunct Canadian remote sensing training institute (CRSTI) program which was originally operated by CCRS as a clearing house for information on Canadian opportunities for remote sensing training. This program addressed a clear need in this field and had a certain amount of success, however, for various reasons was discontinued. It is recommended that by allowing the private sector to market these educational opportunities internationally, administrative costs may be kept to a minimum.

The fifth and final proposal for government funding involves Canadian cooperation in foreign space remote sensing programs. As the requirements for remote sensing systems become more complex and costly, international cooperation will play an increasingly important role in this industry. Canadian contributions to NASA and ESA have already established a precedent for this type of involvement and have had generally positive effects on the Canadian industry. Cooperation in these programs should be balanced with funding for national programs such as Radarsat 2 and should be judged with respect to returns on Canadian investment. A number of possible joint projects should be considered. These include the following:

- (a) The NASA Earth Observing System (EoS);
- (b) ERS-2 (ESA);
- (c) SPOT 5 (France);
- (d) The NOAA meteorological satellite program.

The EOS program is a major international initiative aimed at providing a worldwide environmental monitoring capability for the next century. The cost of this program is expected to be very high and it is uncertain what the prospects are for commercial usage of the data. Canadian contributions to this program will ensure access to the data for national and possibly commercial purposes. As well, the economic benefits of contributing sensors may pay off in future implementations of the technology developed. One specific contribution which Canada could make is for the construction or integration of the proposed SAR sensor to be included in the EoS satellite program.

To date, Canadian involvement in ESA remote sensing programs has involved design and consulting work and supply of ground station components for the ERS-1 radar satellite to be launched in late 1990. Assuming a follow-on satellite is planned (ERS-2), Canada could take a much larger role in the construction of this satellite through optional contributions to this specific program. By taking a leading role in the design and construction of spaceborne radar sensors, Canada will have a much better chance of maintaining its technological lead in this field. Contributions to ESA should be carefully considered, however, as they do not necessarily represent a prime return on Canadian investment.

The French SPOT 5 program is in the early development stage at this time. The high costs estimated for this advanced satellite may force the French government to seek out cost sharing arrangements with other nations. This could be a unique opportunity for Canada to gain access to the relatively closed French market which has its own launch capability and an existing commercial remote sensing system. One possibility is to use the SPOT 5 satellite to carry a Radarsat type sensor, thus ensuring the supply of Radarsat data into the twenty-first century.

The current meteorological satellite program consists of several geostationary satellites at high altitude supported by a number of polar orbiting satellites at low altitude operated by the NOAA administration of the U.S.A. At present, access to the data acquired by these satellites is unrestricted, however, this situation is not guaranteed to continue. By supplying sensors or other support systems to these operational satellites, Canada could ensure future access to these vital data while at the same time expanding the capabilities of the Canadian industry.

5.5 Basis For Further Studies

Many of the proposals advanced in the previous section could potentially form the basis for future studies into the technical and commercial implications for Canadian industry. Based upon the author's judgement, the following topics warrant primary attention:

(a) Study of Requirements and Benefits of Radarsat 2 Program

The original requirements for Canada's Radarsat program are based on the need for an environmental monitoring and ice surveillance system for Canada's northern areas. Commercial sales of these data to other governments and private users will provide valuable funding which may support the operation of the space segment on an on-going basis. These funds will primarily be acquired in three ways; namely, through the sales of yearly licensing fees to foreign ground stations, through direct sales of imagery, and finally, through the sales of upgrade systems for ground stations to receive Radarsat data. Technical factors which will affect the level of sales and thus the benefits accruing to Canada will include the capabilities of the Radarsat sensor as applied to the prospective client's application, the cost of Radarsat data, and the expected improvements to be incorporated in the second Radarsat system.

(b) Implementation of Commercial Marketing Support for the Value Added Industry

Specific studies which should be considered include the determination of the optimum location and qualifications for marketing officers as well as the requirements for funding and industry interaction for the industry support program.

(c) Investigation of the Structure of Federal and Provincial Environmental Monitoring Requirements and Programs

Under the policy recommendations given above, the Canadian environmental monitoring system should be given a unified structure. Before any changes are made to federal or provincial legislation, a study should be performed to determine the exact status and level of interaction between the various agencies responsible for these programs.

(d) Investigation of the Opportunities to Promote Canadian Educational Programs Overseas

In order to develop an optimal strategy for the implementation of the educational program recommended above, studies should address the administrative factors involved in provision of professors to various foreign institutions and the benefits which may be expected from these programs. As well, recommendations should be sought out for the structure of a unified Canadian remote sensing training program operating inside and outside the country. Such a study could compile a data base of all available institutions and firms which offer applicable technology transfer courses.

Depending upon which, if any, of the above proposals are implemented, a follow-on study to determine the effects these programs have had on the market share held by Canadian industry would also be required. Finally, it should be noted that many of the proposals could potentially be applicable to the stated aims of the earth environment space initiative (EESI) specifically, the topics of small satellites, non-radar sensors, and integrated environmental monitoring systems.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Study Overview

This report presents the results obtained from the review of the global market for remote sensing and earth observation technologies and services as they relate to existing and potential Canadian industrial capabilities. For the purposes of this study, the remote sensing industry has been subdivided into three sectors. These sectors may be generally characterized as suppliers of satellite systems and components, suppliers of ground receiving stations, and suppliers of value added systems and services.

The methodology for the assimilation of the information required to perform this review was based upon an extensive literature review supplemented by interviews with knowledgeable representatives of government organizations and private corporations. A final source of data was a series of questionnaires which were distributed to a large number of organizations throughout the world.

The market review focused upon a number of key issues including:

- tabulation of current and planned expenditures on space remote sensing systems;
- quantification of the international supply and demand for systems, services, and data;
- identification of current uses of available data and the sources of such data;
- investigation of planned remote sensing systems;
- a review of alternative methods of data acquisition; and,
- the impact of foreign government policies.

6.1.2 Market Review Conclusions

In general, the major suppliers of space based systems, data, and value added services have been identified as the U.S.A., Japan, and the major European nations, dominated by France, Germany,

the United Kingdom and Italy. While Canada maintains a presence in all sectors of the market, her primary strengths are in ground receiving stations and value added services. The international demand for remotely sensed data appears to be growing in a number of sectors of the earth sciences. However, a number of critical applications are highly dependant upon timely delivery of the data and have specific requirements for both spectral and spatial resolution. It is these applications which offer the potential for significant market growth over the coming decade, providing the needs of the user community can be met with existing technology.

A number of space based remote sensing systems are planned for the next decade, offering a wide array of data characteristics. It should be noted that some of these proposed systems will not be completed due to lack of funding or technical difficulties. At the present time, it is clear that France, Japan, ESA, the U.S.A. and Canada have confirmed intentions to each launch at least one satellite over the coming decade for the purpose of earth observation. Less certain intentions have also been expressed by Brazil, India and China. The plans of the Soviet Union are not clear at this time but this country is known to have considerable capability in earth observation technology.

The primary alternative to space based data collection remains aerial photography. In some cases this is only due to the general familiarity of the user community with this form of information. In other cases, this situation persists because of the superior resolution and operational flexibility of airborne data collection. This indicates a potential need for ultra-high resolution visible and infrared optical sensors which are expected to be available before the end of the decade. The imagery obtained could have direct application to engineering and land use mapping, thus opening up large new markets for the space remote sensing industry.

Government policies which impact directly or indirectly on Canadian industry are generally positive as world trade barriers are lowered and the value of remotely sensed data is recognized for planning and monitoring purposes. France and Japan stand out as potential negative areas, however, as these countries strive to promote their national interests through protection of local markets and heavy subsidization of national industry. The remainder of Europe and the U.S.A. are mixed in terms of opportunities and disincentives for business. In general, these areas represent potentially lucrative markets, however the level of competition for these markets is high. The third world countries, especially those in South America and Asia, represent the largest potential market for products and services. These are also the least developed markets in terms of user sophistication and identification of requirements.

Generally, the international market volume for satellite systems is expected to total roughly \$22 billion over the coming decade. Due to the long term nature of these contracts, yearly market volumes are difficult to assess and somewhat misleading. The market for ground receiving stations is expected to total \$122 million over the same period. Value added systems and services are currently estimated to represent a \$25 million per year market. Growth in this industry is likely to exceed 15% per year, leading to a total volume of over \$700 million for the decade.

6.1.3 Capability Assessment Conclusions

Canadian industrial capabilities were assessed by:

- identifying Canadian companies competing in the three sectors of the industry and their specific capabilities.
- defining the existing technology base in Canada for earth environment monitoring with specific emphasis on capabilities for:
 - design, development, and building of earth observation instruments or sensors;
 - small satellites and other types of platforms; and,
 - data reception, processing and information extraction, dissemination, and assimilation systems.
- identifying the deficiencies in the Canadian technology base and the development and improvement needed to compete in international markets.

Using the results of the capability survey, and information extracted from industry directories and interview notes, the capabilities of Canadian companies and institutions were tabulated according to the three market sectors. Several companies had significant capabilities in more than one sector but for the majority of firms, the classification was unique. The potential for the Canadian space industry to compete in international markets appears to be increasing. This is due in large part to the expertise being acquired through the development of the Canadian Radarsat program. Other contributing factors are technological achievements which have resulted from Canada's involvement with NASA and ESA through cooperative agreements.

The Canadian technology base is still weak in several key areas. Specifically these are:

- Attitude control systems;
- Orbit control systems;
- Lack of launch capability;
- Satellite bus design;

- Optical sensor technology.

These deficiencies prevent Canada from developing and operating satellite systems without the involvement of other countries. Due to cost considerations and the increasing availability of these technologies from foreign sources, the development of these technologies are unlikely to become priorities in the near future. The exception to this statement is optical sensor technology. Current research and development efforts indicate that these technologies are within Canada's means to develop on a commercial scale. Whether this technology is as promising as other sensors is a subject for further study.

6.1.4 Strategy Conclusions

The final requirement of this project was for the development of strategic recommendations, based on the above findings, aimed at improving the competitive status of Canadian industry. Specific items addressed were:

- identification of growing market areas that are most aligned with Canadian capabilities and competitive position;
- prediction of the market share in products and services that may be obtained together with an assessment of the technological enhancements that would have to be supported to realise this market share;
- development of strategic proposals for the federal government to assist Canadian industry in penetrating the international market;
- suggesting mechanisms for exploiting the identified market opportunities; and,
- indicating a basis for further study in this sector.

The strategic proposals developed were the result of discussion among the researchers based upon ideas and recommendations generated through the questionnaire and interview processes. The major proposals focused on expanding the international market share held by Canadian industry, however major consideration was given to the need to promote the overall expansion of the remote sensing market. The overall theme of the developed strategy is that the federal government should demonstrate a firm, long-term commitment to the expansion of the Canadian remote sensing industry through the support of international marketing efforts, an active space program, and the cultivation of the national market. The highlights of the strategic proposals are as follows:

- increase requirements for use of remotely sensed data through expanded environmental monitoring programs and regulations;
- commitment for a follow-on program to Radarsat;

- support funding for research and development into advanced sensor technology and small satellites;
- direct support for international marketing of value added firms; and,
- partial funding for a technology transfer program to foreign institutions and organizations.

While support for research and development of remote sensing satellites is primarily a government responsibility, the contribution of the value added sector, which acts as the main sales force for the data products, must be recognized and supported if commercialization of the Radarsat program is to take place. By promoting the profitability of current remote sensing programs, the government can reduce the requirements for funding for future programs as space remote sensing becomes a self supporting industry.

6.2 Recommendations

Based on the strategic recommendations given above, further studies are warranted in a number of areas. Foremost among these is the need for a determination of the possible future economic benefits to Canada which would follow from a commitment for the construction and launch of Radarsat 2. Such benefits would stem from sales to foreign markets of ground station upgrades, data acquisition licenses, radar processing software and value added services. The potential magnitude of these sales will have a direct relationship to the eventual payback to Canada for supporting this program. Naturally, such a study would be a prerequisite to any government commitment to such a program.

Other recommendations include studies into;

- Implementation of Commercial Marketing Support for the Value Added Industry;
- Investigation of the Structure of Federal and Provincial Environmental Monitoring Requirements and Programs; and,
- Investigation of the Opportunities to Promote Canadian Educational Programs Overseas.

A final recommendation would include a follow-on study to this project which would update the database of market information and Canadian companies and assess the progress of Canadian industry in the world market.

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GLOSSARY

GLOSSARY

| | | |
|-----------|---|--|
| A/D | - | Analog to Digital |
| A-OLS | - | Advanced Operational Line Scanner |
| ACRIM II | - | Active Cavity Radiometer Irradiance Monitor II |
| ACS | - | Array Computing Systems Limited |
| ADEOS | - | Advanced Earth Observation Satellite (Japan) |
| AEM | - | Atmospheric Explorer Mission |
| AES | - | Atmospheric Environment Service (Canada) |
| AGRISTARS | - | Agriculture and Resources Inventory Through Aerospace Remote Sensing |
| AIRS | - | Atmospheric Infrared Sounder |
| AIT | - | Advanced Information Technology Corporation |
| ALT | - | RADAR Altimeter |
| AMI | - | Active Microwave Instrumentation |
| AMIR | - | Advanced Microwave Imaging Radiometer |
| AMORS | - | Australian Modular Optical Remote Sensor |
| AMRIR | - | Advanced Medium Resolution Imaging Spectrometer |
| AMSR | - | Advanced Microwave Sounding Radiometer |
| AMSU | - | Advanced Microwave Sounding Unit |
| AOCM | - | Advanced Ocean Colour Monitor |
| APACM | - | Atmospheric Physical and Chemical Monitor |
| APT | - | Automatic Picture Transmission |
| ARA | - | Advanced Radar Altimeter |
| ARGOS | - | French Data Collection and Location System |
| ARIANE | - | European Expendable Launch Vehicle (ESA / France) |
| ARSC | - | Alberta Remote Sensing Centre |
| ASA | - | Austrian Space Agency |
| ASI | - | Italian Space Agency |
| ATLID | - | Atmospheric Lidar |
| ATS | - | Advanced Technology Satellite |
| ATSR/M | - | Along Track Scanning Radiometer/Microwave Sounder |
| AVCS | - | Advanced Vidicon Camera System |
| AVHRR | - | Advanced Very High Resolution Radiometer |
| AVIRIS | - | Advanced Visible and Infrared Imaging Spectrometer |
| AVNIR | - | Advanced Visible and Near Infrared Radiometer |
| AWL | - | Atmospheric Wind Lidar |
| AXIS | - | Atmospheric X-Ray Imaging Spectrometer |
| | | |
| BC | - | British Columbia |
| BHASKARA | - | Indian Satellite for Earth Observation |
| BMFT | - | Bundesministerium für Forschung und Technologie (Coordinating Ministry FRG) |
| BNSC | - | British National Space Centre |
| BRESEX | - | Brazil Earth Satellite Experiment |
| | | |
| CACRS | - | Canadian Advisory Committee on Remote Sensing |
| CAL | - | Canadian Astronautics Ltd. |

GLOSSARY - Continued

| | | |
|--------------|---|---|
| CASI | - | Canadian Aeronautics and Space Institute; also Compact Airborne Spectrograph Imager |
| CCD | - | Charged Coupled Device |
| CCR | - | Corner Cube Reflector |
| CCRS | - | Canada Centre for Remote Sensing |
| CCT | - | Computer Compatible Tape |
| CD-ROM | - | Compact Disk - Read Only Memory |
| CDTI | - | Centre for the Development of Industrial Technology (Spain) |
| CIDA | - | Canadian International Development Agency |
| CIPE | - | Interministerial Committee for Economic Planning (Italy) |
| CIS | - | Cryogenic Interferometer Spectrometer |
| CLAES | - | Cryogenic Limb Array Etalon Spectrometer |
| CNES | - | Centre National d'Etudes Spatiales |
| COLUMBUS | - | European Polar Orbiting Platform (EPOP) |
| COSMOS RADAR | - | Soviet X-Band Real Aperture Side Looking Radar |
| CQCT | - | Centre du Quebecois de Coordination de la Teledetection |
| CR | - | Correlation Radiometer |
| CRSTI | - | Canadian Remote Sensing Training Institute |
| CSA | - | Canadian Space Agency |
| CZCS | - | Coastal Zone Colour Scanner |
| DARA | - | Deutsche Agentur fur Raumfahrtangelegenheiten (German Space Agency) |
| DEM | - | Digital Elevation Model |
| DF | - | Dual Frequency |
| DFS | - | Dual Frequency Scatterometer |
| DFVLR | - | Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt e.v. |
| DLR | - | Deutsche Forschung und Versuch Sanstalt fur Luft und Raumfahrt (FRG Science and Technology) |
| DMSP | - | Defense Meteorological Satellite Program (USA) |
| DoC | - | US Department of Commerce |
| DoD | - | US Department of Defense |
| DoI | - | US Department of the Interior |
| DORIS | - | Dual Doppler Receiver |
| DRIE | - | Canada Department of Regional and Industrial Expansion |
| EESI | - | Earth Environment Space Initiative |
| EGS | - | Experimental Geodetic Satellite |
| ELV | - | Expendable Launch Vehicle |
| EMSI | - | Electro-Magnetic Sensing and Interpretation Ltd. |
| EOS | - | Earth Observation System (USA) |
| EOSAT | - | Earth Observation Satellite Corporation (USA) |
| EPOP | - | European Polar (Orbiting) Platform |
| ERB | - | Earth Radiation Budget |

GLOSSARY - Continued

| | | |
|-----------|---|---|
| ERBI (ns) | - | Earth Radiation Budget Instrument (non-scanning) |
| ERBI (s) | - | Earth Radiation Budget Instrument (scanning) |
| ERBS | - | Earth Radiation Budget Satellite |
| EREP | - | Earth Resources Experiment Package (Skylab) |
| EROS | - | Earth Resources Observation System |
| ERS | - | European Remote Sensing Satellite |
| ERSDAC | - | Earth Resource Satellite Data Analysis Center (Japan) |
| ERTS | - | Earth Resource Technology Satellite Renamed LANDSAT |
| ESA | - | European Space Agency |
| ESD | - | European Space Directory |
| ESMR | - | Electronically Scanning Microwave Radiometer |
| ESRO | - | European Space Research Organization |
| ESSA | - | Environmental Satellite Service Administration and NOAA Meteorological Satellite for this agency |
| ESTAR | - | Electronically Scanned Thinned Array Radiometer |
| ETM | - | Enhanced Thematic Mapper |
| EUMETSAT | - | European Meteorological Satellite Corp. |
| EUTELSAT | - | European Telecommunications Satellite |
| EXOS-D | - | Experimental Observation Satellite |
| | | |
| F/P-INT | - | Fabry-Perot Interferometer |
| FENGYUN | - | Meteorological Satellite |
| FILE | - | Feature Identification and Location Experiment |
| FLI | - | Fluorescent Line Imager |
| FLIR | - | Forward Looking Infrared Radiometer |
| FPR | - | Flat Plate Radiometer |
| FRAGMENT | - | Most Advance Soviet Electro-Optical Multispectral Imager |
| FRG | - | Federal Republic of Germany |
| FY-1 | - | Fengyun 1 for Atmosphere and Ocean Observation |
| | | |
| GE | - | General Electric Company |
| GEOS | - | Geodynamics Experimental Ocean Satellite |
| GEOSAT | - | Geodesy Satellite |
| GGM | - | Gravity Gradient Missions |
| GIS | - | Geographic Information System |
| GLRS | - | Geodynamic Laser Ranging System |
| GM | - | General Motors |
| GMS | - | Geostationary Meteorological Satellite |
| GNP | - | Gross National Product |
| GOES | - | Geostationary Operational Environmental Satellite |
| GOMR | - | Global Ozone Monitoring Radiometer |
| GOMS | - | Soviet Meteorological Satellite |
| GPS | - | Global Positioning System |
| GRM | - | Geopotential Research Mission |

GLOSSARY - Continued

| | | |
|---------------|---|--|
| HALOE | - | Halogen Occultation Experiment |
| HCMM | - | Heat Capacity Mapping Mission |
| HCMR | - | Heat Capacity Mapping Radiometer |
| HDDT | - | High Density Digital Tape |
| HERMES | - | European Manned Reusable Space Vehicle |
| HFMR | - | High Frequency Microwave Radiometer |
| HIRIS | - | High Resolution Imaging Spectrometer |
| HIRS | - | High Resolution Infrared Radiation Sounder |
| HIS | - | High Resolution Interferometer Sounder |
| HMMR | - | High Resolution Multifrequency Microwave Radiometer |
| HRDI | - | High Resolution Doppler Imager |
| HRIR | - | High Resolution Infrared Radiometer |
| HRIS | - | see HIRIS |
| HROI | - | High Resolution Optical Imager |
| HRPT | - | High Resolution Picture Transmission |
| HRTIS | - | High Resolution Thermal Infrared Radiometer |
| HRV | - | Haute Resolution Visible or High Resolution Visible Imager |
| HRV/IR | - | High Resolution Visible/Infrared Radiometer |
| HRVIR | - | Improved High Resolution Visible Imager |
| HSR | - | HCMM Scanning Radiometer |
| | | |
| IBM | - | International Business Machines, Inc. |
| IDIAS | - | Ice Display and Image Analysis System |
| IFOV | - | Instantaneous Field of View |
| IMAGER (next) | - | GOES-next Imaging Subsystem |
| INMARSAT | - | International Maritime Satellite Organization |
| INSAT | - | Indian National Satellite |
| INTA | - | National Institute of Aerospace Technology |
| INTELSAT | - | International Telecommunications Satellite Organization |
| INTERCOSMOS | - | Soviet Ocean Satellite |
| IPS | - | Instrument Pointing System |
| IR | - | Infrared |
| IR-RAD | - | Infrared Radiometer |
| IRI | - | Infrared Interferometer |
| IRIS | - | Infrared Interferometer Spectrometer |
| IRLS | - | Infrared Line Scanner |
| IRS | - | Infrared Spectrometer or Indian Remote Sensing Satellite |
| IRSO | - | Indian Space Research Organization |
| ISAMS | - | Improved Stratospheric and Mesospheric Sounder |
| ITIR | - | Intermediate Thermal Infrared Radiometer |
| ITOS | - | Improved TIROS Operational Satellite |
| ITPR | - | Infrared Temperature Profile Radiometer |
| | | |
| JERS | - | Japan Earth Resource Satellite |
| JPOP | - | Japanese Polar Platform |

GLOSSARY - Continued

| | | |
|----------------|---|---|
| KATE-140 | - | Soviet Topographical Camera |
| KATE-200 | - | Soviet Topographical Camera |
| KFA-1000 | - | Soviet Multispectral Topographical Camera |
| KOSMOS | - | Soviet Satellite Series |
| KRS | - | Kodak Remote Sensing Company |
| LACATE | - | Lower Atmosphere Composition and Temperature Experiment |
| LACIE | - | Large Area Crop Investigation Experiment |
| LAGEOS | - | Laser Geology Satellite (USA) |
| LAMMR | - | Large Antenna Multifrequency Microwave Radiometer |
| LANDSAT | - | Land Satellite formerly ERTS |
| LASA | - | Lidar Atmospheric Sounder and Altimeter |
| LASE | - | Lidar Atmospheric Sounder Experiment |
| LASER | - | Light Amplification through Stimulated by Emission of Radiation |
| LASSO | - | Laser Synchronization from Stationary Orbit |
| LAWS | - | Laser Atmospheric Wind Sounder |
| LFC | - | Large Format Camera |
| LFMR | - | Low Frequency Microwave Radiometer |
| LGS | - | Laser Geology Satellite (Italy) |
| LGSOWG | - | Landsat Ground Station Operators Working Group |
| LIDAR | - | Light Detection and Ranging |
| LIMS | - | Limb Infrared Monitor of the Stratosphere |
| LISS | - | Linear/Imaging Self Scanner Sensor |
| LR | - | Laser Retro-Reflector |
| LRIR | - | Limb Radiance Inversion Radiometer |
| LRUV | - | Low Resolution Ultraviolet |
| LS | - | Limb Sounder |
| LWIR | - | Long Wave Infrared |
| MAG | - | Magnetospheric Currents and Fields Detector |
| MAGSAT | - | Magnetic Field Satellite |
| MAPS | - | Measurement of Air Pollution From Space or Satellites |
| MAPSAT | - | Mapping Satellite |
| MDA | - | MacDonald Dettwiler and Associates Ltd. |
| MECB | - | Missao Espacial Compelta Brasileira |
| MEIS | - | Multispectral Electro-Optical Imaging Scanner |
| MERIS | - | Medium Resolution Imaging Spectrometer |
| MESSR | - | Multispectral Electronic Self-Scanning Radiometer |
| METEOR | - | Soviet Meteorological Satellite |
| METEOR-PRIDODA | - | Soviet Land Observation Satellite |
| METEOSAT | - | ESA Meteorological Satellite Program |
| METSAT | - | USA Meteorological Satellite Program |
| MFE | - | Magnetic Field Experiment (USA) |
| MIR | - | Soviet Space Station |

GLOSSARY - Continued

| | | |
|---------|---|---|
| MIPAS | - | Michelson Interferometer for Passive Atmospheric Sounding |
| MK-4 | - | Soviet Multispectral Camera |
| MKF-6 | - | Multispectral Topographic Camera used by the Soviets and built by Carl Zeiss |
| MKF-6M | - | Modified Version of MKF-6 |
| MLA | - | Multispectral Linear Array |
| MLS | - | Microwave Limb Sounder |
| MODIS-N | - | Moderate Resolution Imaging Spectrometer -Nadir |
| MODIS-T | - | Moderate Resolution Imaging Spectrometer - Tilt |
| MOMS | - | Modular Optoelectronic Multispectral Scanner |
| MOP | - | Meteosat Operational Program (ESA) |
| MOS | - | Marine Observation Satellite (Japan) |
| MPD | - | Magnetospheric Particle Detector |
| MPS | - | Microwave Pressure Sounder |
| MRIR | - | Medium Resolution Imaging Radiometer |
| MRSC | - | Manitoba Remote Sensing Centre |
| MRSE | - | Microwave Remote Sensing Experiment |
| MRST | - | Ministry for Science and Technology Research (Italy) |
| MRUV | - | Moderate Resolution Ultraviolet |
| MRV | - | Moderate Resolution Visible |
| MRV/IR | - | Moderate Resolution Visible/Infrared Radiometer |
| MS | - | Microwave Sounder |
| MSAT | - | Mobile Satellite |
| MSI | - | Multispectral Scan Imaging |
| MSR | - | Microwave Scanning Radiometer |
| MSS | - | Multispectral Scanner |
| MSSCC | - | Multicolor Spin Scan Cloud Camera |
| MSSR | - | Multispectral Spin-Scan Radiometer |
| MSU | - | Microwave Sounding Unit |
| MSU-E | - | High Resolution Multispectral Scanner with Electronic Scanning Based on CCD's (3 Bands) |
| MSU-M | - | As above only Low Resolution (4 Bands) |
| MSU-S | - | As above only Medium Resolution (2 Bands) |
| MSU-SK | - | As above only Medium Resolution (4 Bands) |
| MWIR | - | Middle Wave Infrared |
| NASA | - | National Aeronautics and Space Administration |
| NASDA | - | National Space Development Agency (Japan) |
| NCIS | - | Nadir Climate Interferometer Spectrometer |
| NEMS | - | Nimbus-E Microwave Spectrometer |
| NESDIS | - | National Environmental Satellite, Data, and Information Service |
| NIMBUS | - | Oceans and Meteorological Satellite (USA) |
| NIR | - | Near Infrared |
| NIRV | - | Nederlands Instituut voor Vliegtuigontwikkeling and Ruimtevaart |
| NOAA | - | National Oceanic and Atmospheric Administration |

GLOSSARY - Continued

| | | |
|------------|---|---|
| NOSS | - | National Oceanic Satellite System |
| NPOP | - | NASA Polar Orbiting Platform |
| NRC | - | National Research Council |
| N-ROSS | - | Navy Remote Ocean Sensing Satellite |
| NSCATT | - | NASA Scatterometer |
| NTNF | - | Norwegian Council for Scientific and Industrial Research |
| OCE | - | Ocean Color Experiment |
| OCI | - | Ocean Color Imager |
| OCRS | - | Ontario Centre for Remote Sensing |
| OCTS | - | Ocean Color and Temperature Scanner |
| OLS | - | Operational Linescan System |
| OMS | - | Orbital Manoeuvring System |
| OPS | - | Optical Sensor System |
| PC | - | Personal Computer |
| PEM | - | Particle Environmental Monitor |
| PEPS | - | Programme d'Evaluation Preliminaire des donnees SPOT (France) |
| PLA | - | Panchromatic Linear Array |
| PLCR | - | Passive Laser "Connucube" Reflectors |
| PMR | - | Pressure Modulated Radiometer |
| POES | - | Polar Orbiting Operational Environmental Satellites |
| POPSAT | - | Precise Orbit Positioning Satellite (ESA) |
| POSEIDON | - | Radar Altimeter |
| PPS | - | Precise Positioning System |
| PR | - | Precipitation Radar |
| PRC | - | Peoples Republic of China |
| PSLV | - | Polar Satellite Launch Vehicle |
| PSN | - | National Space Plan (Italy) |
| R & D | - | Research and Development |
| RA (ers-1) | - | Radar Altimeter for ERS-1 |
| RADAR | - | Radio Detection and Ranging |
| RADARSAT | - | Radar Satellite (Canada) |
| RAR | - | Real Aperture Radar |
| RBV | - | Return Beam Vidicon |
| RCA | - | Record Company of America |
| RESTEC | - | Remote Sensing Technology Centre (Japan) |
| RF | - | Radio Frequency |
| ROHINI | - | India Land Observation Satellite |
| S190 | - | Skylab Earth Terrain Camera |
| S065 | - | Multiband Camera Consisting of an Array of Hasselblad Cameras |
| SAGE | - | Stratospheric Aerosol and Gas Experiment (USA) |

GLOSSARY - Continued

| | | |
|----------------|---|---|
| SAL | - | Synthetic Aperture Lidar |
| SALYUT | - | Soviet Land and Ocean Satellite |
| SAM | - | Stratospheric Aerosol Measurement; also Sensing with Active Microwaves |
| SAMS | - | Stratospheric and Mesospheric Sounder |
| SAR | - | Synthetic Aperture Radar |
| SASS | - | Seasat Scatterometer System |
| SBSA | - | Swedish Board for Space Activities |
| SBUV | - | Solar Backscatter Ultraviolet |
| SCAMS | - | Scanning Microwave Spectrometer |
| SCARAB | - | Scanning Radiation Budget Sensor |
| SCATT | - | Scatterometer |
| SCD | - | Satellite de Coleta de Dados : Land and Oceans Observation Satellite (Brazil) |
| SCMR | - | Surface Composition Mapping Radiometer |
| SCR | - | Selective Chopper Radiometer |
| SEASAT | - | Sea Satellite |
| SEAWIFS | - | Sea Wide Field Scanner |
| SED | - | SED Systems Inc. |
| SEM | - | Space Environmental Monitor |
| SIR | - | Shuttle Imaging Radar |
| SIRS | - | Shuttle Infrared Spectrometer |
| SIS | - | Shuttle Imaging Spectrometer |
| SISP | - | Surface Imaging and Sounding Package |
| SLAR | - | Side-Looking Airborne Radar |
| SM | - | Scaler Magnetometer |
| SMIRR | - | Shuttle Multispectral Infrared Radiometer |
| SMMR | - | Scanning Multifrequency Microwave Radiometer |
| SMS | - | Stationary Meteorological Satellite; also Supra Thermal-Ion Mass Spectrometer |
| SOLSTICE | - | Solar/Stellar Irradiance Comparison Experiment |
| SOUNDER (next) | - | GOES-NEXT Sounder Subsystem |
| SPO | - | Science Policy Office (Belgium) |
| SPOAA | - | Surface Pressure by Oxygen A-Band Absorption |
| SPOT | - | Système pour l'Observation de la Terre (France) |
| SR | - | Scanning Radiometer |
| SRC | - | Saskatchewan Research Council |
| SRON | - | Netherlands Space Research Organization |
| SSB | - | Gamma and X-Ray Spectrometer |
| SSC | - | Swedish Space Corporation |
| SSCC | - | Spin Scan Cloud Cover Camera |
| SSH | - | Special Sensor H: Passive Radiometer |
| SSM | - | Sensor System Microwave |
| SST | - | Sea Surface Temperature |
| SSU | - | Stratospheric Unit |

GLOSSARY - Continued

| | | |
|----------------|---|---|
| STAR | - | Satellite Tracking and Reporting Sensor |
| STIMS | - | Shuttle Thermal Infrared Multispectral Scanner; also see TIMS |
| STM | - | Shuttle Tethered Magnetometer |
| SUB-MM | - | Submillimeter Spectrometer |
| SUSIM | - | Solar Ultraviolet Spectral Irradiance Monitor |
| SWIR | - | Short Wave Infrared |
| | | |
| TASC | - | The Analytical Science Corporation (USA) |
| TDRSS | - | Tracking and Data Relay Satellite System |
| TERS | - | Tropical Earth Resources Satellite (Netherlands / Indonesia) |
| THIR | - | Temperature Humidity Infrared Radiometer |
| TIMS | - | Thermal Infrared Multispectral Camera |
| TIR | - | Thermal Infrared |
| TIROS | - | Television and Infrared Observation Satellite (US Meteorological Satellite) |
| | | |
| TM | - | Thematic Mapper |
| TMR | - | Topex Microwave Radiometer |
| TOMS | - | Total Ozone Mapping Spectrometer |
| TOPEX | - | Topex Radar Altimeter |
| TOPEX/POSEIDON | - | Ocean Topographic Experiment (USA/France) |
| TOVS | - | TIROS Operational Vertical Sounder |
| TREM | - | Tropical Rain Explorer Mission |
| TRIFAR | - | Three Frequency Wave Spectrometer |
| TSC | - | Tanegashima Space Centre |
| TTC | - | Telemetry, Tracking and Control |
| | | |
| UARS | - | Upper Atmosphere Research Satellite |
| UK | - | United Kingdom |
| UME | - | Ionosphere Sounding Satellite |
| UN | - | United Nations |
| URV/IR | - | Ultrahigh Resolution Visible/Infrared Radiometer |
| US | - | see USA |
| USA | - | United States of America |
| USDA | - | US Department of Agriculture |
| USSR | - | Union of Soviet Socialist Republics |
| UV | - | Ultraviolet |
| | | |
| V | - | Visible |
| VAS | - | VISSR Atmospheric Sounder |
| VCS | - | Vidicon Camera System |
| VHRR | - | Very High Resolution Radiometer |
| VIR | - | Visible and Infrared Radiometer |
| VIRGS | - | VISSR Image Registration and Gridding System |
| VIRR | - | Visible and Infrared Radiometer |
| VIS-UV | - | Visible Ultraviolet Spectrometer |

GLOSSARY - Continued

| | | |
|-----------|---|---|
| VISHRR | - | VIS High Resolution Radiometer |
| VISS | - | VIS Spectrometer |
| VISSR | - | Visible Infrared Spin Scan Radiometer |
| VLS | - | Vandenberg Launch Site |
| VM | - | Vector Magnetometer |
| VMS | - | Vegetation Monitoring Sensor |
| VNIR | - | Visible and Near Infrared Radiometer |
| VTIR | - | Visible and Thermal Infrared Radiometer |
| VTPR | - | Vertical Temperature Profile Radiometer |
| VTT | - | Technical Research Centre of Finland |
| | | |
| WIA | - | Wide Swath Interferometric Altimeter |
| WIND | - | Solar Terrestrial Physics Satellite (USA) |
| WINDII | - | Wind Imaging Interferometer |
| WINDSCATT | - | Wind Scatterometer |
| WMO | - | World Meteorological Organization |
| WSI | - | Western Space Initiative |
| | | |
| X-SAR | - | X Band Synthetic Aperture Radar |

SATELLITE SYSTEMS CAPABILITIES

[illegible]

SATELLITE SYSTEMS CAPABILITIES

[illegible]

SATELLITE SYSTEMS CAPABILITIES

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SATELLITE SYSTEMS CAPABILITIES

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SATELLITE SYSTEMS CAPABILITIES

[illegible]

SATELLITE SYSTEMS CAPABILITIES

| COMPANY | PLATFORM | | | | | | | | | ATTITUDE CONTROL | | | REACTION CONTROL | | | TRACKING TELEMETRY CONTROL | | | POWER | | | SENSORS | | | | | | OTHER | | | | | | | | | | | | |
|------------------------------------|--------------------|---------------|-----------------|----------------------|-----------|-----------------|----------------|-----------------------|---------------------|------------------|-----------------|----------------------------|-----------------------|------------------------|-----------------------------|--------------------------------|------------------|---------------------------|-------------|-----------|------------|-----------|--------------------|--------|----------------|--------------|----------|--------|---------------|-----------------|--------------------|------------------|---------------------|-------------------|------------|------------|--------------------|----------|------------------|---------|
| | System Integration | System Design | Test Facilities | Military Contractors | Structure | Thermal Control | Electrical Bus | Environmental Control | Horizon/Sun Sensors | EM Torques | Momentum Wheels | Gyro Stabilization Systems | Integration Thrusters | Control Systems Design | Integration Control Systems | Transmitter & Receiver Antenna | Amplifier (LN/A) | System Design Integration | Solar Array | Batteries | Converters | Inverters | Design Integration | Sensor | Control System | Data Storage | Downlink | Optics | Antenna (SAR) | Optic Countings | Design Integration | Component Design | Precision Machining | Metal Fabrication | Composites | Insulation | Cable Fibre Optics | Software | Small Components | Rockets |
| SOTA Electronics Corp. | | | | | | | | | | | | | | | | | | | X | X | | | | | | | | | | | | | | | | | | | X | |
| SPAR Aerospace Ltd. | X | X | X | X | X | X | X | X | | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| Spectrum Technologies Ltd. | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SYSLOG Inc. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | |
| Telemus Electronic Systems Inc. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | |
| Telesat Canada | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Telespace Ltd. | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| The SNC Group | | | X | X | | | | | | | | | | | | | | | | | | | | X | | | | | | | | | | | | | | | | |
| Thompson Hickling Aviation Inc. | | X | | X | | | | | | | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | | |
| Thomson - CSF Canada Ltd. | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | |
| Thomson & Nielson Electronics Ltd. | | | | X | | | | | | | | | | | | | | | | | | | | X | X | X | | | | | | | | | | | | | | |
| T.R. Cox Aerofoils Ltd. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | | |
| TRI Telepresence Research | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Tube Fab Ltd. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | | |
| UDT Industries Inc. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | X | X | | | | | | | |
| Unisys Canada Inc. | | X | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | |
| Vadeco International Inc. | | | | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | | | | | | |

SATELLITE SYSTEMS CAPABILITIES

[illegible]



GROUND STATION CAPABILITIES

| COMPANY | Antenna | Amplifiers | Receiver/Transmitter | Dedicated Processors | Computer Systems | Data Storage | Output Devices | Display Systems | Software | Integrator/Testing | Components |
|---|---------|------------|----------------------|----------------------|------------------|--------------|----------------|-----------------|----------|--------------------|------------|
| Advanced Information Technologies Corp. | | | | | | | | x | | | |
| PSCO Microwave Tech. Inc. | | | | | | | | | | | x |
| MacDonald Dettwiler & Assoc. | | | x | | | | x | x | x | x | x |
| SED Systems Inc. | | x | x | x | | x | x | x | x | x | x |
| Skyware Electronics Ltd. | | | | | | | | x | x | | |
| RMS Instruments Ltd. | | | | | | | | | | | |
| MPR Limited | | | | | | | | x | x | x | |
| Array Systems Computing | | | x | x | x | | x | x | x | x | x |
| Canadian Marconi | x | x | x | | | x | x | x | | | |
| Computing Devices Co. | | | | | | | | x | | | x |
| DY-4 Systems | | | x | | | | | x | | | x |
| SPAR Aerospace | | x | x | | | | | x | x | x | |
| Canadian Astronautics | | x | x | | | | | x | x | x | |
| Caleum Technologies Ltd. | | x | | | | | | x | | | x |
| Andrew Canada Inc. | x | x | | | | | | | | | |
| TIW Systems Ltd. | x | x | x | | | | | | | | |
| Industrial Measurements Ltd. | | | | | | | | x | | | x |
| Prior Data Sciences | | | | | | | | x | | | |
| Ratheon Canada | | | x | x | x | x | x | x | x | x | x |
| Frontec Logistics | | | | | | | | x | x | | |
| Rohde & Schwarz Canada Inc. | x | | | | | | | | | | |
| Unisys Canada Inc. | | | | x | | x | x | | | | |
| IBM | | | | x | | x | x | | | | |
| DEC | | | | x | | | x | | | | |
| Hewlett Packard | | | | x | | x | x | | | | |
| Myrias | | | x | x | | | | x | | | |
| Miller Communications | | | x | | | | | x | x | x | |
| Wardrop Engineering | | | | | | | | x | x | | |
| Telespace | | | | | | | | x | | | |

VALUE ADDED SERVICE CAPABILITIES

| COMPANY | Area of Application | | | | Supply Image Processing & Analysis Systems | | Products | | | | | | | Added Services |
|----------------------------------|---------------------|------|-------|----------|--|--------|----------------|---------------------|------------------|---------------------|----------------------|-----------------------|-----------------|------------------|
| | Atmosphere | Land | Ocean | Hardware | Software | G.I.S. | Image Analysis | Training Program(s) | Image Processing | Research Activities | Information Services | Plotting & Data Proc. | G.I.S. Services | Data Acquisition |
| ACRES International | | x | | | | | x | | x | x | | | | |
| Advanced Satellite Products | | x | | | | | x | | x | | | | | |
| AEROE Research Inc. | | x | | | | | x | x | x | x | | | | |
| Amenatech Inc. | | x | x | | | | x | | x | x | | | | |
| Applied Terravision Systems Ltd. | | x | | | x | x | x | | x | x | | | x | |
| Arctec Canada | | | | | | | | | | | | | | |
| Arctic Sciences Ltd. | | | x | | | | x | | x | x | | | | |
| T.M. Thomson & Assoc. | | x | | | | | x | | | | | | | |
| Bartech Photogrammetric Surveys | | x | | | | | x | | | | | | | |
| Bercha Group | x | x | x | | | | x | x | x | x | x | | x | x |
| Binary Image Corp. | | x | | | | | x | | x | | | | | |
| Bird & Hale Ltd. | | | | | | | | | | | | | | |
| Borstad & Associates Ltd. | | | x | | | | x | x | x | x | x | | | x |
| BSR Resource Data Corp. | | x | | | | | x | | x | | | | | |
| Cold Regions Remote Sensing | | | x | | | | | | x | x | | | | |
| College of Geographic Sciences | x | x | x | | | | x | x | x | x | | | x | |
| Canpolar Consultants Ltd. | | | | | | | | | | | | | | |
| Carto Sat Inc. | | | | | | | | | | | | | | |
| Dataspan Inc. | | x | | | | | x | | x | | | x | x | |
| Dendron Resource Surveys | | x | | | | | x | x | x | x | x | | | |
| Ducks Unlimited | | x | | | | | x | | x | x | | | x | |
| Dipix Technologies | | | | x | x | | | x | x | | | | | |
| B.C. Forestry | | x | | | | | x | | x | x | x | | x | |
| Earth Probe Systems | | | | x | x | | | x | x | | | | | |
| Ecosat Geobotanical Surveys Inc. | | x | | | | | x | | x | x | | | | |
| Eidetic Digital Imaging Inc. | | | | x | x | | | x | x | | | | | |

VALUE ADDED SERVICE CAPABILITIES

[illegible]

VALUE ADDED SERVICE CAPABILITIES

| COMPANY | Area of Application | | | | Supply Image Processing & Analysis Systems | | Products | | | | | | | Added Services |
|---|---------------------|------|-------|----------|--|--------|----------------|---------------------|------------------|---------------------|----------------------|-----------------------|-----------------|------------------|
| | Atmosphere | Land | Ocean | Hardware | Software | G.I.S. | Image Analysis | Training Program(s) | Image Processing | Research Activities | Information Services | Plotting & Data Proc. | G.I.S. Services | Data Acquisition |
| McLaren Plansearch Ltd. | | x | | | | | x | x | x | | | x | | |
| Marshall Macklin Monaghan Ltd. | | x | | | | | | | | | | x | x | |
| Manitoba Hydro | | x | | | | | x | | x | x | | | | |
| MacDonald Detwiller & Assoc. | | | | x | x | | | | x | | | | | |
| Nordco | | x | x | | | | x | x | x | x | x | | | |
| Norland Science & Engineering Ltd. | | x | x | | | | x | | | | x | | | |
| NUCOR Computing Resources Ltd. | | | | x | x | x | x | x | x | | | | x | |
| Ontario Hydro | | x | | | | | x | | x | x | | | x | |
| Octograph Inc. | | x | | x | x | | x | | x | | | | | |
| Paul Fuenning & Assoc. Inc. | | x | | | | | x | | | | | | | |
| Pacific International Mapping Corp. | | x | | | | | x | | x | | | | | |
| Pamap | | x | | x | x | | x | x | x | x | | | x | |
| Paul Hawkins & Associates | | x | | | | | x | | | | | | | |
| Photosur Geomat Inc. | | | | | | | | | | | | | | |
| PhD Associates Inc. | x | x | x | | | | x | | x | | | | | |
| Polar Sea Research | | x | | | | | x | x | x | x | x | | x | |
| PCI Inc. | | | | x | x | x | x | x | x | x | x | | | |
| Reid Collins & Assoc. Ltd. | | x | | | | | x | | | | | | x | |
| Quebec Hydro | | x | | | | | x | | x | | x | | | |
| Sir Sanford Fleming College | | x | | | | | x | x | x | x | x | | | |
| Terra Surveys Ltd. | | x | x | | | | | | x | | x | x | x | x |
| Timberline Forestry Inventory Consultants | | x | | | | | x | | x | | | | | x |
| TYDAC | | | | | | x | | x | | x | x | | x | |
| Lavallin Bell Geomat Inc. | | x | | | | | | | | x | | | x | |
| Universal Systems Ltd. | | x | | | | | x | | x | x | | | | |

VALUE ADDED SERVICE CAPABILITIES

| VALUE ADDED SERVICE CAPABILITIES | COMPANY | Area of Application | | | | Supply Image Processing & Analysis Systems | Products | | | | | | | Added Services | |
|--|--------------------------------------|---------------------|------|-------|----------|--|----------|----------------|---------------------|------------------|---------------------|----------------------|-----------------------|-------------------|------------------|
| | | Atmosphere | Land | Ocean | Hardware | Software | G.I.S. | Image Analysis | Training Program(s) | Image Processing | Research Activities | Information Services | Plotting & Data Proc. | G.I.S. Services | Data Acquisition |
| | UMA | | x | | | | | x | | x | x | | | | |
| | University of Alberta | x | x | x | | | | x | x | x | x | x | | | |
| | University of Calgary | x | x | x | | | | x | x | x | x | x | | | |
| | Laval University | x | x | x | | | | x | x | x | x | x | | | |
| | University of Manitoba | | x | | | | | x | x | x | x | x | | | |
| | University of British Columbia | x | x | x | | | | x | x | x | x | x | | | |
| | Carlton University | | x | | | | | x | x | x | x | x | | | |
| | University of Sherbrooke | x | x | x | | | | x | x | x | x | x | | | |
| | University of Waterloo | x | x | x | | | | x | x | x | x | x | | | |
| | University of Victoria | | x | | | | | x | x | x | x | x | | | |
| | University of Saskatchewan | | x | | | | | x | x | x | x | x | | | |
| | UNIES Ltd. | | x | | | | | x | | | | x | | | |
| | University of Guelph | | x | | | | | x | x | x | x | x | | | |
| | Dalhousie University | | x | x | | | | x | x | x | x | x | | | |
| | University of New Brunswick | | x | x | | | | x | x | x | x | x | | | |
| | Weather Tec Services Inc. | x | | | | | | x | x | x | | x | | | |
| | Memorial University | | x | x | | | | x | x | x | x | x | | | |
| | Univ. Quebec/Mont. | | x | | | | | x | x | x | x | x | | | |
| | Univ. Quebec/Chicou. | | x | | | | | x | x | x | x | x | | | |
| | Saskatchewan Research Council | x | x | | | | | x | x | x | x | x | | | |
| | Alberta Research Council | x | x | | | | | x | | x | x | x | | | |
| | Ontario Centre for Remote Sensing | x | x | x | | | | x | x | x | x | x | | x | x |
| | Manitoba Remote Sensing Centre | x | x | x | | | | x | x | x | x | x | | | |
| | CQCT | x | x | x | | | | x | x | x | x | x | | | |
| | NWT Remote Sensing Centre | | x | x | | | | x | x | x | x | x | | | |
| | University of Moncton | | x | | | | | x | x | x | x | x | | | |
| | Moniteq | | | | x | x | | x | | x | | | | x | x |

VALUE ADDED SERVICE CAPABILITIES

| VALUE ADDED SERVICE CAPABILITIES | | | Area of Application | | | Supply Image Processing & Analysis Systems | | | Products | | | | | Added Services | |
|--|------------|------|------------------------|----------|----------|--|----------------|---------------------|------------------|---------------------|----------------------|-----------------------|-----------------|-------------------|--|
| COMPANY | Atmosphere | Land | Ocean | Hardware | Software | G.I.S. | Image Analysis | Training Program(s) | Image Processing | Research Activities | Information Services | Plotting & Data Proc. | G.I.S. Services | Data Acquisition | |
| | | | | | | | | | | | | | | | |
| Coreco Inc. | | | | x | x | | | | | | | | | | |
| Various Government Agencies | x | x | x | | | | x | x | x | x | x | | x | x | |
| Morton Limited Partnership | | x | | | | | x | | | | | | | | |
| Crofield Muirfield (Canada) Ltd. | | | | | | | | | | | | | | | |
| Hewlett Packard | | | | x | | | | | | | | | | | |
| IBM | | | | x | | | | | | | | | | | |
| APPLE | | | | x | | | | | | | | | | | |
| DEC | | | | x | | | | | | | | | | | |
| SUN | | | | x | | | | | | | | | | | |
| Gulf Canada Resources Ltd. | | x | | | | | x | | x | x | | | | | |
| P.A. Lapp & Assoc. | | | | | | | | | | | x | | | | |
| Lionsgate International | | | | | | | | | | | x | | | | |
| Ecoplans Ltd. | | x | | | | | x | | | | | | | | |
| Northway Map Tech. Ltd. | | x | | | x | | x | | x | x | | | | | |
| Teledetection Int. Ltd. | | | | | | | | | | | x | | | | |
| Wickware & Assoc. Inc. | | x | | | | | x | x | x | x | | | | | |
| Prime Wild GIS Ltd. | | | | x | x | x | | | | | | | | | |
| Array Systems Computing | x | x | x | x | x | | | | x | | | | | | |

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Final report on long term space based earth observation and remote sensing strate

DATE DUE - DATE DE RETOUR

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