Canadian Space Agency Agence spatiale canadienne

CSA ASC

GLOBAL SPACE SECTOR MARKET TRENDS AND DRIVERS

YEAR 2002 EDITION

SATELLITE COMMUNICATIONS
EARTH OBSERVATION
SPACE ROBOTICS AND AUTOMATION
SATELLITE NAVIGATION
SPACE SCIENCE

Canada

MISSION OF THE CANADIAN SPACE AGENCY

The Canadian Space Agency is committed to leading the development and application of space knowledge for the benefit of Canadians and humanity.

The External Relations Directorate

The External Relations Directorate manages the strategic relationships between the Canadian Space Agency and its domestic and international partners. Key mandates include the development and implementation of policies and strategies relating to cooperation partnerships with domestic stakeholders (Federal and Provincial governments, industry and academia) and international agencies and industries, as well as support to the commercial initiatives of Canadian space companies on world markets. In connection with the latter, the Directorate provides strategic and timely information to industry and other stakeholders.

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foreword

I am very pleased to release the latest edition of our *Global Space Market Trends and Drivers 2002*. Developed by the External Relations Directorate of the Canadian Space Agency and now in its fourth year of publication, it provides an in-depth analysis of the principal market and regulatory trends in key areas of the Canadian Space Program, namely: satellite communications; remote sensing; robotics, navigation and space science.

Over the past year, as President of the Canadian Space Agency, I have benefited from numerous exchanges and consultations with all partners in the Canadian Space Sector and have developed a profound appreciation of both the multitude of challenges confronting us and the great opportunities which lie in our future.

I note with pride that the Canadian Space Sector remains internationally competitive, export-oriented and is recognized as a major contributor to Canada's goal of becoming the best knowledge-based economy in the world. For example, the results of a recent round of consultations with our federal departments and agencies underscored the very tangible ways in which space applications already provide knowledge-oriented solutions that benefit Canadians, while revealing a host of potential future opportunities.

In order to remain competitive, the Canadian Space Sector must stay abreast of key changes in the global marketplace and be ever aware of the trends and forces that influence the vitality and commercial success of our industry. As part of the Canadian Space Agency's ongoing commitment to promoting a highly competitive space industry, Global Trends 2002 captures the major market changes which occurred over the past year, updates the forecasts for growth opportunities and provides a discussion of the market conditions and international trends that government and industry partners need to be aware of. I trust you will find this information beneficial and relevant to your organization's strategic planning.

Marc Garneau
President
Canadian Space Agency

GLOBAL SPACE SECTOR MARKET TRENDS AND DRIVERS

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This document has been prepared to provide general information to the reader about major trends affecting the various sectors. The Canadian Space Agency does not guarantee the accuracy of the information contained herein, and assumes no responsibility for any course of action taken as a result thereof.

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SATELLITE COMMUNICATIONS SYSTEMS

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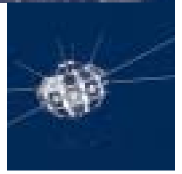

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EXECUTIVE SUMMARY

The past year has been a difficult one for the global telecommunications sector, and the space component of this sector has been no exception. Large projects have faltered, and some operators have gone under. This has had a significant negative impact on the Canadian satellite communications industry. Several suppliers have seen their order books shrink as a result of reduced demand from large global prime contractors, leading to a reduced turnover and some job losses. However, an examination of prevailing trends provides cause for optimism for a rebound in the near future. We expect this cyclical downturn to be over in 1-2 years, and for the Canadian industry to continue to reap the benefits of past and on-going investments in technological excellence. This will require a continuation of the strategic partnership between the industry and the Canadian government.

Over the next few years, the main global trends will be:

- North America will continue to lead world demand for communications services.
- The US market for telecommunications services and equipment will remain predominant.
- Television will remain the dominant application.
- DBS will continue to gain ground on cable systems.
- In-flight multimedia services should be deployed widely by 2005.
- Roll out of Ka band services on a regional basis will be gradual and cautious.
- High volume data transmissions will become a niche market.
- Demand for GEO transponders will increase slowly, requiring new satellites in the 2004-2010 period.
- The lifetime of GEO satellites will continue to increase.
- US prime contractors will continue to dominate the market.
- Consolidation and vertical integration will continue among satellite operators.
- Manufacturing overcapacity in US and Europe will remain a problem.
- ITARs will remain an irritant in dealing with US manufacturers.
- The financing outlook will improve for some satellite communications operators.

MARKET CHARACTERISTICS AND MAJOR EVENTS OF 2001-2002

OVERALL SITUATION

In late 2000 and 2001, the ".com" stock market bubble burst, and the telecommunications sector in general suffered a meltdown, with the difficulties of several high profile companies gracing the front pages[1], including in Canada[2]. The telecommunications sector's difficulties were due to a significant over-capacity in terrestrial networks as well as bad management (unworkable debt loads) at several carriers and Internet companies. These combined events led to a loss of confidence in the investment community at large as to the profitability and viability of telecommunications companies, with a spillover effect on satellite communications companies. This in turn soured the investment climate for most other space companies. The events of September 11, 2001, and the recession which followed in North America and elsewhere, contributed to further weakening investor confidence in general. Now, and for the next 1-2 years at least, would-be lenders are especially stringent in their requirements for new loans (attempting to eliminate or transfer most risks), and the stock markets are inhospitable to new public offerings. Less financing means fewer projects, and fewer opportunities for Canadian space companies.

Compounding the industry's problems, 2001 was a bad year for the satellite insurance industry[3]. Several design errors were behind a string of failures that could raise the total claims against insurers to US$1.5 B for 2001, suggesting total payouts could surpass the record levels set in 1998-2000. This vastly surpasses the premiums collected (for instance, total premiums amounted to US$490 M in 2001), aggravating an insurance capacity crunch, which appeared in 2000[4], and forcing key insurers to raise premium prices[5]. Insurers have also demanded that satellite manufacturers strengthen their quality control mechanisms, including greater scrutiny over sub-contractors. This may lead to a greater reluctance on the part of prime contractors to change established designs, making it more difficult for Canadian and other suppliers to sell new technologies. This means that the role of the Canadian Space Agency (CSA) in helping Canadian companies develop and flight validate new technologies is becoming that much more important, in reducing the perceived costs and risks to prime contractors.

These problems in the commercial satellite communications industry affect all satellite prime contractors, and by extension their suppliers in Canada and elsewhere. US prime contractors, however, enjoy an edge because of their access to large and increasing military programs (such as those related to GPS Modernization, or Homeland Security). European prime contractors do not enjoy this benefit, since Europe has no supra-national military space program of significance, and national programs are few and far between. It is generally difficult for Canadian space suppliers to access defense space contracts in the US and other foreign countries, although there are exceptions.

In the US, the effects of the 1999 transfer of export licensing authority for commercial satellites from the Commerce to the State Department and the applications of the International Traffic in Arms Regulations (ITARs) continued to be felt in 2001 and 2002. Even though during this period the US government and US companies beefed up their licensing staff and some regulations were streamlined, and even though the Canadian government was successful in getting the previous Canadian ITARs exemption partially restored, satellites (even commercial communications satellites) remain generally subject to ITARs and TAAs are required for almost all technology exchanges and discussions with US space manufacturers, and this process takes time.

1 For example, 360Networks, Global Crossing and WorldCom filed for Chapter 11 in the US in June 2001, January 2002 and July 2002, respectively. In July 2002, Alcatel reported a US$1.4 B loss, and had previously announced plans to lay off 30% of its work force.

2 In May 2002, BCE Inc. announced it was reviewing its funding commitments to Teleglobe and the possibility of renegotiating or restructuring its debt.

3 See "Worsening Insurance Crunch Worries Space Industry", Aviation Week and Space Technology (AWST), May 20, 2002, p. 47.

4 Insurance capacity fell to US$970 M in 2001, compared to US$1.1 B in 2000, and is expected to sink to US$700 M in 2002 and further in 2003. Among the most affected projects will be the large 4-5 metric ton communications satellites and the new heavy lift boosters required to launch them. See "Worsening Insurance Crunch Worries Space Industry", AWST, May 20, 2002, p. 47.

5 Rates for launch and 1 year of operations coverage are already 50% higher than in 1999, when in-orbit coverage often extended to 5 years. Insurance costs can reach up to 20% of total acquisition costs of satellites. See "Worsening Insurance Crunch Worries Space Industry", AWST, May 20, 2002, p. 47.

On the other side of the coin, these US measures have been somewhat compensated for by the continued elimination of investment restrictions, monopolies and other forms of trade barriers in some areas of the world. While protectionism is still palpable in some countries, liberalisation of telecommunications regimes and more open market access as envisaged by the World Trade Organisation (WTO) Agreement on basic telecommunications are gradually being implemented globally. For instance, the Canadian Fixed Satellite Service (FSS) market was formally opened to foreign satellite operators in March 2000. Since that time more than 50 foreign satellites have been authorized by the Canadian government to provide services in Canada.

Many in the satellite communications industry (manufacturers and operators) see 2002 as a year of stagnant growth and of consolidation, in preparation for a rebound expected to start in the 2003-04 time frame.

EVENTS IN FIXED SATELLITE SERVICES AND BROADCASTING (TRADITIONAL AND DIRECT)

In 2001, the top nine operators were (in order) SES Global[6], Intelsat, PanAmSat, Eutelsat[7], JSAT, Loral Skynet, SCC, New Skies and StarOne. Telesat Canada is in 12th place overall. Despite the broader meltdown of the telecommunications sector in 2000 and 2001, satellite operators performed generally well, supported by growth in Internet traffic and the TV market. Many were able to report growing profits and stronger balance sheets. Indeed, a group of 41 operators from around the world earned about US$7.1 B in 2000, an increase of 14.7% over 1999[8].

However, the downturn in the telecommunications sector made investment and launch insurance for new projects more expensive and difficult to obtain, forcing satellite operators to squeeze additional efficiencies out of their existing fleets and to refocus their attention on their core businesses (traditional services) and markets. This has slowed the development and introduction of new services.

At year end 2000, 81% of the total fixed communications and broadcasting transponder capacity (C and Ku bands) was being used, compared to 78% in 1999, with overcapacity being highest in Asia (27% of transponders were unused in 2001)[9].

In Canadian news, Industry Canada granted Telesat a license in June 2001 to launch a C-Ku band satellite (ANIK F3) at 118.7º West. The satellite is expected to be launched in 2004. In August 2002, NSI Global Inc. received contracts to provide wireless communications networks in China. NSI said it would supply Very Small Aperture Terminal (VSAT) networks for satellite-based communications to six new customers in China, and will expand an existing NSI-supplied network. Since the beginning of 2002, NSI has secured contracts with a value of CA$4.2 M to supply VSAT networks to China. In December 2001, International Datacasting (IDC) announced the signing of a contract valued at CA$1.1 M to provide a SuperFelx hybrid broadband data and video distance learning system to a Mexican government client.

Direct to Home Television (DTH) continued to perform very well in many markets. In the US, EchoStar[10] and DirecTV[11] significantly expanded their subscriber base. In October 2001, General Motors Corp. agreed to sell Hughes Electronics Corp., parent of DirecTv and PanAmSat, to Echostar, for US$26 B. The merger is expected to create a stronger competitor to large, US cable and broadband providers. The deal still requires regulatory approvals, which are not guaranteed, given the competitive (anti trust) implications. The combined entity will serve all 210, US TV markets, but is still barred from providing services in Canada by licensing rules requiring minimum Canadian content. SES Global is opposing the merger[12].

In Canada, Bell Expressvu announced in November 2001 it had signed up 1 million customers, the first to do so. Construction of Telesat's Nimiq 2 direct broadcast satellite remains on target at Lockheed Martin Commercial Space Systems, with service initiation planned for early 2003. Bell ExpressVu agreed with Telesat in June 2001 to use Nimiq-2's full capacity[13] (32-transponders). In addition to providing broadcast services, Nimiq 2 will have a Ka-band payload to provide Internet and multimedia services.

In the field of Direct Audio Broadcasting (DAB), three operators, WorldSpace Corp., Sirius Satellite Radio and XM Radio Corp., dominated the scene, aiming to provide CD-quality radio services to consumers, using proprietary terminals. While Worldspace targets populations in Africa, the Middle East and Asia, the other two systems provide services in the US only. As of March 31, 2002, XM Satellite Radio had more than 76,000 total subscribers, targeting 350,000 subscribers by the end of 2002. Sirius expects to roll out its service across the US in the third quarter of 2002. Most financial analysts expect demand for DAB to develop very rapidly, especially in the vehicle markets.

EVENTS IN MOBILE TELEPHONY AND PAGING SERVICES

In 2001, the debacle of LEO projects for mobile telephony continued. International Licensees L.L.C. acquired Orbcomm for US$13 M and Iridium Satellite L.L.C. acquired Iridium L.L.C. for US$25 M, fire sales in both cases. Both systems, as well as Globalstar and ICO Global, are still struggling to provide services and expand their user base. Aside from handset marketing and delivery problems, these difficulties are due to fundamental economics: the cost (and cash flow impact) of deploying these systems (many satellites in LEO) was not justified by market demand, which was drastically reduced by the relentless

6 In 2001, SES acquired GE Americom for US$4.3 B, moving it to first rank among global operators.

7 In July 2001, the assets and activities of the EUTELSAT intergovernmental organization were transferred into Eutelsat S.A., a limited liability company headquartered in Paris. This continues the trend established by the earlier privatizations of Intelsat and Inmarsat.

8 World Satellite Communications and Broadcasting Markets Survey, Prospects to 2010, Euroconsult, Paris, 2002 p. 23 (hereinafter "Euroconsult" 2002)

9 Euroconsult 2002, p. 1.

10 In February 2002, EchoStar reported quarterly revenues of approximately US$1.15 B, compared to US$805 M for the corresponding period in the previous year, and passed the 7 million subscriber milestone in February 2002.

11 DIRECTV added a net total of 1,345,000 new subscribers in 2001, ending the year with a total of 10.7 million customers.

12 In May 2002, SES Americom asked the US FCC to examine the merger.

13 Three of the DBS transponders will be available for resale to Canadian broadcasters.

MARKET CHARACTERISTICS AND MAJOR EVENTS

development of cellular systems in lucrative urban markets. Cumulatively, in excess of US$25 B was spent on these and other systems, and despite all this, mobile services remain a regional niche market serving about 800,000 users worldwide. Given this poor track record, it is surprising that some of the promoters of failed projects are continuing to promote new LEO constellations[14].

None of the above systems ever seriously challenged the domination of Inmarsat Ventures and of Qualcomm's OmniTracs system, both GEO-based systems with global coverage which together account for 80% of the world user base.

Some regional GEO systems have also done reasonably well: Pasifik Satelit Nusantara's Asia Cellular Satellite (ACeS)[15]; a similar system by Thuraya Satellite Communications; and Insat 2E (India). Other systems are planned, including in Japan[16].

In Canadian news, Telesat acquired 100% of Infosat from BCE for CA$24 M. Infosat is a telecommunications solutions provider, using MSAT, Inmarsat, Iridium and other systems. In November 2001, the satellite division of US Motient Corporation and Canada's TMI Communications joined forces to form a new entity, Mobile Satellite Ventures. The union allows these two companies, both leaders in the satellite communications industry, to combine their strengths and knowledge to build a system capable of taking North American satellite communications into the future.

In April 2002, the Canadian Centre for Marine Communications (CCMC), in partnership with the Communications Research Centre (CRC), requested concept proposals under Marine Information Skyway — a CA$1.5 M initiative to stimulate and support the development and commercialization of satellite communications applications for the marine sector.

EMS Technologies has landed a number of contracts for its mobile data terminal, PDT 100, including providing 1200 units a year to the US military.

In January 2001, NSI purchased 79.4% of Vistar for US$51.2 M from a group of shareholders that included BCE. Vistar is a world leader in satellite-based mobile communications terminals and asset-tracking services for applications such as long-haul trailer tracking and remote asset monitoring.

CMC Electronics has captured more than 75% of all Aero-H/H+ airline installations with its Satellite Communications (Satcom) antennas. The popularity of CMC's high gain antenna system, known as the CMA-2102, was confirmed in July 2002 with major new orders placed by some of the world's leading airlines. Japan Airlines ordered the CMA-2102 for 18 firm and 16 optional B747s. Singapore Airlines ordered the antenna for its fleet of 18 new B777s and six B747s. Qantas ordered the antenna for 6 new B747s and 13 A330s.

EVENTS IN BROADBAND SERVICES

In the late 1990s, all satellite prime contractors were planning one or more Ka-band systems. Many of these have now been quietly abandoned or delayed indefinitely (e.g. SES' Pioneer, Loral's Cyberstar, Alcatel's Skybridge, Lockheed Martin's Astrolink[17]). Another program which has suffered significant delays and redesign is Teledesic. It is, however, apparently still proceeding[18].

Despite this, some companies are still championing projects in the near to medium term. In August 2001, the FCC authorized eleven new and established satellite operators to provide Ka-band satellite service in the US. The newly licensed companies include CAI Data Systems, Lockheed Martin, Celsat America, Loral Cyberstar, DirectCom Networks, Pacific Century Group, Hughes Communications, PanAmSat, KaStarCom World Satellite, Pegasus Development Corporation and TRW. All companies intend to use these satellites to provide Ka-band fixed-satellite services (FSS).

In a February 2002 report, the US FCC found satellite broadband offerings growing but still dominated by cable web services. According to the new FCC data, there were 9.6 million high-speed Internet users as of June 30, 2001, a 36% increase during the first half of 2001 and a 250% increase from the FCC's second report issued in August 2000.

14 Globalstar awarded a contract to Space Systems/Loral for the construction of a 2 GHz satellite system for delivering advanced services. Globalstar envisions a constellation of 56 low-earth-orbit (LEO) satellites supplemented with four geostationary orbit (GEO) satellites. The first launches are anticipated for 2006. In July 2001, the FCC granted Globalstar a license to use a 2 GHz mobile satellite radio spectrum.

15 ACeS is co-owned by PT Pasifik Satelit Nusantara (PSN), Lockheed Martin Global Telecommunications, Philippine Long Distance Telephone Company and Jasmine International of Thailand. ACeS is the first satellite based, geostationary handheld mobile voice and data communications system specifically designed for the Asian region.

16 In July 2002, 20 Japanese corporations announced a plan to build a satellite communications network known as "Figure-8" or "Quasi-Zenith" for cellular phones and other mobile communications services at a cost of some US$1 B beginning in 2005. Also, the Mobile Broadcasting Corporation (MBC) of Japan and Space Systems/Loral will build the MBSAT communications satellite. MBSAT will deliver digital multimedia information services such as CD-quality audio, MPEG-4 video and data to mobile users throughout Japan.

17 In November 2001, both TRW and Lockheed Martin announced that they were halting further investment in Astrolink. In May 2002, Liberty Satellite & Technology, Lockheed Martin, TRW and Telespazio agreed to restructure Astrolink. The restructuring plan proposes the acquisition of all the assets of Astrolink by Liberty Satellite, which plans to pursue a revised operating plan for the new Astrolink system.

18 In February 2002, Teledesic selected Alenia Spazio to build the first two satellites for its system. Negotiations are underway with Alenia and other manufacturers for the remainder of the satellites needed. Teledesic's latest network architecture calls for 30 medium-Earth-orbit Ka-band satellites. The first 12 satellites are expected to cost under US$1 B, substantially less than previous system designs, and provide coverage needed to launch service in several areas of the world. The remaining 18 satellites would expand coverage globally.

Telesat increased its share of Wildblue to 20% from the 6.2% it had acquired in 2000. Development of the KA Band payload for Telesat's Anik F2 continues with launch scheduled for mid- 2003. This multimedia payload includes ComDev's BeamLink and EMS Technologies Canada's SpaceMux, both developed under CSA's Flight Payload demonstration Program. Once in service, Anik F2 will be one of the most powerful commercial satellites, a significant addition to Canada's telecommunications infrastructure and will play a key role in meeting the goal of becoming the most connected nation in the world.

In the second quarter of 2002, Telesat launched Telesat High Speed Internet (HSi), a two-way satellite turnkey service for Web-based Internet/ Intranet access and many data and IP multicast applications, with coverage throughout Canada and the continental U.S.

In June 2002, EMS Technologies Canada and Alcatel Space signed a cooperation agreement for the development of Broadband Satellite Access Solutions compliant with the DVB-RCS open standard.

On April 18, 2001, Norsat announced an agreement with China Netcom Corporation Limited (CNC), China's leading broadband infrastructure provider, to supply a large, fully redundant SpectraWorks DVB (Digital Video Broadcasting) Data Hub for CNC's Internet gateway in Beijing.

In October 2001, Norsat International announced that the People's Daily, China's largest daily newspaper, had selected Norsat's broadband Digital Video Broadcasting (DVB) data hub to manage the movement of newspaper and sizable video files across its corporate network.

In June 2002, Norsat International announced a contract with Globecomm Systems Inc. (GSI) for its open standard Digital Video Broadcasting (DVB) forward link satellite network and services. GSI will integrate Norsat's established DVB forward link subsystem with a return channel product to provide an interactive DVB-RCS system. Another contract was announced in June with Quick Link Communications for the sale of up to 500 VSAT Ku-band terminals for broadband communication to remote locations, primarily in the oil and gas industry.

EVENTS IN SATELLITE MANUFACTURING

Satellite prime contractors and their suppliers had a good and a bad year in 2001. On one hand, at the end of 2001, 99 GEO commercial satellites were in development or awaiting launch, with a cumulative value of US$11.6 B[19]. This represented an increase of 9% compared to end 2000 due to a surge of orders in 2000 (42 satellites ordered for US$4.8 B) and launch delays. On the other hand, only 26 new satellites were ordered in 2001. Several orders were also cancelled during this period.

19 Euroconsult 2002, p. 81.

20 For instance, space represented just 10% of EADS' and 12% of Alcatel's operations in 2000.

21 Euroconsult data presented at the "Espace, Stratégie et Sécurité" Colloquium, February 13, 2002.

MARKET CHARACTERISTICS AND MAJOR EVENTS

Whereas in 2000 European prime contractors (Alcatel, Astrium) had shocked US primes by netting 16 of 22 satellite orders, they were only able to win 6 orders out of 26 in 2001, with most awards going to American manufacturers.

In the US, Northrop Grumman acquired TRW in a US$7.8 B transaction in July 2002. The European (Alcatel, Astrium) and American (Boeing, Lockheed Martin, Northrop Grumman) conglomerates are very diversified[20]. In July 2002, European Aeronautic, Defense and Space Company (EADS) announced that it had bought out BAE Systems' 25% share in Astrium.

Unlike Canadian space companies, which are generally not diversified, these foreign primes are better protected against cyclical industry downturns. This said, US prime contractors remain much less vulnerable to commercial market cycles than their European counterparts. In 2002, estimates show that total US space (including satellites) sales of US$20.5 B will be 81% military and 19% commercial, while total European industry sales of US$8 B will be 61% military and 39% commercial[21].

Boeing Space and Communications (BSC) announced in 2001 its intention to outsource more of its components and sub-systems, in a move away from vertical integration. The CSA and Industry Canada have initiated a dialogue with BSC to help position Canadian space companies as suppliers to BSC. A series of targeted meetings will be organized between some Canadian space companies and BSC to explore possible opportunities. CSA is planning to replicate this model, in which CSA would act as "broker", with other prime contractors in the US, Europe and Japan.

REGULATORY DEVELOPMENTS

In February 2002, the US FCC announced that, in order to expedite delivery of satellite services and reduce the time required to assess applications, it will revamp existing procedures[22]. Further, the FCC announced in April 2002 that it had approved a plan that would let companies share spectrum used by satellite television services as long as it does not create interference. The agency plans to auction off the spectrum that could be used by bidders for a variety of services, including pay television, similar to those offered by EchoStar Communications Corp., as well as high-speed Internet access.

In June 2002, the Canadian Radio Telecommunications Commission (CRTC) issued an invitation to submit expressions of interest to Industry Canada with respect to developing satellites using new broadcasting-satellite service spectrum to be available effective April 1, 2007. To date, Bell ExpressVu and Telesat Canada have filed expressions of interest[23].

22 The FCC is proposing two possible licensing approaches to replace the existing application process. Currently, the FCC considers all satellite license applications together in "processing rounds," where the FCC and applicants have the opportunity to negotiate a solution to all potential conflicts between proposed satellites. The FCC would like to replace this process with one of two possible new procedures. The first is a "first come, first served" system in which the FCC would consider the first application for specific spectrum and/or orbit location. Applications filed subsequently would be included in a queue according to their date of filing. This would expedite the system. The second proposal is to modify the current processing round approach by establishing a 60-day deadline for completing negotiations and requests for comment.

23 See http://strategis.ic.gc.ca/SSG/sf05907e.html

24 Euroconsult 2002, p. 4.

25 Euroconsult 2002, p. 4.

26 Euroconsult 2002, p. 1.

27 Euroconsult 2002, p. 122.

28 Euroconsult 2002, p. 122.

MARKET TRENDS

TRENDS IN FIXED TELEPHONY (FSS) AND BROADCASTING (TRADITIONAL AND DIRECT)

North America will continue to lead world demand for communications[24]:
Of the 8,904 transponders expected to be in use in 2010, 25% will serve N. America, followed by Asia Pacific and Western Europe (22% each), Latin America (12%), Africa and the Middle East (8%), Central/Eastern Europe (6%) and South Asia (5%).

Television will remain the predominant application[25]:
Of the 8,904 transponders expected to be in use in 2010, television and video feeds will represent 52% of transponder usage, followed by voice and data traffic (excluding Internet) (20%), Internet trunking (18%), direct Internet access (9%) and on-board processing signalling capacity (1%).

Demand for GEO transponders is increasing slowly, requiring new satellites in the 2004-2010 period[26]:
Despite the increasing efficiencies operators are getting from existing satellites, and the increasing competitive threat from terrestrial fiber networks, various factors continue to drive up demand for geostationary satellite communications, including growth in internet traffic and sales of VSATs and DBS dishes. As FIGURE A indicates, Euroconsult predicts that transponder demand will continue to grow by about 5.6% per year in the next 10 years.

Transponders currently in development should satisfy demand until end 2003, after which time new transponders will be required. This will drive demand for new satellites, with 175-201 satellites to be delivered between 2001-2010, for an aggregate value of US$21.9-26.5 B (excluding the cost of launch and insurance). Excluding satellites already under construction, this leaves a potential for 50-80 new satellite orders during this period. As FIGURE B indicates, Euroconsult expects 19 commercial GEO satellites to be launched annually in the 2001-2010 period, compared to 22 satellites annually in the 1990s. This decline, however, must be seen in the context of larger and higher performance satellites.

The number of transponders on GEO satellites continues to increase[27]:
For C and Ku-band satellites, the average number of transponders on satellites launched from 1995-2000 was 36 units at 36-MHz. For satellites in construction as of mid-2001, the number had grown to 48 transponders, and the largest GEO satellites can accommodate as many as 100 transponders.

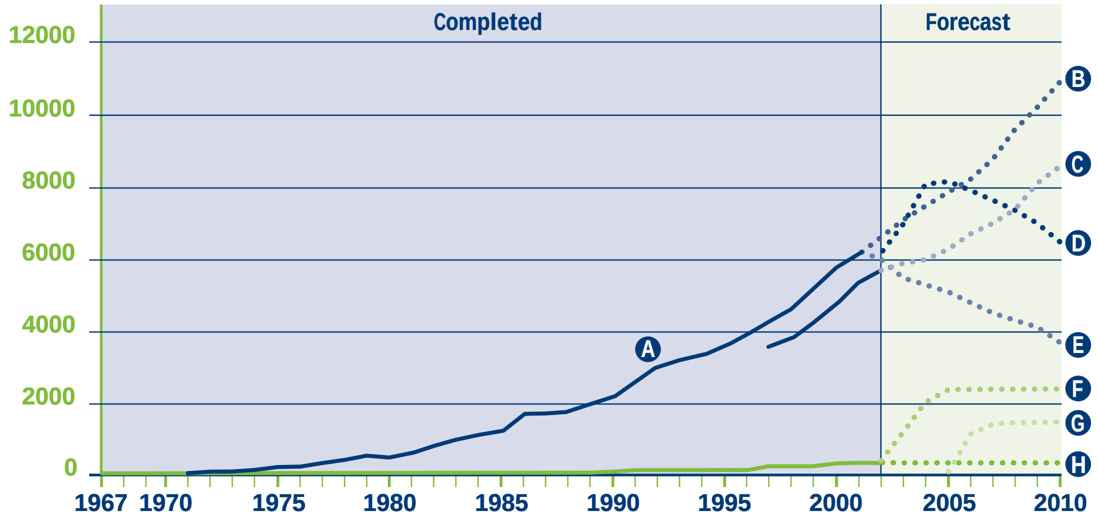
The lifetime of GEO satellites will continue to increase[28]:
The design lifetime for satellites launched in 2001 was 13.5 years and this is expected to increase to 14.8 years for satellites to be launched around 2004.

Canada has traditionally focused on the development of sub-systems and components for geostationary satellites, a strategy validated by the above trends.

MARKET TRENDS

FIGURE A

GROWTH OF THE WORLD TRANSPONDER FLEET (1967-2000, PROSPECTS FOR 2010)



A Supply (C & Ku)
B Transponders needed to meet the demand model (including a 20% margin*)
C Transponders utilization C & Ku-band
D Transponders in construction as of 03/30/01 (C & Ku-band)
E Transponder fleet attrition
F New Ka-band projects** as of 03/30/01
G Probable shift in ka-band projects
H Supply (Ka-band)

New C/Ku tx
70's: + 485 tx
80's: +2423 tx
90's: + 5711 tx
00's: + 6719 tx
(to meet the demand model)

*historical average
**according to promoters' expected date of launch

Source: Euroconsult's ECOSPACE database

DBS will continue to gain ground on cable systems:
In developed countries, this will be especially true in regions unserved by cable, but also to a lesser extent in cities. Growth will be fastest in developing countries, especially in Asian countries where cable systems are less prevalent[29].

DBS operators are now introducing enhanced and interactive TV services: Improvements in set-top-box technology and a more sophisticated utilisation of the capabilities of the Digital Video Broadcast (DVB) standards are enabling home shopping, banking and other value added services to be offered.

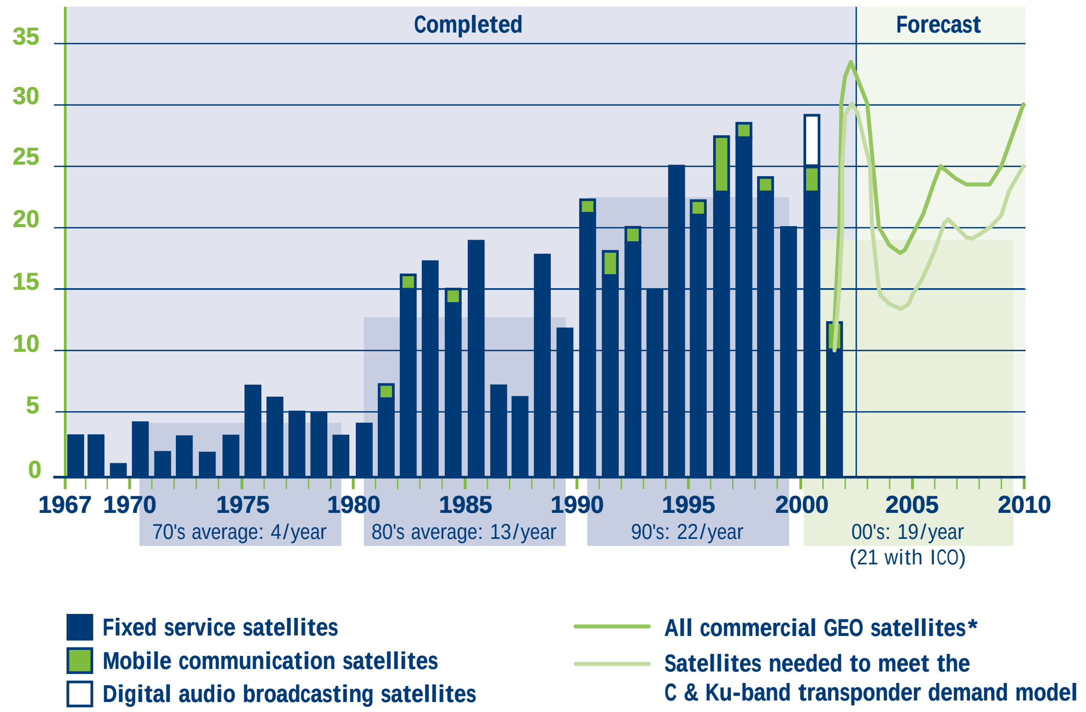
29 Asia-Pacific has five times more television households than North America but only one quarter of DBS satellite television users, according to research firm, Frost & Sullivan. As a result, Asia has great DBS potential but it is a struggle for profitability against the more established—and cheaper—cable TV services. "DBS in Asia: More Patience Before Profits", www.satnewsasia.com, March 2002.

30 Euroconsult 2002, p. 203.

31 In May 2002, Boeing's Connexion division received US Federal Aviation Administration (FAA) certification for its satellite-based airborne communications system. Mitsubishi Electric will provide the aircraft antennas. As a result of the weakened travel business following the attacks of September 11, American Airlines, Delta and United Airlines have decided to withdraw as equity partners in Boeing's planned Connexion Internet service, although they could be test users. In July 2002, Japan Airlines agreed to become Asia's first launch customer for Connexion.

FIGURE B

COMMERCIAL GEOSTATIONARY COMMUNICATION SATELLITES LAUNCHES (1967-2001, PROSPECTS FOR 2010)



*The non-geostationary satellites in the ICO and Sirius systems are included because they are closely derived from geostationary models, a separate trend is shown without the ICO system because of its large size and uncertain status.

Source: Euroconsult's ECOSPACE database

With the move to introduce massive local storage in the next generation of set top boxes, the broadcast satellite industry looks set to capitalise further on its large installed user base.

TRENDS IN MOBILE SERVICES

GEO systems will dominate:
Until the disadvantageous economics of LEO systems are resolved, we can expect the market for GEO based services and terminals to continue growing,

MARKET TRENDS

FIGURE C

ROLE OF SATELLITES IN INTERNET DELIVERY

Category	Description	Providers	Strength
Internet Backhaul (pull)	Transport Internet traffic from ISP to requesting ISP	Intelsat, Panamsat, Eutelsat, New Skies, Astra, Shin Satellite, Loral Skynet	Alternative to terrestrial backbone (fiber, undersea cable)
Deliver high-bandwidth content to ISP POP (Push)	Internet content transmitted to ISPs and cached to provide more rapid delivery to users	Same as above plus Cidera	Broadcasting capability of satellites an advantage; bypasses congestion in internet
Broadband internet access (last mile)	End-user/last mile Access from fixed locations	Gilat, Hughes, ICO, Spaceway, Astra, WildBlue, Skybridge,	Where terrestrial broadband unavailable; synergy with DTH
IP VSAT networks	IP connectivity for VSATS; combines voice, video, data	iDirect, Cyberstar; Hughes; Shin; Asiasat	Upgrade of VSAT networks

Source: Leslie Taylor Associates, January 2002

32 In September 2001, Airbus and Astrium announced a similar initiative.

33 Air Canada has completed its 6-month trial of Tenzing's email access service, and Cathay Pacific is offering this same service on some flights.

to 3 million terminals in 2005 and 11 million terminals by 2010[30]. Inmarsat and Qualcomm's OmniTRACs will continue to prevail. Some of the new GEO systems to be introduced in the near future include Inmarsat 4 satellites and one more satellite from Thuraya.

Growth through specialized services:
We can expect future growth to be driven in good part by the development of new, specialized services (e.g. pipeline monitoring).

In-flight services should be deployed widely by 2005:
Boeing Space and Communications has launched its Connexion system[31], and other projects[32] have been proposed to provide in-flight TV, email and Internet access. The events of September 11, 2001 have precipitated a series of failures among airlines and forced the remaining ones to remap their priorities in the near term. Yet, polls indicate a latent demand for in-flight services. Already, some trials have been conducted, and limited services for email access are available[33].

MARKET TRENDS

TRENDS IN BROADBAND SERVICES

Global demand for Internet access is growing fast: According to the research firm In-Stat/MDR, at the beginning of 2002, the worldwide broadband subscriber base passed the 30 million mark, and is expected to reach 46 million by end 2002[34]. Growth has been strong in Asia[35] and could be faster in other parts of the world, but this is hindered by the limited local access infrastructures left in place in many countries as a legacy of decades of monopolies. The widespread deregulation of the telecommunications industry will, over time, open up a lot more markets to competition, and facilitate the roll out of new services, including broadband[36].

Satellites will play a vital role in delivering services:
DSL and cable have become predominant[37], and this trend will continue, especially in developed countries. However it is estimated 20% of the population in North America will remain out of reach of traditional DSL and Cable modems services. Space currently serves only about 5% of the worldwide demand[38]. Direct access to the Internet by satellites, on which satellite operators count to generate growth beyond the trunking market, has progressed much slower in recent years than anticipated, owing to the delay in the implementation of multimedia Ka Band satellite systems. Yet, the potential for growth is very good, because satellites can play an important role, complementing terrestrial systems, as indicated by FIGURE C.

For these reasons, we can expect satellites to play a small but vital role in delivering services to consumers. Euroconsult estimates that there will be 1 billion Internet users in 2010, requiring 1,547 36 MHz transponders[39], making Internet trunking the fastest growing segment in the satellite market. As FIGURE D indicates, Euroconsult estimates that 843 36 MHz transponders and 12.6 million user terminals will be in service by 2010[40], with demand growth in all regions.

Roll out of Ka band services will be gradual and cautious:
Initial services have already been introduced in Ku-band[41], allowing service providers to test the waters. Ka-band transponders are also being installed (often as test payloads) on more traditional satellite systems, such as Telesat's ANIK F2 and other systems by SES Astra (Astra 1K), Eutelsat, Loral Skynet and others in Asia[42]. The first limited systems should come on stream in the 20003-04 time frame. These will be key to developing future market demand.

Some barriers to Ka-band deployment must be overcome:
Various factors hinder the deployment of commercial systems in Ka-band: the stigma of past failures of LEO telephony systems, and especially the high price[43], limited standardization[44] and limited availability of Ka-band customer premise equipment. Technical issues involving bit error rates and queue management, for example, can seriously impact IP (Intellectual Property)-over-satellite performance, although the satellite industry has managed to work around the latency and TCP (Transmission Control Protocol) performance issues with a number of

34 "InStat: Broadband Still Growing", www.skyreport.com, July 23, 2002.

35 Asia has embraced the Internet faster than any region in the world. By 2004, the Asia-Pacific region is expected to account for 20% of worldwide online spending, with e-commerce revenues reaching US$1.6 T. Annual e-commerce growth from 2000 to 2004 is estimated at 140% annually. Internet use is increasing strongly in China and India and is progressing fast in Japan (currently Asia's leading Internet country), South Korea, Singapore, Hong Kong and Taiwan.

36 See "The Development of Broadband Access in OECD Countries", OECD, October 29, 2001, p.4.

37 According to the research firm InStat, worldwide DSL subscribers passed the 17 million mark in late 2001, allowing DSL to replace cable modem service as the most widely used broadband technology on the planet. A sharp rise in the number of DSL subscribers in the Asia Pacific region sparked the growth. In the United States, cable modem subscribers continue to outnumber DSL subscribers. At the beginning of 2002, there were 7.12 million U.S. cable/Internet subscribers and 4.6 million DSL subscribers. See "InStat: Broadband Still Growing", www.skyreport.com, July 23, 2002.

38 "InStat: Broadband Still Growing", www.skyreport.com, July 23, 2002.

39 Euroconsult 2002, p. 215.

40 Euroconsult 2002, p. 270.

41 A crop of 2-way satellite service providers started appearing in the late 1990s, using mostly Ku-band dishes: SES Astranet; Hughes' DirecWay, Intelsat's Broadband VSAT; StarBand Communications (which filed for Chapter 11 protection in the US in May 2002), and others. New Skies' NSS-6, to be launched by end 2002, will be Asia's first intra-regional Ku/Ka-band satellite, and will cover India, China, the Middle East, South Africa, Australia, and South East Asia and North East Asia. Twelve super-high-gain uplink spot beams in the Ka-band will facilitate high data-rate transmissions from antennas as small as 90 cm.

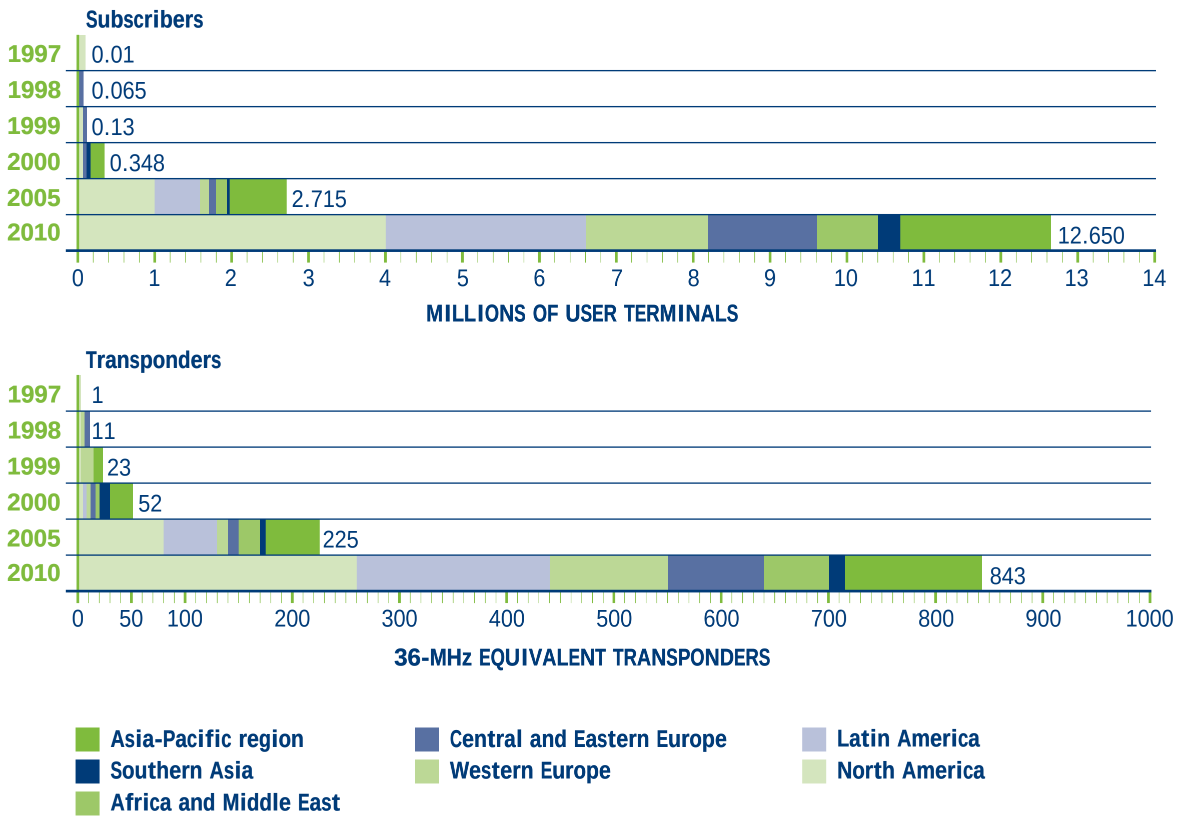
42 Thailand's Shin Satellite (ShinSat), Asia's second largest satellite operator, will launch in 2003 its new iPSTAR 1 broadband Internet satellite. iPSTAR 1 will have a capacity of 40 gigabytes per second to 14 gateways in the Asia-Pacific covering China, Japan, India and Australia, providing pay TV and VOD services, IP voice telephony and high-speed Internet connections. ShinSat expects 13 million users by 2008, of which 600,000 customers will be in Thailand. Its biggest market, however, is expected to be China. ShinSat has already sold 30% of iPSTAR's capacity to companies in China, Malaysia and India.

43 Satellite 2-way access is more expensive than terrestrial access.

44 It is unclear at this time whether the DVB-RCS open standard, or whether proprietary systems such as those of Hughes Network Systems or Gilat, will prevail. Much hangs in the balance for some Canadian companies, such as EMS Technologies Canada and Norsat, which have invested heavily in the DVB-RCS standard. In November 2001, Eutelsat decided to buy DVB-RCS hub and terminals from EMS for use over Ku-band FSS satellites.

FIGURE D

TERMINALS AND TRANSPONDERS FOR DIRECT SATELLITE INTERNET ACCESS, 1997-2010



Source: Euroconsult

MARKET TRENDS

technical fixes. An investment community is assessing all this with a very limited appetite for risk. However, we can expect that broadband Internet access by satellite will be facilitated once this service is offered by most direct-to-home TV providers by 2005, leveraging the distribution and customer support infrastructure already in place.

Initially, satellite operators are unlikely to provide services directly:
In general, satellite operators will act as carriers for the foreseeable future, reselling capacity to service providers and letting the latter worry about providing services to consumers. But as new applications and services are developed and demonstrated, operators could become interested in providing services directly, or through subsidiaries, in specialized market segments[45].

Developing regions will not be left out of satellite broadband:
Asia will lead the pack in implementing regional systems, followed by Latin America[46] and other regions.

High volume transmissions will become a niche market:
In February 2002, Telesat Canada and Galaxy Entertainment (a Canadian film exhibitor) conducted a demonstration of a new system that allows cinema exhibitors to receive content, such as feature films, live events, advertising and other programming directly from distributors in digital format via satellite. Even more demanding would be gigabit class requirements from some industrial sectors (e.g. the offshore oil industry) to gather and distribute large volume data. One system aiming to serve this niche market is Cascade, proposed by MacDonald Dettwiler and Associates.

TRENDS IN SATELLITE MANUFACTURING

US prime contractors will continue to dominate the market:
Of the 94 satellites on order for 2002-06, 62 were contracted to US companies (Boeing with 28; SS Loral with 21, Lockheed Martin with 12 and OSC with 4). European primes come in second at 24 (Alcatel with 16, Astrium with 7 and Alenia with 1). Obviously, these large companies will remain crucial customers for Canadian space suppliers. Yet, we believe that Japanese companies also present opportunities in the mid-term. Japanese prime contractors have not been internationally competitive, and both the Japanese government and industry realize they must work together differently if this is to change. A stagnant or declining Japanese domestic market will force Japanese contractors to increasingly look to foreign markets for business, and high domestic prices will require them to look abroad for qualified, cost effective parts. This could present important opportunities for Canadian industry. For all foreign prime contractors, Canadian space companies will need to continue establishing long-term supply agreements[47].

45 One example is the announcement in December 2001 that Hugues Network Systems and Chicago-based AgriStar Global Networks, Ltd. will provide DIRECWAY® two-way, high-speed satellite communications services to the U.S. agricultural industry.

46 In May 2002, the presidents of Andean investment consortium Andesat and Brazilian satellite company, Star One, announced the launch of the Simon Bolivar satellite towards year-end 2004.

47 For instance, in January 2002, COMDEV Space signed a Long Term Supply Agreement with Boeing Satellite Systems, to supply waveguide switches.

48 In March 2002, Boeing Space and Communications received US$336.4 M in funding from the US Air Force to build the first two satellites in the Wideband Gapfiller Satellite system. The contract also includes long-lead material for a third satellite. With all options exercised, the contract for up to six satellites has a total potential value of US$1.3 B.

49 In November, the U.S. Air Force awarded Lockheed Martin Space Systems and TRW Space & Electronics a contract for up to US$2.7 B to begin the System Development and Demonstration phase of the Advanced Extremely High Frequency (Advanced EHF) Program, the next generation of global, highly secure, survivable communications system for all services of the Department of Defense.

US prime contractors will continue to benefit from significant US DOD contracts:
Examples include the Wideband Gap Filler[48], Advanced EHF[49] and MUOS systems[50]. More modernization programs can be expected[51], including as a result of the events of September 11, 2001[52]. Because of their military nature, it is not easy for Canadian space suppliers to get sub-contracts in these projects, but there are exceptions, as demonstrated by COM DEV[53], EMS Technologies Canada[54] and other companies.

Will Loral have to merge?
We can expect Loral to merge with another US prime contractor, probably Lockheed Martin[55].

Emerging industrial players have high ambitions:
Industries in China[56], Russia and India, and later on in South Korea and Brazil, could present opportunities for Canadian industry, initially in their domestic markets, and perhaps abroad later on. China's space industrial capacity is folded into an umbrella called the China Aerospace Science and Technology Corporation (CASC). CASC and its components are responsible for the production of all launchers, satellites and other systems in China. Long March launchers have been marketed globally for years, and CASC has indicated its intention to move, over the medium term, to the marketing of its satellites and subsystems globally. Russia's space industry has been battered by the break-up of the USSR and the ensuing sustained budget crunch. Still, some organizations, often sustained through foreign joint ventures, have maintained impressive technical capabilities, and an improving budgetary situation in the country will lead to new programs in the near term[57]. India has been determined to develop its internal technological infrastructure for its own domestic program, and we can expect over time, under the umbrella of the ISRO-owned Antrix Corporation, that these capabilities will be marketed abroad. All this could lead to attractive opportunities for Canadian companies, which could supply to these industries for use in their domestic markets, perhaps paving the way for later opportunities when and if these organizations become competitive internationally.

Manufacturing overcapacity in US and Europe will remain a problem:
Euroconsult estimates that market demand will justify building, at most, 200 GEO satellites in the 2001-2010 period, while existing capacity would allow the main prime contractors to build 400-490 satellites, or 2.5 times the demand[58]. This could be aggravated by the plans of some primes to further expand the capacity of their plants in the next few years. As business remains slow for at least the next 1-2 years, this will continue to make it difficult for Canadian space suppliers to convince the already vertically integrated primes (at once their customers and often their competitors) to "buy" rather than "make".

Can a prime contractor also be a service provider?
Lockheed Martin said a resounding no in May 2002 when it announced it had sold an 81% stake in COMSAT International to World Data[59]. Yet, other prime contractors have not rushed to follow suit. Boeing Satellite and Communications' business model is in fact oriented towards providing more value added solutions using space infrastructure, to address niche (but large) requirements such as air traffic management, broadband connectivity to aircraft. Alcatel and Astrium, chastened as they are by the failures or delays in their constellations plans, have nevertheless maintained an active watch towards future opportunities.

50 The US Navy is planning the Mobile User Objective System (MUOS) program, to provide global communications to all U.S. forces in such hard-to-reach places as thick jungles, urban canyons, mountainous terrain or at sea. The Navy is expected to select two teams for an initial 14-month design period. A final multi-billion dollar production contract is expected to be awarded late 2003. Initial operational capability for the satellite is expected in early 2008, with full capability by 2013.

51 According to the USAF, the U.S. military communications satellite system and the small satellite receivers used by American forces to talk with each other are in critical need of overhaul to enable U.S. troops to fight the war on terrorism – See AWST, January 21, 2002.

52 On September 11, 2001, the attack on the World Trade Center knocked out 14 cellular base stations, effectively crippling terrestrial communications networks. But satellite systems were unaffected and offered one of the first links. Budgets for homeland defense have increased, and departments across the US are looking at how they can keep their emergency responders better connected. Satellite based systems can be part of the solution. See "Satellite Technology Comes of Age in Public Safety", Wireless Future Magazine, July-August 2002.

53 In May 2002, COM DEV Europe won a contract valued at US$9.5 M from TRW Inc. to supply the Beam Select Switch (BSS) subsystem for the first two satellites of the AEHF program.

54 In April 2002, EMS Technologies announced a contract to supply PDT-100 packet data satellite terminals to the U.S. government. The multi-year contract, for 1,200 units per year, represents the first sale of the EMS PDT-100 to a military customer.

55 In June 2002, Lockheed Martin Corp. and Loral Space & Communications announced they are considering joining their commercial satellite operations to better compete with Boeing.

56 In September 2001, the Chinese government announced that China would launch 35 satellites, presumably in the DFH class, in the 2001-2006 timeframe, and several of those are expected to be communications satellites for domestic and regional requirements. See "China's space exploration enters "new stage", experts say", Xinhua news agency, Beijing, 16 September 2001.

57 In November 2001, a Russian official noted that Russia currently has 30 unoccupied orbital positions in GEO, and intends to launch satellites to maintain those. In a related transaction, the state company Space Communications (GPKS) has contracted with Krunichev the construction and launch of one small satellite based on the Dialog series, weighing 500 kg and equipped with ten to 12 transponders. EMS Technologies Canada will manufacture the payload for the satellite.

58 Euroconsult 2002, p. 89.

59 COMSAT International originally was a component of COMSAT Corporation, which Lockheed Martin acquired in 2000 through its Lockheed Martin Global Telecommunications unit. When Lockheed Martin determined it would exit the global telecommunications services business in December 2001, it indicated it would divest itself of certain telecommunications assets, including COMSAT International.

60 "Chute brutale du marché des sitcoms", Air & Cosmos, 8 mars 2002, pp. 32-3.

61 "Global Trends 2015 – A dialogue about the future", CIA, December 2000. See www.odci.gov/cia/publications/globaltrends2015.

62 In March 2002, Intelsat raised a total of US$1 B in new credit facilities from a syndicate of lenders arranged by Salomon Smith Barney. PanAmSat raised US$2.05 B of debt in February 2002.

WHAT TO EXPECT IN THE NEXT FEW YEARS

The commercial satellite market will remain depressed for a few years:
Euroconsult predicts that the market will not reach the levels set in the late 1990s until at least 2006, possibly longer. The timing and scope of the recovery will depend on how fast new applications such as broadband and digital radio develop. An average of 20 commercial satellites will be launched per year to 2010. It is predicted that total industry sales and employment will continue to decrease until mid-2003, when the market will start rebounding. Soft commercial demand will be partially offset by growing government needs, especially security related in the wake of the events of September 11, 2001. Governments could require as many as 40 satellites per year in LEO and MEO, and 7-12 satellites per year in GEO[60].

The US market for telecommunications services and equipment will remain predominant, but others will grow faster:
The US will be followed by Europe and other G-7 countries. But other regions will develop fast. Among developing countries, India will remain in the forefront in developing information technology, led by the growing class of high-tech workers and entrepreneurs. China will lead the developing world in utilizing information technology, with urban areas ahead of the countryside. Latin America's Internet market will grow exponentially, with Argentina, Mexico, and Brazil getting the greatest benefits because of larger telecommunications companies, bigger markets, and higher international investment[61].

ITARs will remain an irritant in dealing with US manufacturers:
Despite best efforts on the part of the Canadian Government (through DFAIT), and despite pending legislation in the US Congress to return licensing authority for commercial satellites to the Commerce Department, ITARs continue to cover almost all satellite related exchanges. As experience with ITARs grows on both sides of the border, the delays associated with TAAs should be reduced. Still, we can expect that such delays will, in some cases, continue to close off opportunities for Canadian companies to respond in a timely way to US opportunities, and in a reverse scenario also prevent US companies from bidding on Canadian or foreign opportunities, to the detriment of all. Already, agencies and companies in Canada, Europe and elsewhere have taken measures to avoid future problems in sourcing from the US, including deciding to manufacture critical components and even whole satellite sub-systems domestically or finding alternate non US suppliers.

Better financing outlook for some satellite communications operators:
After the current storm over the telecommunications industry meltdown and corporate accounting subsides in the next 1-2 years, investors are likely to be impressed by the relatively strong balance sheets of FSS and broadcasting satellite operators. These operators should find it easier to secure financing[62] and affordable launch insurance. This will not apply to mobile or broadband project promoters, at least in the near and medium term, as financiers have been badly burned by several project failures. Generally, an improvement in the financing market will not help Canadian suppliers much – prime contractors will continue to require suppliers to cover any R&D and to have already flight proven any new technologies. This argues for continued and increased support from the Canadian government.

Consolidation and vertical integration among satellite operators:
SES' acquisition of GE Americom in 2001, which gives it access to key markets in the US and the Americas, could point the way to more mergers. The high capital costs involved and the continued effects of WTO market liberalization and the ensuing benefits of scale, as well as regulatory requirements, encourage this[63]. In addition, rather than full acquisitions, we could also see organisations acquiring small equity stakes in partners operating in other parts of the value chain[64]. Telesat Canada, the world's most experienced operator, remains 100% owned by conglomerate Bell Canada Entreprises (BCE). While Telesat has achieved tremendous success in consolidating its Canadian domestic market base in an era of deregulation and in expanding its base in the US and Latin America, limited access to capital could be problematic in its core market (the Americas), which is already dominated by much larger players, also making it very difficult to access markets in other regions. For this reason and also to raise cash more generally, BCE announced in January 2002 it was seeking an investor for Telesat Canada as part of its plan to sell CA$4.5 B in assets.

The Role of Satellites in Serving Communications Needs
The global population is growing fast[65], and the networked global economy will require increasing connectivity. The question is: what role will satellites play in serving these needs? A few prognostics:

In relation to trunking and backhaul services:
We can expect satellites to maintain an important role in the delivery of content for the next several years. This is because, even if under-sea cables carry most transatlantic traffic, satellites are essential to carry traffic on many other routes. In the long term, the role of satellites could be marginalized as additional fiber cables are laid on high traffic routes.

In relation to local access services: At present, satellites are the only solution to provide "last mile" services to an estimated 20% of customers who are not within reach of cable or other terrestrial systems. This role for satellites in accessing remote regions will remain into the future. At this time, satellites are not price competitive in providing telephony or data services to customers in urban centers, but this could change. We can expect that, perhaps through the subsidization of user equipment by service providers (adoption of the cellular phone and DBS models), overall cost to consumers could be attractive enough to provide a real alternative to terrestrial systems, at least in niche markets (e.g. corporate segment) requiring the key benefits of satellites (instant regional or global reach, and high bandwidth capacity). However, in North America at least, the challenge will be significant for satellites given the existing over capacity of fiber lines in key markets[66].

63 Intelsat and Inmarsat are required by US legislation to offer around 20% of their capital to the public by end 2002. Eutelsat is required by the European Commission to offer 30% of its shares by July 2003.

64 SES Global has taken holdings in both Netsystem.com and Kokua Communications Ltd, while Eutelsat has invested in TV Files. Inmarsat has also strengthened its vertical positioning by acquiring applications developers such as Rydex Industries.

65 World population in 2015 will be 7.2 B, up from 6.1 B in the year 2000. Most growth will be in developing nations. See "Global Trends 2015 – A dialogue about the future", CIA, December 2000. See www.odci.gov/cia/publications/globaltrends2015.

CONCLUSIONS

66 Although available data is incomplete, a June 2001 study by Salomon Smith Barney reported that only 5% of the U.S. fiber networks was being used. See Simon Romero, "Shining Future of Fiber Optics Loses Glimmer", The New York Times, June 18, 2001. It is unclear whether this figure takes into account the significant "dark" or unused fiber that was laid alongside the operational (or "lit") fiber in many US markets. This means that the costs of building terrestrial fiber connections across the major US markets (much the same can be said of European and other markets) has largely been sunk, and can now be amortized over time. Given some of the telcos bankruptcies now taking place, new operators could be taking over these networks on the cheap, improving their competitive position vis-à-vis satellite operators.

In the longer term, probable marginalization of satellites for trunking and local access in developed countries: The progress of fiber optic submarine and terrestrial networks has been very rapid, and over time it is possible that these could dislodge satellites from the long haul transport markets and last mile access in the most developed regions of the world. Still, the best strategy is probably for satellite operators to pursue the current course, i.e. instead of attempting to compete head-on against established terrestrial services, they are concentrating on satellite's intrinsic advantages in broadcasting, bridging the digital divide by providing service to rural areas and complementing terrestrial services through techniques such as multicasting. In these areas, the demand for satellite services is strong and still growing, and at a faster rate than basic services.

CONCLUSIONS

Satellite telecommunications is only one of the elements of a global infrastructure driven by the ultimate need to satisfy the end user and to provide benefits to society as a whole. Yet in Canada satellites play an especially crucial role. Because of Canada's geography, satellites are essential to deliver on the Federal policy of guaranteeing basic telecommunications services to all Canadians, regardless of location. This is done through Telesat Canada's fleet of Anik satellites, which provide telephony, data and broadcasting services in Canada and regionally. The role of satellites also extends to broadband services. In June 2001, the National Broadband Task Force tabled its recommendations to the Government of Canada on how best to make high-speed broadband Internet services available to all Canadian communities by the year 2004. Concerning the transport link, their report recognized that "…solutions will involve a mix of …fiber, wireless and satellite technologies…". Concerning local access, the report stated that "…next generation broadband two-way multimedia satellites, expected to be available over the next three to four years, promise to improve access by several orders of magnitude compared to today's service …at comparable prices."

Canadian space companies have developed impressive and globally competitive competencies in some niche areas of satellite communications. This has allowed them to be very successful in the home and export markets. In fact, 63% of the total 2000 revenues of CA$1.4 B were in Telecommunications. Telecommunications revenues for 2001 are again strong, representing a large percentage of overall industry revenues. As such, Satellite communications continues to be considered the cornerstone of the Canadian space industry at large. But the viability of the Canadian industry is being threatened. Government support in the US, Europe, Japan and elsewhere far outstrips the support available to Canadian companies, aside from the larger domestic markets, leading to an uneven playing field.

In recent years, there has been recognition at senior levels of the Federal government of the importance of an advanced telecommunications infrastructure in ensuring a knowledge - based economy. Satellites can and do play a major role in supporting this – Canada can only achieve its goal of becoming the most connected nation by exploiting space-based technology. All these factors argue in favor of a sustained partnership between the Government and industry, involving the development of advanced communications technologies and Government acting, where possible, as anchor tenant for new services.

The author would like to acknowledge the participation of Mr. Jack Rigley of the Communications Research Centre in the preparation of this chapter.

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EARTH OBSERVATION

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External Relations

EXECUTIVE SUMMARY

The global satellite remote sensing industry is at the stage of semi-commercialization. Though still characterized by heavy government intervention, the industry is maturing and the market is becoming more commercial. Governments remain eager to privatize and commercialize remote sensing activities, often through creative partnerships with the private sector, and—while still protecting national security interests—to loosen the regulatory regimes governing the industry.

The industry is young and growing quickly. Technologies on the satellite, ground, and data processing and distribution sides of the business are still evolving rapidly. More and more countries and companies are entering the field, promising to increase competition, improve remote sensing products and services, decrease prices—and precipitate a shakeout in the industry.

The major market trends in the space remote sensing industry are the following:

- The market is growing quickly, though estimates of the overall market size and rate of growth vary
- Commercial observation business models are changing towards operational services
- Demands are moving from descriptive to predictive information products
- Real opportunities in coastal monitoring will exist for Canadian companies
- Existing satellites do not adequately address coastal zone problems
- Better sensors and better access networks and interpretative software are coming into the marketplace
- Convergence of EO and other technologies, is fuelling mergers and acquisitions
- The data market is becoming split between the expensive high end and the inexpensive low end
- Data usage will change in the future, and SAR usage will double
- There will be a move towards smaller EO satellites flying in formation
- The value-added industry is becoming increasingly specialized
- Data policies will give more room to distributing images at marginal cost for research
- Industrial consolidation will increase and a shakeout can be expected
- Privatization and commercialization will continue
- The critical success factors will increasingly be those of more mature industries
- Controls on access to EO data will become multilateral

MARKET CHARACTERISTICS

A MULTI-TIERED INDUSTRY:

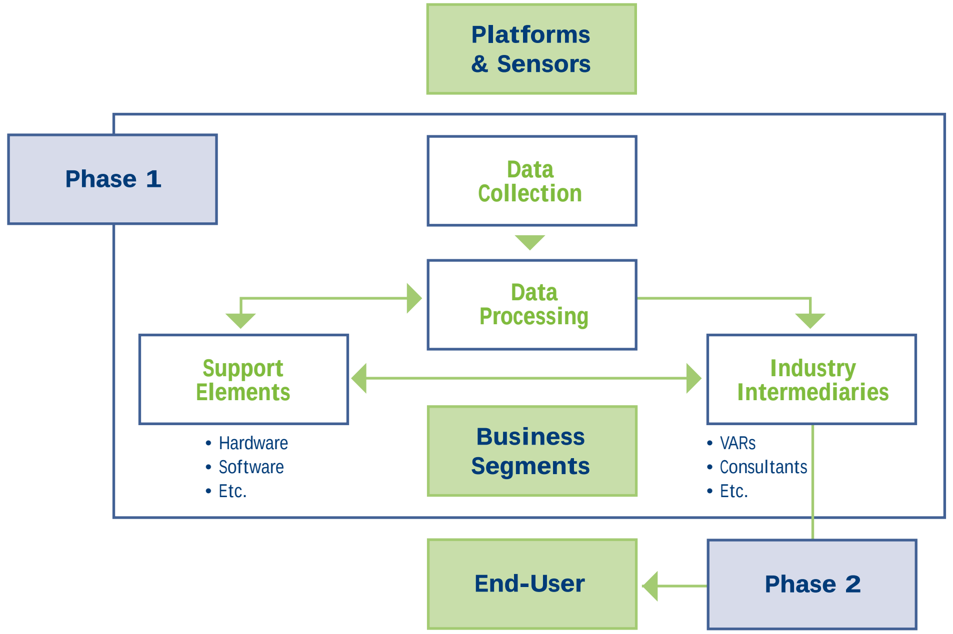
As indicated in FIGURE A[1], the remote sensing industry is divided into several tiers: sensors (space and others), ground segment (reception, processing, archiving, distribution), supporting business segments (hardware and software), value-added companies, all delivering information to end users.

The downstream part of the EO industry is the most lucrative: The money and the growth are in information services and not in remote sensing data sales or building satellites. This is true also for other space sectors. This explains the increased

1 American Society for Photogrammetry and Remote Sensing (ASPRS), "The 10-Year Remote Sensing Industry Forecast", Study for NASA, Reported at the ASPRS-ACSM-FIG Conference, April 2002 (hereinafter "ASPRS Forecast").

FIGURE A[1]

REMOTE SENSING INDUSTRY DEFINITION



emphasis placed by Radarsat International Inc. (RSI) on providing customized solutions to customers, in addition to selling Radarsat and other imagery.

The EO industry is still in the earliest stages of the Industry Life Cycle and still only semi-commercial: FIGURE B illustrates the Satellite Remote Sensing Industry Life Cycle through the Kondriatieff/Shumpeter S-Curve:

Some observations stemming from the early maturity of the sector are:

- ***Fast, early growth:*** According to a recent major study commissioned by NASA, the overall commercial remote sensing market (space and aerial) is growing at about 10%-13% per year, a healthy rate perhaps attributable in part to the effects of 9/11[2]. This growth is propelled by a growing recognition of the major business and public good benefits from using EO information. This, in turn, attracts capital and more and more entrants into

2 ASPRS Forecast.

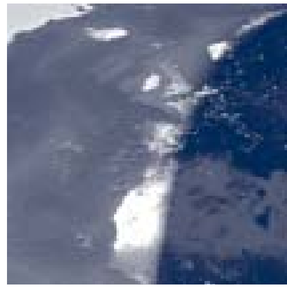
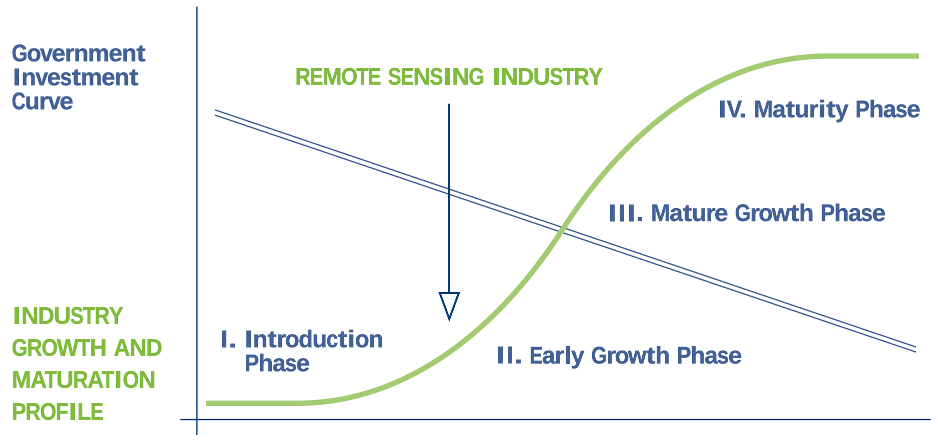


FIGURE B

SATELLITE REMOTE SENSING INDUSTRY LIFE CYCLE
(KONDRIATIEFF/SHUMPETER LONG-WAVE/S-CURVE)



Source: Canadian Space Agency, 2001

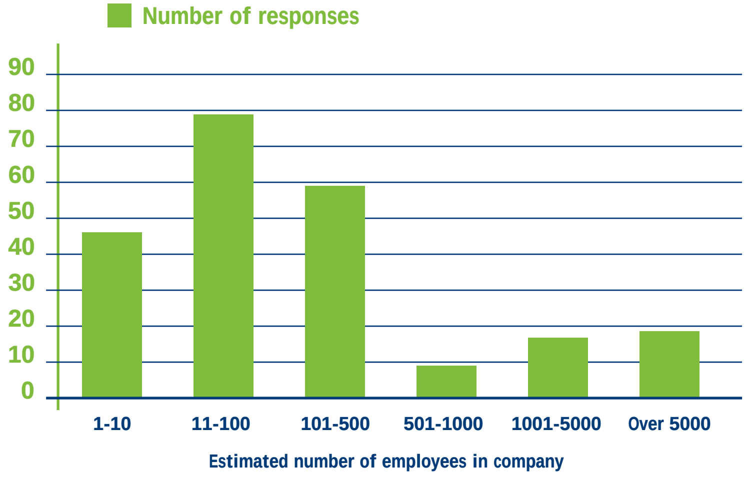
the market. It is during the Early Growth phase that government investment in a technology is at its highest levels, which is certainly the case for Earth observation-related technologies. And it is usually at the end of the Early Growth phase that the technology starts to undergo design standardization, a development which propels the industry into the Mature Growth phase. This has not yet happened for Earth observation.

- ***The remote sensing business model is still driven by governments:*** Almost all remote sensing satellites are defined, developed and launched by governments or by private companies relying heavily on governmental support. A key reason is that, on the demand side, there simply has not been sufficient growth in the number of users to pay for the cost of developing and operating systems, and the applications and user-areas remain too fragmented and highly specialized to generate a low enough cost to revenue ratio. This is true in Canada, Europe and Asia, and even in parts of the US industry (e.g. Landsat).
- ***Governments and industries seek to develop innovative public-private partnerships:*** Governments in many countries are hoping to encourage and accelerate the gradual privatization and commercialization of the EO sector. In Canada, whereas Radarsat 1 was almost all financed through public funds and is operated by the Canadian Space Agency (CSA), Radarsat 2 involves a significant investment from, and the satellite will be owned and operated by, the Canadian prime contractor MacDonald Dettwiler and Associates (MDA). This trend is expected to continue with Radarsat 3, now in planning. Other countries are closely watching the Canadian model and adapting it to their needs, as evidenced by the German government's partnership with Astrium in TerraSAR X-Band and with RapidEye AG in the optical EO system of the same name. Such public-private partnerships involve several complexities, in particular those related to data policies and security controls which enable a solid business model while protecting national security interests.
- ***Most government applications relate to environment and security[3]:*** Monitoring climate change, military reconnaissance, resource management, ocean monitoring and emergency response are some of the most important applications for governments world wide. In a nutshell, they relate to the environment and to "security" writ large (civil and military), which should therefore be the areas where Canadian EO companies concentrate in developing information solutions. This leads one to conclude that the European Global Monitoring of the Environment and Security (GMES) initiative, although it deals with civil security only, is well targeted.
- ***Many countries want their national EO systems:*** Several countries continue to want their own EO satellites and ground infrastructures, and continue to support their EO industries through technology development, privileged purchasing agreements, and public-private partnerships. They do so despite growing international coordination, both bilateral and multi-lateral (through CEOS, the Committee on Earth Observation Satellites), and the increasing potential for governments to have their requirements for EO services satisfied commercially. This ensures exclusive and secure access to data, especially for military uses, and ensures local reception for near-real time applications. Such a situation contributes to the growing data glut, but opens up opportunities for Canadian companies selling ground infrastructure and providing training and interpretative software.
- ***Slow transition from a technology push to a market pull emphasis in the development of missions:*** Historically, space agencies developed missions, and data and services were then proposed to the market (increasingly through private companies) with the hope of covering part of the investments. This is slowly changing; space agencies have been increasingly ensuring that user demand will justify the cost of missions, especially in the context of so-called public-private partnerships where the private sector shoulders part of the cost and risk and where commercial distribution is a key driver.
- ***A gap exists between EO data providers and users:*** Hindering the development of a commercial market are two key factors: the lack of understanding on the part of potential users as to the benefits of EO data products, and most importantly, the existence of a gap between the data providers (government agencies or their commercial agents) and the user communities. Users do not care about data, or even perhaps about information products; they want solutions to their needs and problems, and they do not want to know where the information comes from. This creates wide open opportunities for companies able to provide complete solutions, and operational services, to customers.

3 J.A. MacDonald, Presentation at the ImageOne Conference, Tokyo, July 2002.

FIGURE C [4]

COMMERCIAL COMPANY SIZE



Note:
1) This is a fragmented industry.
2) Smaller companies are in the majority:
- about 20% of respondents estimated at 10 or less employees
- about 55% of respondents estimated at under 100 employees
- over 80% of respondents estimated at under 500 employees

- ***The industry is still very fragmented:*** The EO industry generally consists of very few larger companies and numerous relatively small players. This situation can be found in the US (see FIGURE C [4]) and in Canada, where, alongside MDA and its subsidiaries (chief among them Radarsat International, or RSI), there are approximately 150 other small and medium sized companies, often with few employees other than their founders. Since many commercial opportunities need to be pursued around the globe, involving significant resources for project identification and development, it can be argued that small size and under-capitalization act as a detriment to growth.

- ***The US market exhibits the most privatization:*** In the United States, private companies involved in the commercial optical remote sensing business (Space Imaging, Digital Globe, Orbimage) financed all business costs from private sources[5]. But even there, the US EO industry strongly benefits from government intervention upstream (through technology development paid for by the government), downstream (through promises of government data buys to stimulate growth of data suppliers), and via regulatory support.

4 ASPRS Forecast.

5 But they still rely on governments as the main markets: according to the ASPRS study, Government agencies account for about two-thirds of expected revenues in the US through 2006.

MARKET CHARACTERISTICS

FIGURE D [6]

SPATIAL RESOLUTION: COMPARISON OF USERS VS NEED (ALL SECTORS)

Note:
- Academic and Government sectors have similar profiles
- Therre is a distinct difference in the 30 meter range between Commercial and the Academic/Government sectors
- Commercial has the largest fall-off at 1 meter resolution (from Use to Need)
- Commercial Use and Needs tend toward higher resolutions, and are potentially less price sensitive. Academic and Government tend toward lower resolutions.
- Government Needs lean toward the 1-3 feet range

6 ASPRS Forecast.

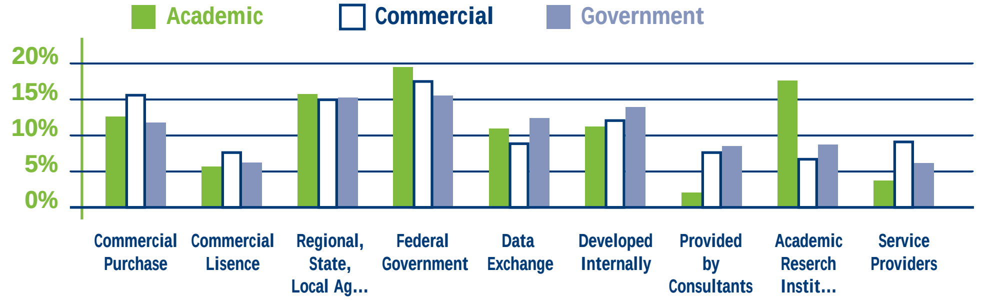
FIGURE E [7]

GEO-LOCATION ACCURACY: USE VS NEED (ALL SECTORS)

Note:
- All sectors show a mismatch in what is Needed versus what is in Use.
- All sectors indicate an unfilled Need of Geo-Location Accuracy at levels of less than three feet.
- The Commercial and Government sectors have pronounced Needs for Geo-Location accuracy at levels of less than six inches.
- Academic and Government sectors indicate a Need for increased accuracy at three feet and less.

FIGURE F [8]

RELIANCE ON SOURCES OF DATA BY SECTOR



Note:
- Government Agencies (FSL) provide about 30% of the data to each Sector.
- Academic sector gets about 50% of its data from other Academics and Government Agencies combined and about 25% from *commercial sources* (Commercial Purchase and License; Consultants; Service Provisers).
- The Commercial and Government Sectors get about 40% of their data from commercial sources.
- The largest single source for all the Sectors is the Federal Government.

Demand varies among government, industrial and academic users: Some of the key parameters of geospatial data are spatial resolution and geo-location accuracy. The ASPRS study offers interesting data in FIGURE D [6] and FIGURE E [7] about the usage as compared to actual need for each factor, among academic, commercial and government users. This US data probably finds a close parallel in Canada and elsewhere.

FIGURE F [8] shows that the sources of data can vary significantly to serve the needs of the academic, commercial and government sectors in the United States (also likely applicable to Canada and other regions).

Civilian and military users also have different requirements: The difference is explained in FIGURE G.

Market drivers and inhibitors have variable importance over time: FIGURE H [9] and FIGURE I [10] from the ASPRS study shows the various factors affecting market success, and their relative impact over time. As indicated in this analysis, barriers to growth appear to be funding, education, training, and awareness and not available technology.

7 ASPRS Forecast.

8 ASPRS Forecast.

9 ASPRS Forecast.

10 ASPRS Forecast.

FIGURE G

REQUIREMENTS

National Defence	Civilian
• Autonomy	• Reasonable pricing
• Confidentiality	• Reasonable availability
• Real-time availability	• Ease of use
• Frequent revisit	
• Imaging agility	

Source: CSA, External Relations, 2002

OTHER INHIBITORS TO GLOBAL MARKET SUCCESS[11]

These include:

- Cost of data and data products: For Radarsat and other high resolution commercial systems, the cost of satellite data can be a large fraction of a small project where many images are required. Similarly, the cost of information products (from Value Added Resellers and consultants) is high when each project is a custom job involving many hours of labour.
- The lack of widespread operational use by the Canadian Federal and provincial governments: Canadian companies need this kind of strong endorsement for use in international marketing.
- Lack of standardization and inter-operability in the software tools used by users, complicating the life of customers.
- Economic and political stability of countries representing markets of interest.
- Availability of EO data on a non-commercial basis, from space agencies (e.g. NASA's Landsat, ESA's ERS,) whose data policies call for data to be available at nominal cost.

Given these characteristics, government involvement in the Earth observation industry is still required, in terms of strategic technology development and market education and awareness (technology demonstration and user education). But industry must also close the information gap to user communities, to provide transparent solutions to problems.

Dual-use nature of Earth observation satellites: In the early days of satellite remote sensing, there was a big difference between the capabilities of civilian and military EO/meteorological satellites, all of which were owned and operated by governments anyway. With the advent of privately owned and operated satellite systems, that gap has narrowed considerably to the point where fine resolutions can attain 0.5 meter for optical systems and 3 meters or better for radar systems (e.g. Radarsat 2; Germany's TerraSAR X Band). As an indication of the military potential of EO satellites, US and other defence departments have become large users of commercial data. In fact, the US National Imagery and Mapping Agency (NIMA) has been directed by the US Congress to procure greater quantities of data commercially. In recognition of these capabilities and the synergies to be obtained from the joint management and funding of satellite systems, some European countries are developing hybrid civilian/defence systems (e.g. the French-Italian Cosmo-Skymed/Pléiades system).

11 TRENDS AND OPPORTUNITIES IN MARINE AND FRESHWATER REMOTE SENSING TECHNOLOGY, Borstad & Associates, Study performed for the CSA, May 2002 ("Borstad 2002 Study").

MARKET CHARACTERISTICS

FIGURE H[9]

ANALYSIS OF SATELLITE MARKET DRIVERS

Drivers	Impact			
	Near Term (1-2 yrs.)	Mid term (3-4 yrs.)	Far Term (5-7 yrs.)	Analysis
Built-in Demand	High	High	High	M, M, M
Development of Marketplace	Medium	High	High	Agree
Increased Temporal Resolution (as # of Satellites increase, # of opportunities for imagery increase	Medium	Medium	High	L, L, M
More Area Coverage per Mission	Medium	Medium	High	M, M, M
Customer Anticipation of New Products	Medium	Medium	Medium	M, M, L
Demand for Surveillance & Change Monitoring	Medium	Medium	Medium	Agree
Ground Stations in Host Countries	Low	Medium	High	L, L, M
Increased Aerial and Satellite Data Availability = lower cost	Low	Medium	High	Agree

Source: Frost & Sullivan, 2001

FIGURE 10

ANALYSIS OF SATELLITE MARKET RESTRAINTS

Restraints	Impact			
	Near Term (1-2 yrs.)	Mid term (3-4 yrs.)	Far Term (5-7 yrs.)	Analysis
Launch Slippage	High	High	High	Agree
Lack of closeness to end-user	High	High	Medium	Agree
Distribution Infrastructure	Medium	Medium	Medium	M, M, L
New & Varied Customers Require Changes to Marketing Strategies	Medium	Medium	Medium	H, H, M
Government Involvement in Collection, Processing and Dissemination	Medium	Medium	Low	?? 9/11
Restraints on Spatial Resolution	Medium	Low	Low	?? 9/11
Problems Related to Weather/Climate Conditions	Low	Low	Low	M, H, H

Source: Frost & Sullivan, 2001

Restrictions and regulations surrounding the collection, processing, and dissemination of remotely sensed data and information: Because of the dual-use nature of EO satellites and the high capabilities of civilian systems, there are concerns about the military potential of EO data should it fall into the wrong hands. The United States has implemented both "shutter control" and "state specific limitations" on data dissemination. Concerns expressed by the US government about the future capabilities of Radarsat 2 (3 meter resolution in fine mode) caused the Canadian and US governments to conclude an access control agreement (dealing with shutter control and priority access) in 1999.

MAJOR EVENTS OF 2001-2002

CIVIL AND SCIENTIFIC REMOTE SENSING

The Charter on Space and Major Disasters (to which CSA is a founding signatory) was activated 24 times since November 2000, including 4 times by Canada. In all, 81 Radarsat images were provided by CSA (46 in Standard mode, 23 in Fine mode and 12 in Wide mode). The Indian Space Research Organization (ISRO) acceded to the Charter in January 2002. The US National Oceanic and Atmospheric Administration (NOAA) has also joined.

In June 2001, the most complete view ever assembled of the world's air pollution churning through the atmosphere was produced by NASA's Terra spacecraft. This will allow scientists to identify the major sources of air pollution and to track its destination. The new global air pollution monitor onboard Terra is Canada's Measurements of Pollution in the Troposphere (MOPITT) instrument.

In February 2002, ESA signed a 70 M € contract with Astrium for the environmental and climate satellite CryoSat. The satellite is planned for an April 2004 launch into a polar orbit and will measure changes in the thickness of ice sheets and polar ocean sea-ice cover with unprecedented accuracy for at least three years after launch.

In March 2002, NASA, in partnership with the United States Geological Survey, selected proposals from Resource 21 and DigitalGlobe for further development. The aim is to provide the US government with Landsat-type data into the future.

In April 2002, the German government agreed to finance a high-resolution X-band radar satellite to be built by Astrium and operated mainly for commercial purposes, called TerraSAR.

In May 2002, Spot-5 was launched by Ariane–4 from Kourou.

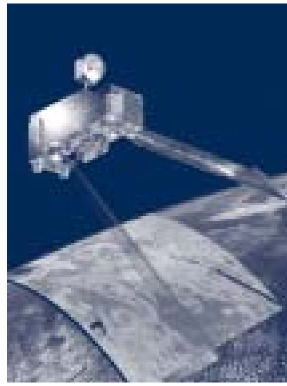
In May 2002, as part of the second cycle of the Earth Explorer Opportunity Missions, ESA selected three proposals to enter feasibility study: ACE+, an Atmosphere and Climate-Explorer; EGPM, the European contribution to Global Precipitation Mission, and SWARM, a constellation of small satellites to study the dynamics of the Earth's magnetic field and its interactions with the Earth system.

In July 2002, the Geostationary Operational Environmental Satellite (GOES), an advanced weather satellite capable of tracking dangerous storms in the atmosphere -- as well as storms on the sun – was launched by the United States.

In August 2002, a US$4.5 B contract was awarded by NASA, NOAA and US DOD to TRW Company to build and deploy the United States future environmental satellite system. The contract is for the Acquisition and Operations (A&O) phase of the National Polar-orbiting Operational Environmental Satellite System (NPOESS). NPOESS will combine the nation's military and civilian environmental satellite programs into a single national system that will significantly improve weather forecasting and climate prediction.

Also in August 2002, the World Summit on Sustainable Development in Johannesburgh, South Africa, emphasized the useful role of remote sensing satellites in providing crucial data and information for sustainable development and climate change research. And Eumetsat launched that same month the first satellite of its Meteosat Next Generation (MSG-1) series.

The European Union and ESA made progress in defining the GMES program, with the first GMES Steering Committee and Expert Forum taking place in March 2002. The goal set by ESA and the EU is



MAJOR EVENTS OF 2001-2002

to complete an interim definition phase by 2003 and bring into operational service by 2008 an autonomous European global monitoring capability for environmental and security purposes.

The China-Brazil Earth Resource Satellite (CBERS-1) went past its nominal life time; CBERS-2 is to be launched later in 2002.

More countries confirmed their plans to develop EO missions and plans, including South Korea, Nigeria and Vietnam.

MILITARY REMOTE SENSING

The US government has embarked on a program to develop the next generation of spy satellites that are being built now and will start going into orbit in 2005. The estimated 20-year price tag is US $25 B, making this program the most expensive venture ever mounted by US intelligence services. In October 2001, Russia also announced plans to launch a number of intelligence spacecraft in the near future.

In September 2001, Germany announced its decision to build its own reconnaissance satellite for the first time. The "SAR-Lupe" radar spacecraft should be operational by 2004. OHB will act as prime contractor, a surprising upset over Astrium Germany.

On October 5, 2001, the National Imagery and Mapping Agency (NIMA) selected two contractor teams led by General Dynamics Electronics Systems and Lockheed Martin Management and Data Systems to develop an approach to modernize the United States Imagery and Geospatial System (USIGS). The USIGS Enterprise is a total systems architecture designed to improve NIMA's ability to task, process, evaluate and disseminate information. The contracts are valued at US$29 M each and represent the second phase of NIMA's USIGS pre-acquisition activities. The deliverables from these contracts will support the Government's Milestone B decision to proceed with the USIGS modernization program.

The Japanese government continued to develop its Data Gathering System, a set of 4 satellites (2 optical, 2 radar) for regional observation requirements. The first satellites are set for launch in 2003.

In September 2002, the US National Imagery and Mapping Agency (NIMA) announced the creation of a National Center for Geospatial Intelligence Standards (NCGIS). The NCGIS will address standards issues relevant to enabling technologies, data architecture, and software tools as NIMA moves toward implementing a comprehensive, enterprise-wide standards management policy for the National System for Geospatial Intelligence (NSGI).

COMMERCIAL EVENTS

In January 2001, Space Imaging announced it had been awarded a license by the National Oceanic and Atmospheric Administration (NOAA) to operate a commercial remote sensing spacecraft capable of providing half-meter resolution imagery of the Earth.

In September 2001, Orbital Sciences Corporation announced that the launch of its Taurus rocket, which was carrying the OrbView-4 satellite for ORBIMAGE and the QuikTOMS satellite for NASA, did not achieve the intended orbit, leading to failure of the two missions. ORBIMAGE had previously won a contract from NASA Stennis Space Center to supply up to US$6 M in imagery from the 200-band hyperspectral camera on its OrbView-4 satellite.

In January 2002, Space Imaging started offering one-meter resolution, stereo imagery from its IKONOS satellite to commercial customers. These products were previously offered only to government customers.

In March 2002, Orbital Imaging Corp. filed for Chapter 11 reorganization in the United States.

In April 2002, ImageSat International (based in Israel) announced the activation of a new ground receiving station in Gatineau, Québec. This ground receiving station, the Company's first in North America, will enable real-time downloading of ImageSat's high resolution EROS electro-optical images taken of about half of the continent.

In May 2002, the White House announced a Major Review of Commercial Earth Observation Policy, to be led by the National Security Council. One of the outcomes of this review could be secured government imagery purchase agreements to ensure control of high-resolution imagery, and at the same time, providing guaranteed revenue to private Earth observation operators.

On May 30, 2002, Space Imaging announced a revamped Carterra Online service[12], which offers web access to a map-accurate and GPS verified digital database for road systems in 49 US states. This includes streets, administrative boundaries and location information for destinations such as hospitals, fire stations and more.

In May 2002, SPOT Image Corporation and Iunctus Geomatics Corporation signed a channel partnership contract under which Iunctus has the exclusive rights to sell SPOT satellite products and services to all Canadian customers.

In May 2002, DigitalGlobe announced plans for its next-generation M5 constellation consisting of four satellites, each of which will collect five-meter resolution multispectral data over a 185 kilometer-wide area. Images will provide visible, near-infrared and short wave-infrared spectral ranges. The first M5 satellite is scheduled to be operational in the first quarter of 2006, and all four by the third quarter of 2007.

In July 2002, Spot Image initiated sales of SPOT 5 imagery, following the spacecraft's launch in May 2002.

In October 2002, Spot Image signed a SPOT data reception agreement with the Canada Centre for Remote Sensing (CCRS) to supply its US subsidiary SPOT Image Corporation with improved service, and imagery from the new SPOT 5 satellite. Under the agreement, Spot Image is to install a SPOT 5 Terminal at the Prince Albert, Saskatchewan receiving station, which covers most of Canada and the United States. This station has been receiving SPOT imagery

12 See carterraonline.spaceimaging.com

MAJOR EVENTS OF 2001-2002

since 1986, and is now upgrading its receiving equipment to perform near-real time image archiving at regional and global archive locations. The terminal will also allow CCRS to process, generate and electronically transmit products more quickly to SPOT Image Corporation.

CANADIAN REMOTE SENSING EVENTS

Canada's RADARSAT 1, operational since 1995, continued to perform well, and surpassed its nominal lifetime. In March 2002, scientists completed the first detailed map of Antarctica, thanks to more than 4,500 images provided by the Radarsat 1 satellite. Until then, more than 3 million square kilometers of Antarctica had been insufficiently mapped.

To ensure data continuity to users, the CSA is pursuing arrangements with the European Space Agency (ESA) whereby images from Envisat (launched March 1, 2002) could be used in case of failure by RADARSAT 1 before the launch of RADARSAT 2.

RADARSAT 2 passed several critical milestones on its way to launch in early 2004. The bus, payload and ground segment all passed the critical design review stage in 2002. RADARSAT 2 is developed under a partnership between the CSA (which is providing most of the funding) and MDA, which acts as prime contractor and will own and operate the system and distribute the images worldwide, through its subsidiary Radarsat International (RSI). RADARSAT 2 will be the world's first operational remote sensing mission implemented through a public-private partnership, where the government and industry share the costs, risks and rewards. This partnership has attracted significant attention around the world, and is being emulated in some countries, notably in Germany (TerraSAR X Band is a partnership between the German Aerospace Centre, or DLR, and Astrium GMBh).

In November 2001, ESA declined to commit sufficient funding to participation in Canada's proposed RADARSAT 2/3 topographic mission. The CSA continued to examine possible domestic (with DND) and international partnerships to implement this interesting concept.

On June 25, 2002, the CSA announced twelve contracts, worth close to CA$2 M, with Canadian companies for developing leading-edge uses of space-based Earth Observation data and applications. These contracts have been awarded to Atlantis Scientific, A.U.G Signals Ltd., Dendron Resource Surveys, Hatfield Consultants, MIR Teledetection, Noetix Research, Paterson, Grant and Watson, EarthScan Ltd., PCI Geomatics, Tecsult, Vantage Point International and Viasat Geotechnologies.

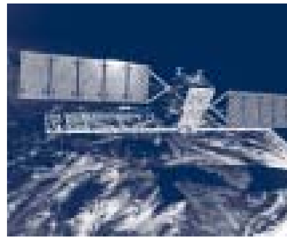
In January 2001, Vexcel Corporation of Colorado and Atlantis Scientific of Ottawa announced a merger between the two corporations. The new company will be active in SAR processing, SAR interferometry, digital elevation model creation, surface change mapping, and image processing and analysis.

In the aftermath of 9/11, Optech's LIDAR technology was used by NOAA's National Geodetic Survey and Aircraft Operations Center to map the wreckage of the World Trade Center in support of recovery and cleanup efforts.

In January 2001, SPOT Image Corporation announced it now holds the exclusive contract for distributing new SPOT satellite image products and services within Canada.

MacDonald Dettwiler & Associates (MDA), Canada's largest geospatial information company, made the news on several occasions. Some examples:

- In February 2001, MDA announced it had amended its agreement with Orbital Imaging Corporation (ORBIMAGE) for the worldwide distribution of RADARSAT-2 data. Until then, ORBIMAGE had the full rights to all economic benefits from RADARSAT-2, in exchange for certain payments to MDA during its construction and operation. MDA now has worldwide rights to RADARSAT-2 distribution, except for the United States of America.
- In September 2001, MDA announced two contracts worth over CA$3 M to provide RADARSAT-1 imagery for ice monitoring and mapping to the Canadian Ice Service (CIS) and the Danish Meteorological Institute (DMI).
- In October 2001, MDA was appointed the sole Canadian reseller of worldwide data from the high-resolution QuickBird satellite by DigitalGlobe of Colorado. The 3-year agreement also includes distribution rights in the United States. MDA also sells certified QuickBird ground stations.
- In December 2001, MDA announced the acquisition, for US$30 M of Earth Satellite Corp., a Maryland satellite imagery company. EarthSat is one of the largest US suppliers of information products to NIMA and other US federal agencies as well as commercial and private clients.
- In March 2002, MDA announced a contract to enhance the GeoConnections Discovery Portal for Natural Resources Canada. The site has hosted over 17 million visitors since its creation in 1996, and has been rated "Best Data Centre" in Canada, the United States, and Australia by its users.
- In April 2002, DigitalGlobe announced that MDA's EarthSat had been appointed a reseller of US data from the high-resolution QuickBird satellite.
- In July 2002, MDA announced that the US National Imagery and Mapping Agency (NIMA) had agreed to purchase RADARSAT-1 products and services, such as near-real time delivery of RADARSAT-1 data.
- In October 2002, MDA announced the award of two Information Systems contracts. The first is to build a planning and scheduling system for satellite data acquisition and reception at CCRS' facilities in Saskatoon and Gatineau, including a new capability to support RADARSAT-2. The second contract is to build the system that controls satellite data reception at those facilities. MDA also announced a CA$4 M contract to develop and deliver a Ground Processing Facility for Defence Research and Development Canada-Ottawa, (DRDC-O). MDA and RapidEye AG also signed an agreement in principle to supply and launch a constellation of Earth observation satellites and provide the ground-related infrastructure for the RapidEye project in Germany. To realize the project, MDA and RapidEye will work together to complete the financing, a process that is well underway. In addition RapidEye and MDA, together with RSI and EarthSat, announced their intention to cooperate closely in their marketing and product development efforts. The supply project is valued at approximately US$100 M.



Radarsat International Inc. (RSI), an MDA subsidiary, also announced several important transactions. A sample:

- In January 2001, RSI was selected as a United States Geological Survey (USGS) business partner. This partnership allows RSI to commercially distribute North American and International data from the LANDSAT 7 satellite archived at the Eros Data Center (EDC). RSI also concluded a RADARSAT-1 network station license agreement with the National Institute for Space Research of Brazil (INPE).
- In July 2001, CIDA announced two contracts to RSI worth CA$1.6 M to develop Information Networks for Bangladesh and Thailand. Also, two international network stations at INPE (Brazil) and the Geo-informatics & Space Technology Development Agency (GISTDA) in Bangkok, Thailand, were awarded RADARSAT-1 product certification, increasing RSI's network of operational and product-certified ground stations to 14 worldwide.
- In October 2001, RSI was named exclusive Canadian distributor of QuickBird data. The agreement, which also includes distribution rights in the United States, has a three-year term.
- In February 2002, RSI and GeoAnalytic Inc. of Calgary renewed a purchase agreement for the supply of RADARSAT-1, LANDSAT 5, LANDSAT 7, and ERS-1 and -2 Earth-observation (EO) satellite images by RSI to GeoAnalytic over the next two years.

In February 2001, PCI was selected by the National GIS Key Lab of the China Scientific Academy as its principal geomatics software solution provider.

MARKET TRENDS

The market is growing quickly, though estimates of the overall market size and rate of growth vary.

As indicated in FIGURE J [13], Frost & Sullivan projects the market for commercial satellite imagery to grow from US$172.9 M in 2000 to US$772 M in 2007, a compound growth rate of 23.8% for the period.

Frost & Sullivan foresees growth for the GIS software market specifically as indicated in FIGURE K [14].

More generally, the total market for all commercial EO imagery (satellite and aerial) and GIS software is expected by Frost & Sullivan to grow as indicated in Figure FIGURE L [15].

Commercial Observation Business Models Are Changing[16]: Driven by clear market demand for technology-transparent solutions to problems, as opposed to just data, many data providers, including RSI in Canada, are switching to a different model, as indicated in FIGURE M .

The increasing vertical integration of the industry is evident as more and more data suppliers move up the value chain. A few recent examples include Space Imaging's acquisition of EOSAT, the birth of Astrium in Europe, MMS acquisition of NRSC (UK), Orbital Sciences consolidated approach to EO business lines, and MDA/RSI's acquisition of value-added companies.

13 Data provided directly to the author by Ron Stearns, Senior Strategic Analyst, Frost & Sullivan, August 2002.

14 Data provided directly by Frost & Sullivan to the author, August 2002.

15 Data provided directly by Frost & Sullivan to the author, August 2002.

16 Review and Analysis of Earth Observation Satellite Data and Policies in Support of Operational and Research Use and Related Commercialization Policies Around the World, Report to the CSA, 2002, Consultants M.L. Stojak Inc.

FIGURE J [13]

COMMERCIAL SATELLITE IMAGING MARKET: REVENUE FORECASTS (WORLD), 1997-2007

Year	Revenues (US$ M)	Revenue Growth Rate (%)
1997	120.0	—
1998	139.3	16.1
1999	153.7	10.3
2000	172.9	12.5
2001	199.4	15.3
2002	236.8	18.8
2003	282.8	19.4
2004	348.4	23.2
2005	441.1	26.6
2006	587.0	33.1
2007	772.0	31.5

Compond Annual Growth Rate (2000-2007): 23.8%

Note: all figures are rounded; the base year is 2000
Source: Frost & Sullivan, 2002

From descriptive to predictive information products: EO information companies have become very adept at describing how the world looks today or looked historically, including change patterns. Borstad & Associates[17] believes in the increasing importance of tools that will help predict the way the world will look, thereby opening significant opportunities for Canadian companies selling decision support systems for ship detection, crop monitoring (e.g. for insurance companies), disaster management and other applications.

Real opportunities in coastal monitoring will exist for Canadian companies[18]: Coastal areas are where man's interaction with the sea is greatest. Some major ocean-related issues will generate opportunities for Canadian companies able to provide appropriate

17 TRENDS AND OPPORTUNITIES IN MARINE REMOTE SENSING TECHNOLOGY, Borstad & Associates, Study performed for the CSA, December 2001, hereinafter "Borstad & Associates"

18 Borstad & Associates.

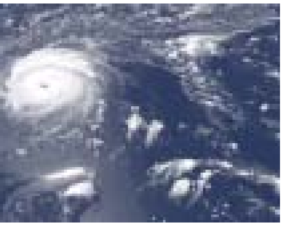
FIGURE K[14]

GIS SOFTWARE MARKET: REVENUE FORECASTS (WORLD), 1997-2007

Year	Revenues (US$ M)	Revenue Growth Rate (%)
1997	871.4	—
1998	876.0	12.0
1999	1,105.8	13.3
2000	1,240.7	12.2
2001	1,379.7	11.2
2002	1,524.5	10.5
2003	1,658.7	8.8
2004	1,783.1	7.5
2005	1,900.8	6.6
2006	2,012.9	5.9
2007	2,129.7	5.8

Compond Annual Growth Rate (2000-2007): 8.0%

Note: all figures are rounded; the base year is 2000



data products: (1) safety and security (real-time weather, sea state and other information as well as longer term information relating to safe navigation), (2) human impacts on the ocean (measuring impacts of development and urbanization on biodiversity, pollution and resources), and (3) climate change (measuring the impact of climate change on weather, on coastal erosion, and on marine and terrestrial ecosystems). See Appendix 2 for a summary of opportunities in coastal zones for Canadian industry.

Users involved in coastal zone management need:

- affordable, accurate and reliable data and information
- time series data products
- geo-referenced map products
- high spatial resolution data in near-real time (for some applications)
- tools to allow easy manipulation, visualization and fusion of large volumes of disparate data in effective ways
- tools and systems for "seamless management and distribution" of data and data products

MARKET TRENDS

FIGURE L[15]

TOTAL COMMERCIAL REMOTE SENSING AND GIS SOFTWARE MARKET: REVENUE FORECASTS (WORLD), 1997-2007

Year	Revenues (US$ M)	Revenue Growth Rate (%)
1997	3,008.0	—
1998	3,307.4	10.0
1999	3,692.6	11.6
2000	4,056.0	9.8
2001	4,409.0	8.7
2002	4,775.3	8.3
2003	5,139.3	7.6
2004	5,511.6	7.2
2005	5,907.8	7.2
2006	6,354.9	7.6
2007	6,848.1	7.8

Compond Annual Growth Rate (2000-2007): 7.8%

Note: all figures are rounded; the base year is 2000

FIGURE M

EVOLVING BUSINESS MODEL

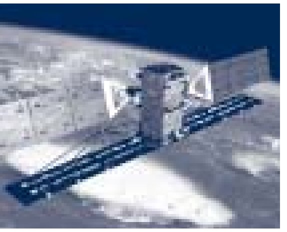
Traditional EO Data Company	Information Age Image Company
Produces/sells data only	Produces information, multiple data sources
Operating largely alone	Partnerships
Limited pricing and access policies	Flexible pricing and access
Knows data only	Integrated into broader spatial/IT marketplace
Only collects, processes and disseminates data	Vertical market expertise

Source: M.L. Stojak Inc, 2002

MARKET TRENDS

[19] Information provided to the author by William E. Stoney, Principal Engineer, Mitretek Corporation – August 2002. See www.mitretek.org.

[20] The growth of the aerial remote sensing industry will increasingly be stalled by the availability of commercial half-meter optical and high resolution radar satellite imagery.



Existing satellites do not adequately address coastal zone problems: This is because current low resolution sensors (AVHRR, MODIS, SeaWiFS, altimeters) are incapable of providing enough spatial detail in coastal zones, while commercial high-resolution sensors (IKONOS, Eros, and Quickbird) have poor spectral resolution and poor repeat cycles, and their data are generally too expensive. ESA's MERIS instrument represents the first true coastal zone colour scanner, with a repeat cycle adequate to overcome cloud limitations. At the present time however, Canada will not be able to benefit from the 300 meter resolution because Canada does not have a direct reception capability for MERIS. Because of their flexibility to meet tidal, cloud or biological time constraints, and because of their high spatial resolution, aircraft sensors have an important and continuing role to play in the coastal zone.

Better sensors and better access networks and interpretative software are coming into the marketplace: The market for the EO services sector is gaining considerable impetus from the availability of timely, extremely high quality high resolution optical data from US, Indian, Italian, German, French and Israeli organizations (see FIGURE N [19]), and RADARSAT 2 data soon to be available from RSI[20]. The growth in supply is much greater than even the most optimistic projections for demand, and we can expect prices to fall, in some cases dramatically. This again argues for the switch to selling information solutions. In addition, better data archiving, retrieval, manipulation, distribution and interpretation technologies are emerging, including automated systems for processing and interpreting data and systems for providing services on-line. The technology required to access and distribute data access is changing

FIGURE N [19]

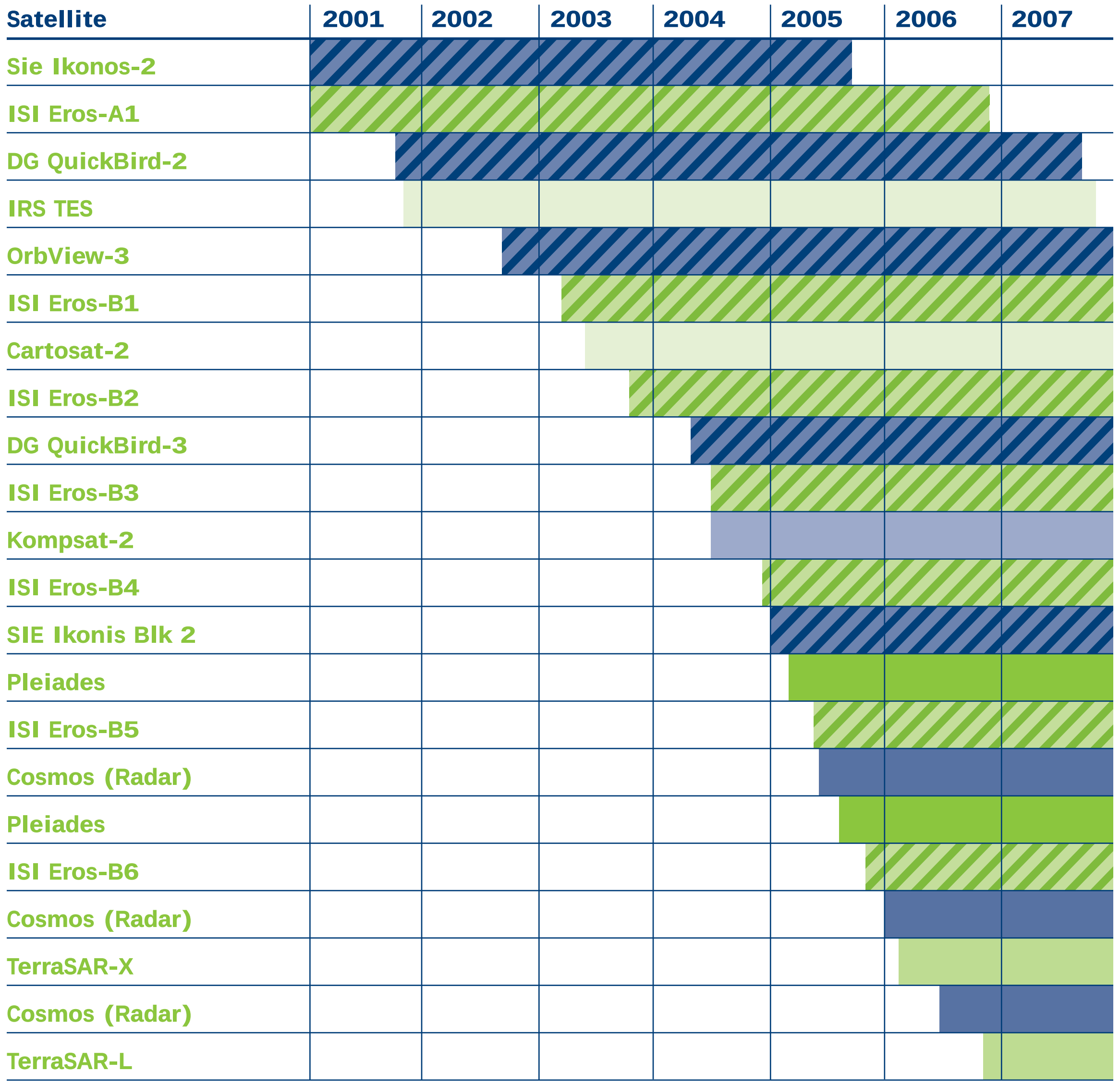
CURRENT AND PLANNED 1 METER AND BETTER SATELLITES

Commercial funded

- France
- Germany
- India
- Italy
- Korea

Commercial funded

- US Com.
- Israel Com.



Note:

- Eros-A1 = 1.8 m resolution.
- Japan has "discussed" developing sets of 1 meter optical and radar satellites

dramatically, as evidenced by the growing infrastructure technology associated with electronic distribution networks such as CEONet (Canada), EOSDIS (US), and CEO (Europe). Canada's CEONet works in some ways similar to how Netscape operates on the Internet. "Electronic commerce" will become possible for EO services. As a result, value-added companies will develop new services. On-line service-providers will customize information products for their clients. Several international ground stations (including Canada) are or will be adding on-line archive browsers and electronic data distribution capabilities (web-based). This should dramatically change the EO services market and create new ones.

We can expect a convergence of EO and other technologies, fuelling mergers and acquisitions: The remote sensing business is increasingly becoming part of a larger geo-referenced information business. A technological capability and an industry called geomatics, are emerging at the cross-roads of three key technologies: remote sensing (space or aerial based), GPS, and communications—providing the capacity to develop precise and easily accessible geo-referenced information. This fusion of capabilities is likely to be at the heart of increased mergers and acquisitions[21], as EO companies seek to provide ever more comprehensive solutions to their customers through integration. FIGURE O [22] illustrates this convergence of technologies:

More and more, the data market is divided between the expensive high end and the inexpensive low end, creating challenges for commercial EO companies: The market is becoming increasingly bifurcated, between the high end market (high resolution, real-time, information-heavy, specialized products and services), on the one hand, and the inexpensive low end market (off the shelf, shrink wrapped imagery and interpretative software or low resolution data distributed at cost) on the other. Disaster management and military applications are expected to grow more quickly than other uses. For these segments, the most important requirements are that the data be received in a timely fashion and that it be of suitably high resolution. These markets have the highest value-added and the highest premiums on the information generated through remote sensing. On the other hand, some satellite systems (e.g. Landsat 7) generate data which can be obtained at COFUR (Cost Of Filing User Request, estimated at US$400 for Landsat 7 images). Such a low price may have an impact on commercial distributors who are charging US$2000 plus per scene. As indicated in FIGURE P , the profit-generating data sales market is being squeezed from both sides, reducing even further the prospects that the commercial data sales business will become self-sustaining.

Data usage will change in the future, and SAR usage will double: FIGURE Q [23] provides a forecast of the shift in data usage in the key US market over the period 2001-2006. SAR data use will grow significantly, but will remain a niche market.

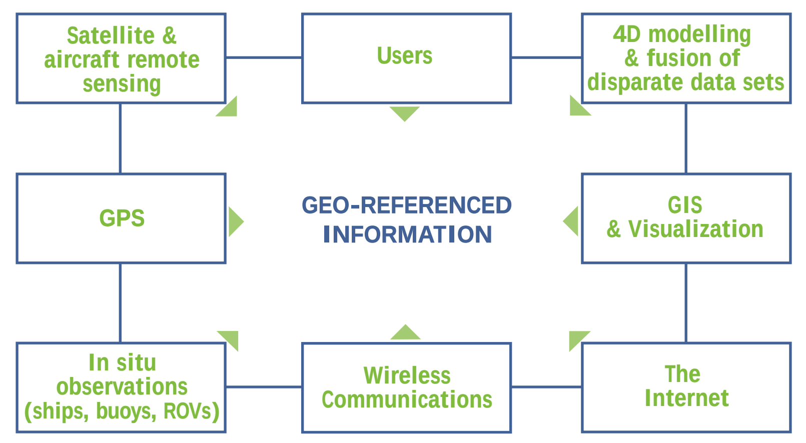
There will be a move towards smaller EO satellites flying in formation: The move towards smaller and cheaper remote sensing satellite systems is being driven by the growing use of mature off-the-shelf systems for sensors, spacecraft components, ground stations and communications subsystems, mission operations and facilities and launchers. This drop

21 For instance Leica Geosystems, a leading GPS company, announced on April, 27, 2001 the acquisition of all the shares of ERDAS Incorporated, a remote sensing and GIS software provider, and the acquisition of the remaining 50 percent of the shares of LH Systems, an aerial photography, remote sensing and photogrammetry company, from joint-venture partner CMC Electronics.

22 Adapted from Borstad & Associates, 2002.

23 ASPRS Forecast.

FIGURE O [22]



Source: Frost & Sullivan, 2000

in costs is even more pronounced when one considers the qualitative improvements brought by many new entrants to the EO market[24]. This cost reduction can enable clusters of smaller satellites to perform the job once reserved for large spacecraft. Such clusters can reduce launch and mission failure risks, and enable faster revisit times.

The value-added industry is becoming increasingly specialized: Each of the EO applications areas, particularly in SAR, requires the development and implementation of enormously specialized algorithms that are designed and developed for that specific application; as a result, companies are developing applications-specific expertise. Each of the market user groups to which satellite-based Earth observation is being applied has very different needs, which in turn affects how the imagery needs to be collected, processed, interpreted, and distributed.

WHAT TO EXPECT IN THE NEXT FEW YEARS

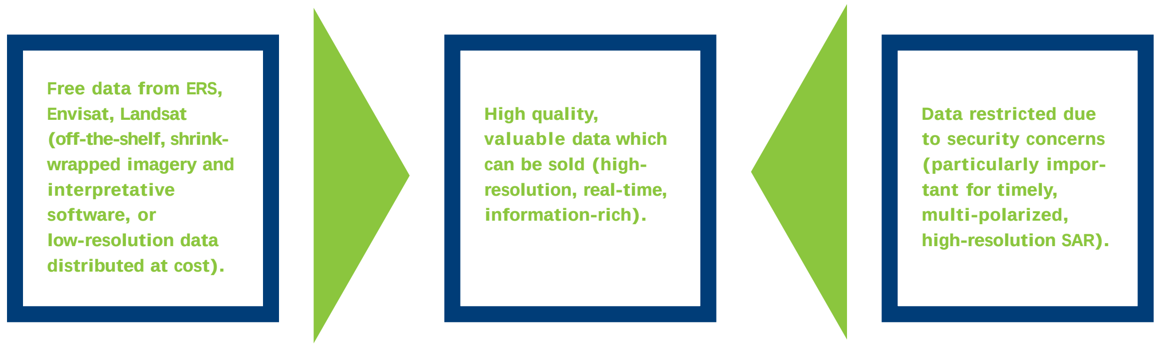
Move to a GMES model of sustainable operational services: Operational information services are still few and far between. Recognizing this, the European GMES program seeks to foster the development of new operational services based on satellite and other EO data, and other technologies, to ensure that European decision makers at various levels have access to the right data products at the right

24 Whereas the early SPOT and Landsat satellites cost between US$300-350 M, the new smaller, high-resolution optical satellites can be built and launched for under US$150 M. (Aerospace America, Focus Sharpens for Imaging Market, September 2000. This is dramatically changing the economics of the satellite remote sensing business, especially on the optical side.

25 E.g. the United States Global Change Research Program (USGCRP), a research program to address key uncertainties about changes in the Earth's global environmental system both natural and human induced.

FIGURE P

SQUEEZED DATA SALES MARKET



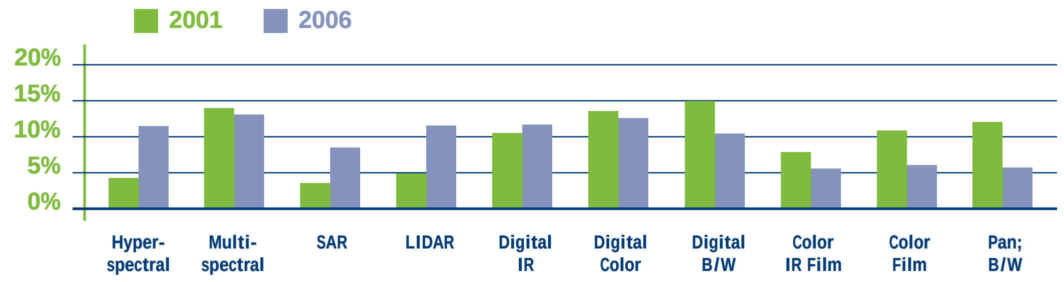
time. Canada already has good experience with this, in the form of the Canadian Ice Service (CIS) of Environment Canada. The CIS is the single largest buyer of Radarsat data, which enables near real time ice maps to be sent to ship captains in Canada's North. Consideration is being given to extending the model to other Nordic countries via the GMES program. The experience of the Canadian industry in providing timely solutions to customers could also position it for the increasing opportunities which are sure to come from GMES and similar initiatives around the world[25].

Data Policies will give more room to distributing images at marginal cost for research: In the case of Spot Image, the French government provided grants and subsidies to French researchers to help offset the market prices set by Spot Image. This policy has been sharply criticized within France. Many have stated that at its inception in 1986, Spot Image should have distributed data to researchers at minimal cost to stimulate the value-added industry sector. A recent shift in policy can be seen with the SPOT VEGETATION program. In support of the GMES initiative, the partners of the SPOT VEGETATION program have recently revised their data distribution policy. A major part of the archive is now opened to the entire user community at no cost. The scientist category will be extended to the world-wide research institutes and laboratories, as well as VEGETATION program partners. NASA's Earth Observing System (EOS) will also make data available at the cost of dissemination or below to facilitate and encourage use. Japan has also adopted a data policy which favors researchers by introducing a two-tier pricing model. Earth observation data, including from the soon to be launched ALOS satellite, will be distributed at marginal cost to researchers who agree to specified terms and conditions. And the CSA has received representations to the effect that Radarsat data should be more affordable for scientific use.

WHAT TO EXPECT
IN THE NEXT FEW YEARS

FIGURE O [23]

USE OF IMAGE TYPES: 2001 VS 2006 (ALL SECTORS)



Most used in 2001 (>10%)	Most used in 2006 (>10%)
• Digital B/W	• Multispectral
• Multispectral	• Digital Color
• Digital Color	• LIDAR
• Pan Film (Pan; B/W)	• Digital IR
• Color Film	• Digital B/W
• Digital IR	• Hyperspectral

Industrial consolidation will increase and a shakeout can be expected: Given the gradual maturation of the industry and the current number of companies in the sector, one can expect further integration, both vertical and horizontal, in the EO industry.

The price of data will drop dramatically in coming years: The imbalance between the rates of growth between supply and demand cannot continue indefinitely. The corollary is that the value of customer-focused solutions and operational services will rise, as EO companies continue to show users how satellite images, often in conjunction with other data, can serve their needs.

Privatization and commercialization will continue: As more customers rely on operational services and solutions from information providers, the revenue models will improve, encouraging more companies to take a share of the risk in funding and operating missions.

The critical success factors will increasingly be those of more mature industries: Marketing, price, distribution, overall customer service, product differentiation, etc., will increasingly emerge as the factors that distinguish the winners. Overall, industry-wide standardization will emerge as a key driver for growth.

Controls on access to EO data will become multi-lateral: The US was the first country to impose national controls on the types of data that could or could not be sold by US providers. When it became apparent that Canada's RADARSAT 2 would have a quite capable 3 meter resolution in fine mode (compared to RADARSAT 1's 8 meter resolution), the US requested the conclusion of an access control agreement with the Government of Canada, which agreement was signed in 1999. Now, the US has initiated similar discussions with the German government, in light of the planned high resolution TerraSAR X-Band system. As more countries seek to provide high resolution images and information products, we can expect the US and its allies to move to a multilateral control regime, akin to those in place for sensitive military technologies (Wassenaar Arrangement), launch technologies (Missile Technology Control Regime) and others. This method will promote the harmonization of applicable restrictions and ensure that, in the face of rapid technological changes, restrictions can be modified in a flexible way.

CONCLUSIONS

Satellite remote sensing is rapidly finding its place in the modern economy. Public good applications are increasingly being developed and recognized by governments as key to their national priorities in environmental monitoring, resource management, disaster mitigation and other areas, to the point where non-traditional government departments are discovering how they can use EO information products. This is happening in Canada: the CSA recently conducted a review of potential requirements of departments for the use of space products and services, and these consultations revealed many new possibilities, including for radar and hyper-spectral sensors. In parallel, the efforts of commercial data providers and value-added companies to educate users about the benefits of EO data are starting to pay off. Markets for data and especially for information products are developing nicely, with stronger growth expected in the area of operational information services.

Whether we are talking of public good or commercial applications of EO data and information, three key priorities remain: (1) data providers must continue to bridge the knowledge gap separating them from potential customers, (2) efforts must continue to integrate satellite EO data with other key technologies to ensure that the richest information possible is produced; and (3) user-centered operational information systems must increasingly be developed, to ensure that the right information reaches the right decision makers at the right time (the Canadian Ice Service's daily use of near real-time Radarsat data can serve as a model). Success on these priorities will require a continued strong partnership between the Canadian Government, industry and academic sectors, to ensure the next level of maturity for the sector.

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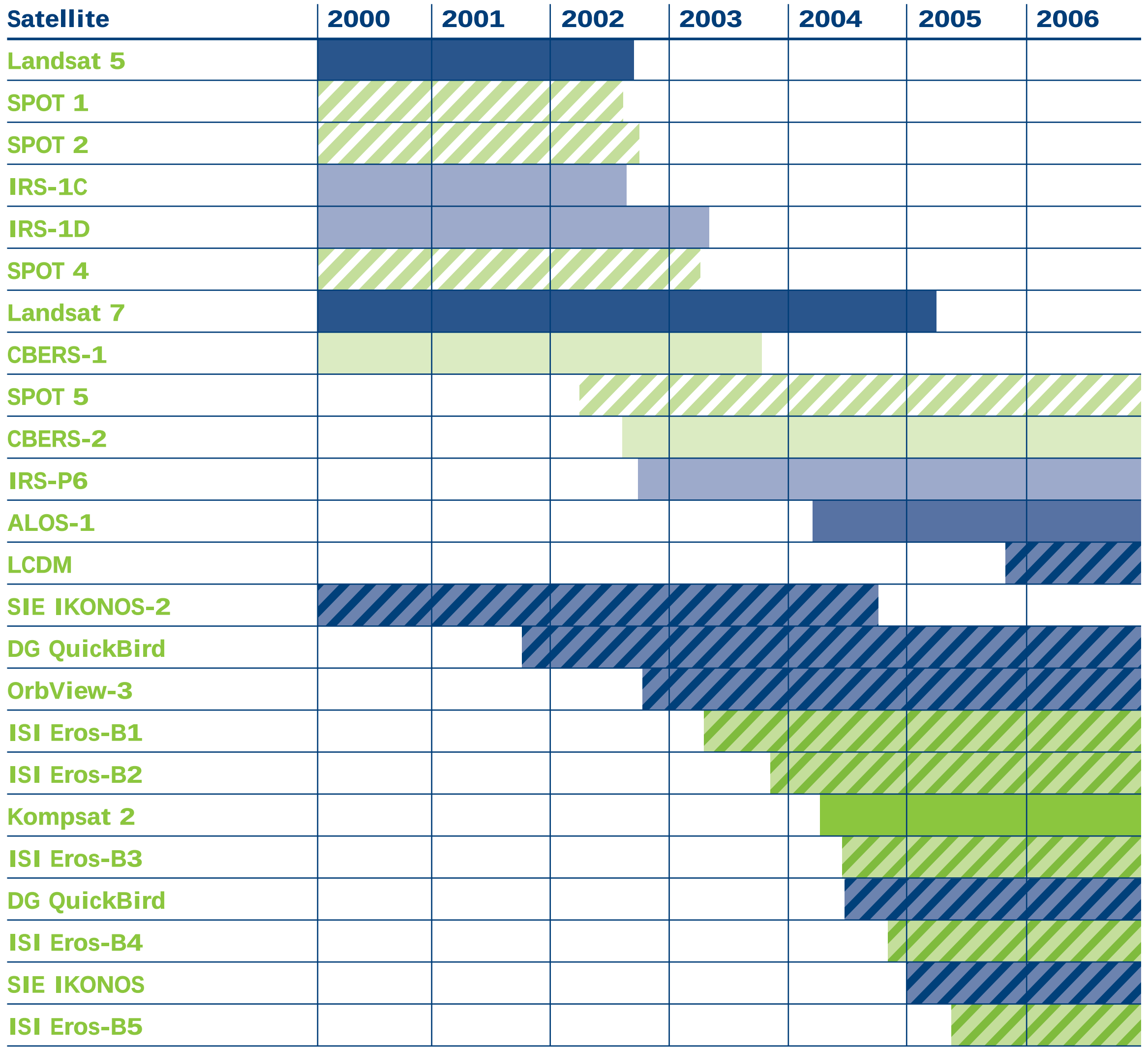
CONCLUSIONS

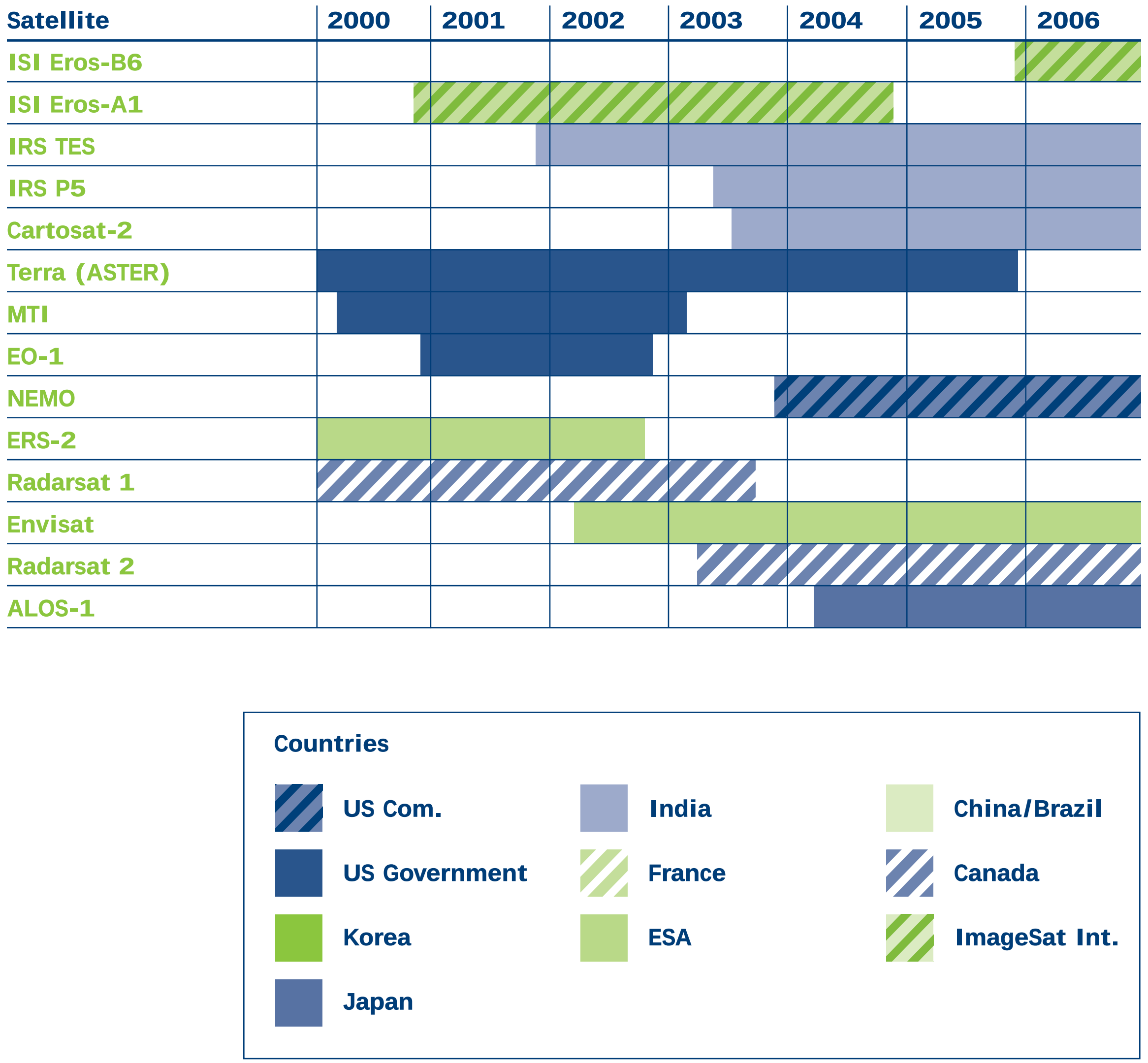
APPENDICES

FIGURE R

APPENDIX 1

REMOTE SENSING MISSIONS IN DEVELOPMENT





Source: William E.Stonay, August 2002 with permission.

26 Exclusive Economic Zone

FIGURE S

APPENDIX 2

SUMMARY OF MARINE REMOTE SENSING OPPORTUNITIES FOR CANADIAN VARS.

Issues As identified from the literature and web site review and used in the survey.	Int'l Waters	EEZ[26]	Coastal Zone	Relevant Product or Service
Cross-sectoral issues				
Availability of suitably trained people to manage and use the information for decision making (including demographics)	L	M	M	Commercial practical and university academic training
Availability of data (e.g. appropriate measurements, accuracy, timeliness);	L	M	H	Commercial data acquisition
Access to appropriate information products and services (e.g. world data centres and standards, data fusion)	L	L	H	Sales by VARs of standardized information products; Ocean portals, GeoConnections, Marine GeoData Information Initiative
Tourism and recreation (e.g. shoreline development)			M	Indirectly creating demand for information
Development of predictive models (e.g. socio-economic-environmental interactions)	L	M	M	Indirect demand for spatial information that can be provided by remote sensing
Environmental monitoring and resources management				
Environmental impact assessment for new developments and quality indicators		H	H	Strong demand for high resolution spatial information
Non-renewable resource management (e.g. oil and gas, beach and seabed mining)		H	H	Real-time local and regional information for safety, also environmental information
Preservation of biodiversity			H	Indirect application for coastal zone habitat mapping
Climate change and variability (e.g. sea level change)	L	L	H	Satellite time series in open ocean and EEZ, but little commercial input. Detailed habitat and resource mapping, DEMs for coastal zone
Habitat management (e.g. marine protected areas, corals, sea grass, mangroves)			H	Very high resolution mapping of coastal zones, especially where development is occurring
Environmental monitoring, change detection and water quality	H	H	H	Climate effects of offshore ecosystem, detailed monitoring in coastal zone near urban areas
Renewable resources management (e.g. stock assessment, straddling stocks, mariculture)	L	L	H	Mapping, monitoring, tracking; support of fisheries research and management
Safety, surveillance and regulation				
Legislative/organizational framework for conflict resolution and implementation of necessary decisions		H	H	Mapping and monitoring products in Decision Support Systems
Regulation of activities in international waters	L			Radarsat to track vessels and some pollution
Regulation of exclusive economic zone activities		M		Radarsat to track vessels and some pollution
Regulatory enforcement (e.g. fisheries surveillance, defence, sovereignty and piracy)	L	H	H	Radarsat to track vessels and sense some kinds of pollution; aerial surveillance
Safety at sea (e.g. hydrographic charting, and other navigation aids, search and rescue)	L	H	H	Real-time weather and sea state. LIDAR bathymetry, very high resolution optical sensors,
Natural hazards (e.g. storms, erosion)	L	L	H	DEMs in anticipation of storm and climate related flooding
Port development and efficient operation			H	Very high resolution optical for engineering and environmental studies
Regulation of ship- and shore-based pollution	L	L	H	Very high spatial resolution monitoring
Regulation of coastal zone activities			H	Mapping and monitoring at all scales

Note:
Most of the issues are public sector responsibilities. The opportunity for a remote sensing contribution (H = high; M = medium; L = low) may be in the form of equipment sales and/or services by a VAR to the responsible agency. H does not necessarily represent a numerically large niche - just that there is one.

Source: Trends and Opportunities in Marine Remote Sensing Technology, Borstad & Associates, 2001.

SPACE ROBOTICS AND AUTOMATION

table of contents

Prepared by:

Sylvie Beland, eng., Ph.D

External Relations

1 Piedboeuf, Jean-Claude and Dupuis, Erick, Recent Canadian Activities in Space Automation & Robotics – An Overview, Proceedings of the 6th International Symposium on Artificial Intelligence and Robotics & Automation in Space: i-SAIRAS 2001, Canadian Space Agency, Québec, Canada, June 18-22, 2001

EXECUTIVE SUMMARY

During the last few decades, Canada has achieved world recognition in space robotics. The exceptional performance of the Canadarm has led to our contribution to the International Space Station (ISS) project. The successful provisioning of the Mobile Servicing System (MSS) for the ISS has reaffirmed Canada's reputation as a leader in robotics technology and now gives us the opportunity to consolidate our expertise and to contemplate new challenges.

This is a crucial time for robotics and automation in space in Canada. At the dawn of the new millennium, space robotics and automation are facing new challenges. The International Space Station is being built and space robotics will play a major role in assembly, maintenance and scientific payload manipulation. The exploration of planets and their moons, asteroids, and comets commands more and more of our attention. In space, servicing of satellites and construction of large structures present new opportunities. For all these applications, increased levels of autonomy and more intelligent systems are needed.

Space robotics and automation is a key element of the Canadian Space Program. The Government of Canada, through the Canadian Space Agency, has made a sizeable investment in space robotics, and several exciting programs are currently ongoing[1]. Strategic robotic technologies are being developed in industry and in the CSA to allow Canada to continue as the world leader in space robotics. The evolution of the current technology base is being enhanced to enable Space Station evolution for operations and robotic science experimentation. In addition, significant robotic technologies are currently being developed in Canada targeted specifically at solar-system exploration and next-generation launch and space vehicles.

The CSA, along with Canada's space industry, must continue to carry out extensive R&D in this field as it anticipates the growing presence of Canadian technologies that go beyond classic manipulator applications. Continued investment by CSA and the space industry in cutting edge technology development will reinforce Canada's leadership and innovation in space robotics, and will open up growth opportunities in commercial markets requiring this advanced technology. It will also prepare Canada to play a key role in international missions as the world space community focuses its attention on the exploration of Mars and other targets in our solar system.

The development of a robotics and automation strategy for Canada is critical. Canada has attained a good international reputation in the space robotics and automation industry but will not be able to take advantage of the technical advances it has made or the human resources it has developed, and will definitely not be able to maintain the forefront in space robotics without a solid strategy for the future.

Although there have been some new developments and projects worthy of mention during the past year, space robotics and automation does not evolve as rapidly as other space sectors such as is the case for satellite communications. As a result, the general market trends for 2002 have not changed significantly from those observed in 2001. Therefore, this chapter provides both an update of the Space Robotics & Automation chapter in the Global Trends 2001 publication, highlighting specific key events from the last year and discusses specific trends to watch for in the near future.

2 Ellery, Alex, An Introduction to Space Robotics, Springer – Praxis Books in Astronomy and Space Sciences, 2000

MARKET CHARACTERISTICS

SPACE ROBOTICS AND AUTOMATION PRODUCTS AND SERVICES

Space robotics and automation products and services consist of the following:

- robot hardware, including materials, joints, gears, interfaces, end effectors, tools, vision systems
- robot control software, including artificial intelligence
- operator interface hardware and software,
- robotic simulations for system development, analysis, mission planning, and training,
- ground segments for robot monitoring and control, and
- training on the operation, ground control, and maintenance of space-based robotic systems.

CUSTOMERS FOR SPACE ROBOTICS AND AUTOMATION

Currently, worldwide projects requiring space robotics and automation products are primarily government supported. This trend will continue as long as these projects are either not of near-term commercial interest or suggest a more sustainable cost return upon investment. This is the case for very large-scale projects such as the construction and maintenance of the International Space Station, manipulation and maintenance of on-orbit equipment and satellites, solar system exploration tasks, and the development of the next generation launch and space vehicles.

The true commercial utilization of space relies mainly on advances in inexpensive reliable space transportation from Earth to reduce launch costs, and on the development of remote complex manipulation for space-based activities. As the goal of reducing launch costs to $2,500/kg or less is realized, more commercial exploitation of space is anticipated[2]. Companies such as Space Adventures Inc. are already planning or making reservations for future space tourists. As well, space-based solar power generation and space-based production and manufacturing will become economically more attractive. Environmental clean up of space debris and re-deployment of space assets will become more affordable. All these potential opportunities will call for significant ground and on-orbit infrastructure requiring state-of-the-art space robotics and automation equipment.

In this context, commercial demand in Canada for space robotics and automation products will evolve significantly when other large-scale projects such as planetary exploration requiring robotic assembly and maintenance are funded and initiated. The robotics and automation industry in Canada should be poised to take advantage of these major opportunities when they arise.

Currently, the governments demanding the bulk of space robotics and automation products are Canada, the member states of the European Space Agency (ESA), the United States, Russia and Japan. The Government of Canada, through the Canadian

Space Agency, has made a sizeable investment in space robotics and automation, a key element of the Canadian Space Program.

MAJOR COMMERCIAL SUPPLIERS OF SPACE ROBOTICS AND AUTOMATION PRODUCTS

Canadian firms have extensive expertise in many robotics products and services: robotic materials, joints, gears, interfaces, end effectors, tools, telepresence, telecontrol, vision systems, autonomous operations, artificial intelligence, training, and software development. Canadian commercial suppliers of these space robotics and automation products are perhaps few but well established. The list below (in alphabetical order) provides a few examples of these large and small-to-medium sized enterprises in Canada, Japan, the USA, and Europe. A more complete listing of Canadian suppliers and researchers can be accessed through the Canadian Space Agency's (CSA) Space Directory, available on the CSA web site at www.space.gc.ca.

Canadian companies

CAE – Canada. Headquartered in Canada and operating globally, CAE is the world's premier provider of simulation and control technologies for training and optimization solutions for the Aerospace, Defence and Forestry sectors.

CAE, under contract to the CSA, was responsible for the development and implementation of the MSS Operations and Training Simulator (MOTS), the high-fidelity MSS dynamics simulator used for development and assessment of MSS operations techniques, training of astronauts, cosmonauts and ground support personnel, and robotic task validation. CAE is contracted to develop specific SPDM functionality for incorporation into the MOTS, including the integration of encapsulated flight software for the SPDM as it becomes available from MacDonald Dettwiler Space end Advanced Robotics (MDR). CAE is also supporting specific MOTS functionality development required to allow a full integration of the SPDM Testing and Verification Facility (STVF). Currently, the SSRMS is being validated and the SPDM model is being integrated in MOTS.

EMS Technologies - Canada. EMS Technologies Canada, Ltd. is a subsidiary of EMS Technologies Inc. headquarted in Atlanta, Georgia. EMS employs over 2,000 people worldwide with modern engineering and manufacturing facilities in Atlanta, Ottawa, Montréal, the UK and Brazil. Drawing from decades of expertise in space robotics, satellite communications and remote sensing, EMS designed and built the dozens of electronic computers and controllers, wrote the software as well as integrated the joints and extremities (Latching End Effectors) of the Space Station Remote Manipulator System (Canadarm2). Similar work was performed for the Special Purpose Dexterous Manipulator (SPDM). Also under contract to MDR, EMS designed and built the Robotic Work Station (RWS) for the International Space Station. The RWS is the interface between the astronauts and the various robotic elements on board the ISS. Two Robotic Work Stations have been delivered to the ISS and several other flight equivalent units are being used for astronaut training. In a related ISS activity, EMS supplied all of the principal communications links to and from the ISS, integrated the Camera-Light Assemblies and the Pan Tilt Assemblies.

International Submarine Engineering (ISE) – Canada. ISE is a privately-owned Canadian company, founded in 1974 to design and build robotic submersibles. Significant subsystems for these submersible robots are robotic manipulators, computer control software, and sensors. These subsystems became the basis of ISE`s products developed for land and space robotic applications.

ISE was responsible for the development of the Special Purpose Dexterous Manipulator (SPDM) Task Verification Facility (STVF) robot, a hydraulic manipulator system that will simulate the SPDM. They were responsible for the development of CSA's Automation and Robotic Testbed (CART) which provides Canadian experts working in the field of robot and automation with an effective tool to further refine and test robotic technologies designed for space and terrestrial applications.

MacDonald Dettwiler Space and Advanced Robotics (MDR) – Canada. MD Robotics (MDR), a wholly owned subsidiary of MacDonald Dettwiler and Associates Ltd, is based in Ontario, Canada with divisions located in Houston, Florida and New Mexico in the United States. MDR currently employs 1000 highly skilled people, over 60% of which are engineers and technologists.

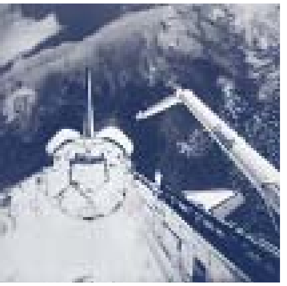
MDR offers automation and robotic solutions for complex, hazardous environments in space and terrestrial markets. MDR provides complete services from mission definition and customer requirements - through solution design, development, integration, test and deployment - to post-deployment operation, maintenance and upgrades. MDR, is best known for the Space Shuttle Remote Manipulator System and the comprehensive suite of robotic equipment on the International Space Station.

MDR provides services to commercial, civil and military customers in Canada and international markets including the United States, Japan and Europe. MDR designs and manufactures systems for applications in Space Exploration, On-orbit Satellite Servicing, Mining Vehicle Automation, Tele-medicine, Nuclear Remediation and Animatronics.

MDRobotics also designed and built the end effector that acts as the hand for Japan's Space Station element remote manipulator. Under a contract to Italy's Alenia, MD Robotics is supplying a power data grapple fixture for the European Space Agency's element.

Neptec. Neptec is a leader in the design, development and integration of mission-critical real-time software, harsh environment electronics design and digital signal processing for mission-critical space, healthcare, aerospace, defense and security applications. Headquartered in Ottawa, Neptec employs over 100 staff. Neptec International, a subsidiary in Houston, Texas, is engaged primarily in mission analysis and operational support for space programs.

Neptec has focused on the design of space vision systems since 1990. Their Space Vision System (SVS) is installed on all of the Space Shuttle Orbiters and the ISS. Using patented algorithms and techniques, SVS processes video signals from cameras in the Shuttle's cargo bay and on the robotic arm to determine the precise position and attitude of objects, assisting astronauts in accurately assembling elements



of the International Space Station. In August 2001, a new laser scanner system developed by Neptec was launched aboard Space Shuttle Discovery to enhance the reliability of the Space Vision System already installed on the Canadarm.

Optech. Optech is a high-tech company located in Ontario specializing in manufacturing laser-based ranging and detection systems. Throughout its 25 years of existence, Optech has moved from its R&D base into a company that manufactures and integrates its own commercial products for a worldwide market. They have concentrated in the area of laser radar (lidar) applications. They have recently expanded into space-based lidars, building on earlier work in range-imaging for space robotic vision carried out with the support of CSA. They have designed a lidar that is now being evaluated for future NASA missions.

Tecsult Eduplus – Canada. Tecsult Eduplus Inc. offers a wide range of human resource development and training services, ranging from basic education, to employability counselling, to the creation of advanced e-learning content and systems that are at the forefront of new training technologies. As one of the largest Canadian companies in the field, they employ 150 specialists in training delivery, instructional systems design, industrial engineering, information technology, multimedia production, psychology and management.

Tecsult Eduplus Inc., not a space company per se, but is under contract to the CSA, responsible for producing the computer-based training software that will train the people (astronauts, cosmonauts, and ground support personnel) responsible for on-orbit operations of the MSS. The company also prepares lesson plans for the CSA's multimedia learning centre, MSS Operations and Training Simulator (MOTS), and for virtual reality exercises.

Foreign Companies

Oceaneering Space Systems - USA. Oceaneering Space Systems (OSS) is a wholly-owned division of Oceaneering International. OSS was formed in 1988 as an advanced-technology division that concentrates on the design, development, integration, and application of new and established technologies to solve the challenges of operations in space. OSS has grown from an initial technical base of robotics and systems engineering into a multi-product, multi-disciplined organization of over 200 people.

OSS has developed robotics and automation processes to prepare, freeze, and store protein crystals grown in space. It has also developed micromanipulators with 50 micrometer positioning accuracy. OSS is a key member of the NASA-JSC Robonaut project to develop and demonstrate the robotic technologies needed to build “human-like” robotic systems that replicate the dexterity of a suited astronaut's arm and hand. OSS has developed tools for use by space-based robotic systems and has participated in the design and testing of the Autonomous EVA Robotic Camera (AERCam) Sprint Free Flyer for space construction operations.

Tecnospazio-Italy. Tecnospazio is a 25-person space robotics company part of Gallileo Avionic located in Italy, probably the most important space robotics company in Europe. Tecnospazio is producing space robotics components and conducts R&D in space robotics. Past and current activities include: the Spider arm (1993-1997); Europa, for which Tecnospazio is responsible for the development of the arm and its controller on the ISS Express Pallet; ROSETTA, where Tecnospazio is developing the drill and its controller; Drill for Mars Sample Return; and, ERA, where Tecnospazio is responsible for the application layer software and the man-machine interface software and robotic servicing (a testbed has been developed to demonstrate assembly task in space).

Toshiba/NEC Corporation – Japan. NEC and Toshiba legally established a new joint venture in April 2001, and have succeeded in transferring their space operations to the new company that has been in operation since that time. The merger has created a heightened presence in the commercial space sector, particularly in space infrastructure, spacecraft and ground systems. This is the only company in Japan engaged solely in the manufacture of a line of space products. The total number of employees is 900 (1,200 including subsidiaries). The headquarters of the company is located in Yokohama City and it has three manufacturing plants. The company focuses on satellite subsystems and components, space station systems, ground control systems, robotics and rocket equipment, as well as design and satellite system integration. While NEC Corporation has a long record of achievements in the satellite business, Toshiba was responsible for the design and development of the robotics components of the ETS-VII satellite and for the Japanese robotic components servicing the Japanese Experimental Module on the ISS.

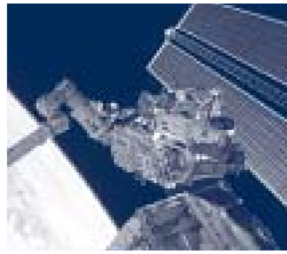
MAJOR CANADIAN EVENTS OF 2001 AND EARLY 2002

The years 2001 and 2002 were marked by the successful provisioning of the Canadarm2 system including the SSRMS and the Mobile Base System, together acting as a sophisticated robotic system critical to the assembly, maintenance and servicing of the International Space Station. This system represents some of the most advanced robotics in the world. Major Canadian events in 2001 and early 2002 are listed below and throughout this chapter.

February 2001: Specialized Canadian robotics software developed by MDRobotics is delivered to the International Space Station (ISS) to operate the next-generation robotic arm for the ISS, Canadarm2.

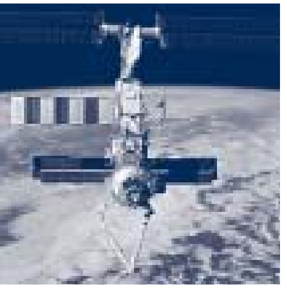
March 2001: The Canadian robotic workstation (RWS) developed by MDRobotics under contract to NASA is brought to the ISS. The RWS is the control station designed to provide an operator with a capability to control and monitor Canadarm2. The Robotic Workstation is built to provide a highly reliable, seamless interface between man and machine and feature display and control panels, hand controllers, video monitors and computers. Two flight units will be installed on the ISS. One will be located in the U.S. Lab Module, while the other will function as a back-up workstation in the Cupola.

April 2001: Canadarm2 designed and built under the guidance of MDRobotics is successfully deployed and installed on the International Space Station. The mission included the most complex and intricate robotics work ever conducted in space: two generations of Canadian robotic arms, Canadarm and



MAJOR CANADIAN EVENTS OF 2001 AND EARLY 2002

3 Diftler, M.A. and Ambrose, R.O., Robonaut: A Robotic Astronaut Assistant, Proceedings of the 6th International Symposium on Artificial Intelligence and Robotics & Automation in Space: i-SAIRAS 2001, Canadian Space Agency, Québec, Canada, June 18-22, 2001



Canadarm2, worked together to transfer from the ISS to Shuttle cargo bay, the packing crate in which Canadarm2 was delivered.

June 2001: Canadian Space Agency (CSA) Astronaut Julie Payette became the first Canadian astronaut to complete training on Canadarm2 operations. Astronauts from around the world receive their training at the Mobile Servicing System Training and Simulation Centre (MOTS) at CSA's headquarters. During the two-week session, they are trained by a team of expert robotics instructors to operate the Canadarm2 first and foremost. Future students will also learn to operate the Mobile Base System (MBS) and eventually the Special Purpose Dexterous Manipulator (SPDM).

July 2001: Canadarm2 began its first operational ISS assembly task. Operated from inside the International Space Station (ISS), Canadarm2 lifted the new 6,000 kg Station Airlock from the Shuttle payload bay and installed it on the Station's Unity module.

March 2002: MacDonald, Dettwiler and Associates Ltd. was awarded a contract by Mitsubishi Heavy Industries to provide an interface that will allow Canadarm2 to assist in berthing the Japanese Transfer Vehicle (HTV) to the International Space Station. The HTV is being developed by NASDA, (National Space Development Agency of Japan), as one of their contributions to the ISS. The mechanism will utilize the same "capture and release" interface developed by MDRobotics for the Canadarm2.

April 2002: Canadarm2 was operated to lift a major truss segment out and away from the Shuttle cargo bay and attach it onto the Destiny laboratory module of the International Space Station. Canadarm2 was then used for the first time to move astronauts to different worksites around the newly installed truss segment.

June 2002: The 1450-kilogram aluminum Mobile Base System (MBS) built by MDRobotics under CSA contract was launched and installed on the U.S.-built Mobile Transporter. For the first time, Canadarm2 stepped off the Station's laboratory module onto the MBS, a move that will greatly extend its reach. During this mission, astronauts also replaced a wrist roll joint that had been malfunctioning on Canadarm2. Unlike the shuttle's Canadarm, the Station's arm cannot be returned to earth, so it was designed to be repaired on orbit.

June 2002: CSA and DLR (German Aerospace Centre) signed a MOU in space robotics covering Ground Operations and Robot Autonomy, and Space Manipulator Dynamics, Simulation and Control Implementation. DLR's Institute of Robotics and Mechatronics is expending design and development robotics efforts on a new generation of intelligent, multi-sensor ultra lightweight robots with articulated hands and high level remote programmability to perform tasks in space. DLR's first major experience with space robotics was with ROTEX, the first remotely controlled robot in space; the company gained its second big space robot experience with NASDA's ETS VII project, the first free-flying space robot which was operational for around two years.

FUTURE PROJECTS

The next few years promise to be very exciting for the space servicing community with several new robotics systems currently under final development and scheduled to be flown. Some of them are listed below.

The NASA Robonaut (robotic astronaut)[3] project is an anthropomorphic design for EVA equivalence to overcome the limitations on the ISS SSRMS and SPDM that require special alignment and grapple fixtures and are too large to fit through EVA access doors and corridors. Robonaut is human in size with 43 degrees of freedom. It is the first humanoid built for space and incorporates technology advances in dexterous hands, modular manipulators, lightweight materials, and telepresence control systems. The robotic hands are designed to handle EVA tools, including power tools, with human-like dexterity. Robonaut will be tele-operated by an ISS astronaut utilizing telepresence technology such as head mounted display helmets and virtual reality gloves.

The Kibo Japanese Experimental Module Remote Manipulator System (JEMRMS)[4] of the ISS represents a central component of the JEM's Exposed Facility experiment platform. The JEMRMS consists of three major subsystems, the Console, the 10m, a 6 degree of freedom Main Arm and the 2m, 6 degree of freedom Small Fine Arm. The National Space Development Agency of Japan (NASDA) began testing robot arms in May 2001.

ESA has a number of space robotics programs, with the ISS providing the focus. Many studies have been conducted including the BIAS (Bi-Arm Servicer), MTSU (Man-Tended Servicing Unit), IRAS (Interactive Remote Automation & Robotics Servicing), EMATS (Experiment Manipulation and Transportation System), HERA (Hermes Robotic Arm) and ERA (European Robotic Arm)[5].

Currently, ASTRIUM is working on a project for a mobile autonomous service and inspection system for the ISS (MISISS). This project was initiated by the German Space Agency (DLR) as part of an ESA project. The experimental mobile Inspection and Service System for the ISS will be used for inspection, payload handling and mobility tasks (walking robots) and will include an experimental demonstration of a new robotic system and innovative technologies. DLR is also planning another demonstration mission, ROKVISS, in cooperation with Rosaviakosmos. ROKVISS is a lightweight two-joint space robot that will be tele-operated from the ground. CSA has been invited to participate under the umbrella of the newly signed Memorandum of Understanding.

The Special Purpose Dexterous Manipulator (SPDM) is a dual-armed robot that will work in conjunction with the Canadarm2 and will provide more intricate robotic maintenance capabilities on the Station. Specifically, the SPDM will support maintenance on the Space Station by handling, payloads, mechanical actuation of tie-down bolts and tool mechanisms, and temporarily accommodating payloads on the SPDM body. The SPDM consists of two (2) seven (7) degree of freedom manipulator arms, two (2) end effectors, one at the end of each

4 Sato, N. and Y. Wakabayashi, JEMRMS Design Features and Topics from Testing, Proceedings of the 6th International Symposium on Artificial Intelligence and Robotics & Automation in Space: i-SAIRAS 2001, Canadian Space Agency, Québec, Canada, June 18-22, 2001

5 D. King, Space Servicing: Past, Present and Future. Proceedings of the 6th International Symposium on Artificial Intelligence and Robotics & Automation in Space: i-SAIRAS 2001, Canadian Space Agency, Québec, Canada, June 18-22, 2001

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arm, an upper body structure fitted with two electronics platforms and a lower body comprised of a roll joint, a latching end effector, a tool holder assembly, an Orbital Replaceable Unit Temporary Platform and two camera/light assemblies. The SPDM is scheduled to be launched aboard the Space Shuttle in 2005.

The Self-Adapting Robotic Auxiliary Hand (SARAH) is a novel design of a self-adaptive and reconfigurable robotic hand for space applications. The 10 degrees of freedom robotic hand consists of three fingers, each equipped with three phalanges. The fingers can grasp various shapes including cylindrical and spherical geometries. The overall envelope of SARAH is similar to an astronaut's glove. However, SARAH's force capabilities are twice that of an astronaut in any EVA activities. SARAH, a collaborative effort between MDRobotics and Laval University is being developed as a potential tool for the Special Purpose Dextrous Manipulator (SPDM) on the ISS to support increasingly complex dextrous robotic operations. SARAH's possible Extra Vehicular Robotics (EVR) operations include: SPDM stabilization when operating on the end of SSRMS in an unplanned environment, thermal blanket manipulation, temporary ORU storage location and auxiliary ORU manipulation.

On the ground station side, CSA and MDRobotics are jointly conducting research aimed at developing an architecture to conduct some of the operations of ISS robotic elements from a ground station. A testbed on which ground control technologies can be tested has been developed at the CSA. The testbed faithfully reproduces the interfaces, capabilities and dynamics of the MSS as well as the communication limitations. The central component of the testbed is the MSS operation and Training Simulator (MOTS): a real-time simulator currently used for MSS operator training and for operation planning. However, a thorough evaluation of MSS ground operations has to be performed. After the concept has been tested and proven in a ground simulation, the next step in this research will be the development of a flight experiment on the ISS, designed to conduct a portion of operations from a ground station in collaboration with an on-board operator.

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There have undoubtedly been successful missions and major advancements in space robotics and automation over the last few years including the provision of the Canadarm2 and the Mobile Base System for ISS that has established Canada as the present world leader in space robotics. However, the application of new and advanced robotics and automation technology in space, as well as the major projects involving space robotics products such as the unmanned Mars missions, have slowed down recently, mainly due to budgetary constraints within the major governmental space organizations.

However, recent press releases from the private and public sectors, including the CSA, indicate that there are many new technologies being developed that will be ready for applications in space in the short to mid-term timeframe. Three main areas of space robotics activities have been identified as critical for technology development in the near to medium term: MSS operation and evolution (including Ground Facilities), Planetary Exploration, and Space Servicing.

MSS OPERATION AND EVOLUTION

Canada is responsible for the sustaining engineering and part of the operations planning of the MSS. Opportunities for enhancement to the MSS and its supporting infrastructure will undoubtedly arise as it enters its operational life. SSRMS and SPDM will likely be required to perform off-nominal operations for which new tools would be required. Already, MDRobotics has received CA$18 M in April 2002 in additional funding on two existing contracts from the Canadian Space Agency for logistical support and engineering services to sustain the MSS. As well as flight operation support activities currently being provided, MDRobotics also received a CA$38.5 M contract from NASA to provide continued engineering support to robotics elements on both the Shuttle and the ISS.

One of the capabilities that will eventually be required is tele-operation from the ground. Crew time is a precious resource and astronauts will be required to perform science experiments on-board the ISS. Studies have shown that the crew would not be able to keep up with the routine maintenance demand, much less be able to perform science experiments. The workload imposed on the crew by maintenance operations of the ISS in its current baseline configuration is not yet determined with certainty but the risk remains of overloading very precious human resources with tedious maintenance activities on-orbit. This is particularly true in the context of the ISS, where potential reduction of crew size due to budgetary constraints will drive the need for more autonomous and tele-operated robotic activities. Ground control development must start now to ensure technology is ready and implemented in space by the time the MSS operations require it.

In addition, enhancements will certainly be made to the ground support infrastructures in order to increase the efficiency of operations planning, verification and training and to incorporate new technologies over the life of the International Space Station. The MSS Operation and Training Simulator (MOTS) will have to be updated to keep up with technology advances. The SPDM Task Verification Facility (STVF) will have to be modified to deal with more complex situations. Modelling and simulation of more complex phenomena like contact dynamics and friction will be required. Evolution of MOTS and STVF is key to preserving a Canadian leadership role in MSS ground support infrastructure.

The understanding of Canadarm2 and free-flyer dynamics requires highly qualified and well-trained operators. Experimental tests and analyses have shown that capture of free-flyers is the most complicated task to be performed by a robotic operator on board the ISS. It is a critical operation with high crew safety impact. The dexterity and accuracy of the astronauts may decrease over time if they are not trained on-board. In that context, an on-orbit simulator to keep the astronauts skills at the required level is certainly desired. In order to support the training scenarios required for the on-orbit training, a simulator has been developed at the CSA. The main objective of the simulation is to determine if an astronaut is ready to perform

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an operation with Canadarm2. The training scenario implemented by the SMP consists of capturing a free-flyer with the Canadarm2.

PLANETARY EXPLORATION

The recent discovery of water on Mars as well as the successful landing of a small robotic probe called NEAR on the surface of an asteroid at nearly 322 million kilometers away in February 2001, have revived the zest for planetary exploration. The asteroid landing illustrated how a nimble and relatively inexpensive robot can extend the hands and eyes of humans to new corners of the solar system. Planetary exploration will represent an important portion of upcoming robotic space missions. Without robots, space exploration will be very limited. And this is even truer when it comes to the possibility of commercial exploitation.

Mars is the primary target of space exploration with many missions planned in the near future: NASA's Mars Surveyor Program is slated to launch missions to Mars every two years in the coming decade. The landers of these missions will perform soil sample collection for in-situ analyses and sample return, as well as executing a wide assortment of astro-biological, geophysical, meteorological and in-situ resource utilisation experiments. In the medium term, missions to Mars will continue to be launched regularly and robotics will be an enabling technology for most of these missions.

Other planetary bodies in the solar system are also targeted for planetary exploration missions in the near future: the Moon, Mercury and Venus are all serious candidates as are some of the moons of the outer planets (Europa and Titan) and the asteroid belt. Private companies are now preparing exploration missions to various places in the solar system such as the Moon and Near-Earth Asteroids. This will pave the way to the commercial exploitation of space resources.

In the long term, human planetary exploration missions to the Moon and Mars will become a reality. Robots will certainly be required in the early phases of these programs to prepare for the arrival of astronauts and be required to assist during the operation phases. Such missions would marry the expertise developed by Canada on planetary exploration missions to that acquired through human space flight activities such as the shuttle and Space Station programs. The robotics and automation industry in Canada must prepare itself to embark upon these future missions. Already, the CSA and MDRobotics co-funded in June 2001 a CA$2.5 M project to develop concepts for low-mass, low-power and low-cost manipulators for use in future planetary exploration missions and to conduct a feasibility study for the development of a Sample Preparation and Handling system based on Norcat's drilling technology. In parallel, a contract was awarded to Norcat to develop a prototype of a drill for planetary exploration. Optech also worked on a feasibility study for an Entry, Descent and Landing LIDAR. Recently, a CA$400,000 contract was awarded to MDR, to support the CSA in defining Canada's contribution to the NASA-led Mars Science Laboratory mission.

The ESA AURORA Exploration Program is currently the largest European effort for planetary exploration. The AURORA long-term exploration scenario considers major missions which will require advanced space robotics and automation support. These missions include a Mars Sample Return, a Moon Landing Mission, and a Robotic Outpost and Human Mission. CSA is a contributor to the AURORA program which opens up space robotics opportunities for the Canadian industry prepared to undertake these new technological challenges.

SPACE SERVICING

As demonstrated by the Shuttle Remote Manipulator System in the past two decades, the added capability and versatility of a payload handling system on an Orbital Vehicle are tremendous. Space servicing capabilities such as precision payload deployment and retrieval, on-orbit construction, EVA support, on-orbit checkout and payload repair have already been performed. Such servicing capabilities will be required for future generations of Reusable Launch and Space Vehicles.

Given the commercial nature of future Space Servicing applications, it is anticipated that the future on-orbit robotics systems will require higher operational efficiency in an increasingly unstructured work environment. Furthermore, on many occasions, spacecrafts bearing robotic elements will be unmanned. This will require technologies in autonomous and semi-autonomous operations with as little human-in-the-loop intervention as possible, adaptive robotics interfaces to handle uncooperative payloads and object recognition vision systems. All these would lead to lower cost of operations for any commercial venture. Effective and user-friendly simulation tools will be needed for the system design and operation to reduce the cost and risks.

In the last two decades, there has been a strong interest in servicing satellites in space. Unfortunately, mainly due to economic reasons, in particular, launching costs, satellites are still not serviced in space, but simply replaced when they become unusable. However, many countries are reconsidering this possibility and are putting together frameworks that would likely permit servicing satellites at a lower cost than replacing them. The time is now ripe for the introduction of remote manipulation technology in space and modern spacecraft are now designed to be serviceable in space.

On-orbit servicing and assembly is now on the agenda of the major space agencies. The German Aerospace Center (DLR) and the CSA are organizing the first bilateral Workshop on On-Orbit Servicing of Space Infrastructure Elements via Automation & Robotics Technologies in November 2002 in Germany. The workshop will address three major areas: technical developments to provide the means for unmanned on-orbit servicing of spacecraft, market and commercialization questions, and future programmatic orientation of agencies and industries. The goal of the workshop is to discuss the on-orbit servicing as a concept for new satellite development. Therefore both representatives from the robotic industry and from the satellites community are expected to participate in this event. This is clearly becoming a new approach in satellite and on-orbit structure development.

There is an increasing interest of the United States Air Force (USAF) in space servicing, demonstrated by their Orbital Express Program funded by the U.S. Defense Advanced Research Projects Agency, (DARPA). Within this program, systems will be developed to demonstrate autonomous techniques for on-orbit re-supplying, upgrading, refuelling and reconfigurating of satellites that could support a broad range of future US national security and commercial space programs.

Since space servicing is very likely to become a viable commercial sector for them, Canadian companies have already invested and proposed concepts that are part of the second phase of this program. In May 2002, MDRobotics partnered with Boeing in the development of robotics systems for the “Orbital Express” program. MDA will provide the robotics system to capture satellites and perform servicing, a ground segment to monitor and control the robotic operations, and all ORU containers and interfaces that will become standard on future missions. The total value of this effort could be as much as CA$12 M and is scheduled for launch in 2006.

THE SPACE-BASED/TERRESTRIAL ROBOTICS RELATIONSHIP

According to the World Robotics 2001 survey published by the United Nations Economics Commission for Europe in cooperation with the International Federation of Robotics, the total stock of operational industrial robots worldwide in 2000 was estimated at 750,000 units, of which 389,000 were in Japan, 198,000 were in the European Union and 90,000 were in North America. In spite of the recession in the first half year 2001, robot investments continue to boom in Europe, showing an increase of 11% over the same period in 2000. However, robot investments in North America fell by as much as 28% and by 10% in Asia mainly because of falling demand from the electronics and telecommunication-equipment industry.

Of the total number of service robots for professional use installed up to the end of 2000, underwater robots accounted for 29%. Demolition robots accounted for 22% and medical robots held 15% of the market share. Laboratory robots had a share of 10% while agriculture robots, mainly robot milking systems, made up 6%. These trends are expected to continue. In the period 2000 – 2003, the stock of service (industrial plus domestic) robots is expected to increase dramatically by 49,000 units. Service robots for professional use are to be found mainly in the medical and underwater sectors, which have 40% of the market respectively.

Once again, as indicated in the Global Trends 2001 publication, with the lull in the demand for application of technological advances in robotics and automation to space-based activities, and the boom in the terrestrial robotics market, it would be worthwhile for space robotics companies to expend efforts in applying existing and new (in the short-term) technologies to terrestrial applications. While not all space-based and terrestrial sectors share the same requirements for robotics and automation products, there are some key areas that could benefit from increased cooperation between the two sectors. These include:

- simulation technology
- mining
- waste remediation

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- operator training
- agriculture, and
- medicine.

In 2001, the relationship between the space-based and terrestrial robotics sectors in Canada was weak, but at least began to be exploited, more significantly than in 2000. There should be a much more concerted effort to encourage and facilitate joint discussion and activity between the two sectors. Some spin-offs from the robotic technologies developed for space led to the development of new robots for use in underground mines, in the operating room and in remote handling of hazardous materials. Some examples, although not exhaustive, are listed below.

The field of surgical robotics represents a new, long-term business opportunity to develop spin-offs of space technology. MDRobotics’ neurosurgery robot is an excellent example of Government investments’ spin-offs through the Canadian Space Agency in the design of leading-edge space robotics technologies. In March 2002, MDA signed a CA$6 M contract with the University of Calgary to develop an advanced robotic device for use in complex neurosurgical procedures. The contract is part of a CA$25 M robotic program funded by Western Economic Diversification Canada, the Seaman Family of Calgary, as well as with additional private funding. A team of MDA engineers is working with surgeons from the Seaman Family MR Research Centre to create the “neuroArm”, an advanced robotic system that will enhance the quality, accuracy, and efficiency of neurosurgical procedures. The robotic system will consist of two robotic arms, each with at least 6 degrees of freedom, and a third arm equipped with two cameras providing 3-D stereoscopic views. The system will function under the direct control of a surgeon at the robotic workstation who will have a virtual sense of touch.

On the mining technology development side, Canada has long been a leader in mining technology development. Developing technology for Mars exploration will allow Canada to maintain its international reputation and status as the world leader in space robotics. In parallel, the technologies under development will enhance and further enable the Canadian mining exploration industry to remain globally competitive. MDA has acquired the assets of Automated Mining Systems (AMS) of Aurora, Ontario, a supplier of electronic products designed to enable robotic operation of underground mining equipment. AMS has considerable expertise in underground mining tele-robotic systems and focuses exclusively on the business of mine automation, specifically in the supply of systems for remote operation (from the surface) of underground mobile production equipment. This acquisition brings MDA’s robotics and software technology together with AMS’ experience, customers, and product, to create a business opportunity in the mining industry.

NORCAT, the Northern Centre for Advanced Technology Inc. demonstrated Canadian drilling technology that could be used in a future mission to collect samples on Mars. Not only has NORCAT developed a new robotics mining technology, which will allow for safer operations underground it has gone further by pioneering a drilling platform for Mars exploration. NORCAT is a not-for-profit, non-share corporation formed in partnership with Cambrian College of Applied Arts and Technology in Sudbury, Ontario. NORCAT assists the Province’s forestry, mining and

mineral, and northern construction sectors by providing a single access point to companies and entrepreneurs for training, technology transfer, and product development. Currently, NORCAT is conducting a feasibility study for the Canadian Space Agency on how Canadian expertise in mining could play a role in exploring the red planet.

R&D CONTINUES

The Space Technology branch of the Canadian Space Agency and other Canadian companies are currently involved in projects intended to open new opportunities for space robotics. Active research is currently being pursued in the following areas:

- Vision Systems for Space
- Ground Control of Space Robot
- SPDM Task Verification Facility
- Advanced Design for Robotic Systems
- Advanced Simulation Tools
- Activities in planetary exploration.

Through the Strategic Technologies Development Program (STDP), CSA is looking at co-managing technology development projects in Robotics and Automation for future space applications and for spinning-off these technologies to terrestrial applications. CSA is also supporting new technology development through internal R&D, matrix support to other sectors, small feasibility study contracts and collaboration with companies.

The technology thrusts and priorities currently under consideration for future automation and robotics activities are provided in FIGURE A.

WHAT TO EXPECT IN THE NEXT FEW YEARS

NEAR TERM

Canada has been successful in capturing a fair market share of the world's space robotics and automation activities. Even with current projections suggesting that demand for space robotics products and services will increase in the near future, it is relatively difficult to forecast the future market for the space robotics and automation industry's products and services.

The focus for robotics and automation technologies for space applications in the near future is on R&D in the areas identified in Figure A and projects associated with MSS operation and evolution (including Ground Facilities), Planetary Exploration, and Space Servicing.

According to the Space Technology Roadmap[6] currently being developed by CSA, the efficiency of conducting operations of the MSS will by 2010 have been increased by controlling many operations from the ground. The MSS will be equipped with dextrous end effectors to assist operators during EVAs and artificial vision will help provide some amount of autonomy. There will be an increasing emphasis placed on the development of technologies associated with the operations of space-based robotic systems (simulation for mission planning and operator/ground support training, tele-operation, autonomous operation, etc.) as more robotic systems are placed in space and the demand on their capabilities and services increases. This is particularly true in the context of the ISS, where

[6] Canadian Space Agency, Space Technology Roadmap Document, Canadian Space Agency, Space Technologies Report, October 2002.

WHAT TO EXPECT
IN THE NEXT FEW YEARS

FIGURE A

PRIORITY AUTOMATION AND ROBOTICS TECHNOLOGIES

Space Servicing (Robotics Systems for Reusable Space and Launch Vehicles)	• Capture & Docking Mechanisms, End Effectors • Docking Simulation/Emulation & Control • Vision System • Autonomous Operations
Small Robotic Arm for Future Missions (i.e. Mars Exploration)	• Advanced Small Robot Arm Design • Autonomous Operation
Mobile Servicing System (MSS) Evolution	• Ground Control of space-based assets; • Force/Moment Control;
Ground Support Facilities	• Real-Time Simulation • Contact Dynamics Simulation • Control for Hardware-in-the-Loop Simulation

serious discussions regarding the reduction of crew size due to budgetary constraints will drive the need for more autonomous and tele-operated robotic activities at an increased frequency.

The same report also indicates that robots will be used to collect samples on the surface of Mars. They will be used to perform in-situ analyses of the properties of the soil, atmosphere, radiation environment, etc. Operations will be planned by a team of operators located on Earth and executed autonomously by the robots located on the remote planet. Both planetary robotic applications and orbital robotic applications will operate semi-autonomously under supervised control from a ground-based operator.

Satellite servicing will become increasingly important to the space industry, especially as the costs for satellite servicing and launching decrease over time and as the number of satellites in orbit steadily increases. This is an area where investment in the development of related robotics and automation technologies (such as vision sensors, general automated rendezvous and docking, simulation, and tele-robotic technologies) would be liable to produce a sustainable commercial benefit if approached strategically and managed properly.

The development of overall robotic systems for solar system exploration would be a high-risk venture in terms of potential commercial benefit. While appealing to the imagination and to the public in general, obstacles such as cutting-edge international competition, few actual solar system exploration missions, and little experience in the development and operation of these types of systems, place Canada in a position where it would have difficulty competing in this small market. A reasonable approach to maintaining an active role in solar system exploration/exploitation missions would be to capitalize on existing niche technologies (vision sensors, simulation, tele-operation) for providing the robotic sub-systems or operations technologies. But that does not exclude the potential for Canada to capture a sizeable part of the action; it is possible to conceive of a Canadian robot performing a mission on a remote planet as a reality.

LONG TERM

As predicted in Global Trends 2001, in the longer term, the bulk of robotic and automation products will be required for satellite servicing, solar system exploration/exploitation, and assembly of large, complex structures (manned bases, mining complexes, space electrical power systems, etc.) in space and on the lunar or martian surfaces. While satellite servicing and solar system exploration/exploitation activities are currently being pursued with current technologies and some development of new technologies, the assembly of large structures in space is an effort that requires – and will therefore drive – major advances in robotics and automation technology.

The paragraphs below are excerpts from the CSA Space Technology Roadmap[6], presenting a vision of the potential future of space robotics and automation. However, it is worth noting that at present there are no concrete missions planned for most of these scenarios.

Let's consider...
Around 2010-2020, it is expected that orbital spacecraft (or a constellation of spacecrafts) will perform Synthetic Aperture Radar imaging of the Martian subsurface using ground-penetrating radar. During the same period, orbiting spacecraft will perform high spatial resolution, high spectral resolution, hyperspectral imaging of the surface of Mars. Scientists will then have a detailed mineralogical map of the surface of Mars and could perform site selection for future missions with a high degree of confidence. Infrastructures to mine and to process resources will be planned and implemented to generate fuel, metals, oxygen and water.

By 2015-2020, an optical communication infrastructure for deep space missions would be put in place. Deep-space probes would communicate with the ground through Earth-orbiting relays encoding command, telemetry and data streams on a laser beam. This would allow a significant increase in the transmission data rate and support for the transfer of larger amounts of information.

Beyond 2020, colonies of robots would work together towards various space applications (on-orbit construction of spacecrafts and large orbiting structures). Automatic extraction and processing plants would exploit resources on near-Earth asteroids and comets as well as on planets being explored by astronauts. Robots will be essential assistants to astronauts in their EVAs. These applications would require a very high level of robot autonomy as well as the capability to self-repair and to re-organise themselves automatically. Networks of robotic explorers would travel kilometres away from the lander and have the capability to operate on mission objectives and to plan operations locally thereby maximizing the scientific return. Advanced mobility concepts would be used to increase the coverage of robotic explorers: large powerful rovers carrying smaller specialized rovers that could walk over rough terrain and rappel down cliffs. To extend their geographical reach, mobile robots would be combined with aerobots and have the capability to fly to geologically diverse locations on Mars.

Beyond 2020, commercial ventures will be prospecting and extracting natural resources in-situ on celestial bodies. In-situ resource utilisation will have started locally on the planets being explored, but also on near-Earth asteroids in search of water for usage in space and possibly precious metals for use on Earth. Space manufacturing plants will produce simple structures for assembly of spacecrafts to continue further exploration activities and create economic value added activities in space.

Around 2030-2040, Mars will now be the stage of manned missions. Robots will have prepared the arrival of humans to Mars by assembling habitats and extracting from the Martian soil and atmosphere, the oxygen and water for life support systems as well as the fuel necessary for the return trip. Robots will be used as sidekicks to astronauts to assist them in the conduct of scientific experiments on the surface of Mars. They will also be used as vehicles to transport the astronauts and to provide specialized instruments and tools. They will operate autonomously based on voice commands from astronauts.

TECHNOLOGY REQUIREMENTS

The technology requirements for Canada to meet the near and long term predictions as presented above are summarized in FIGURE B on page 86.

CONCLUSIONS

The years 2001 and 2002 were marked by the successful provisioning of the Canadarm2 system including the SSRMS and the Mobile Base System, which together act as a sophisticated robotic system critical to the assembly, maintenance and servicing of the International Space Station. This system, representing some of the most advanced robotics in the world, has reaffirmed Canada's reputation as a leader in robotics technology and now gives us the opportunity to consolidate our expertise and to contemplate new challenges.

Also noticeable in 2001-2002, was the rapprochement between the space-based and terrestrial robotics sectors in Canada. It is still a timid tie between the two sectors, but certainly stronger than in previous years. Some spin-offs from the robotic technologies developed for space have led to the development of new robots for use in underground mines, in the operating room and in remote handling of hazardous materials. There should be a much more concerted effort to encourage and facilitate joint discussion and activity between the two sectors.

CONCLUSIONS

At the dawn of the new millennium, the use of robotics technology in space is still at its infancy. Space robots are extremely expensive to design, built and operate. A real breakthrough in the utilization of space relies mainly on the reduction of costs associated with these systems and on advances in inexpensive reliable space transportation from Earth. This can only be achieved by continuous research, development and improvement of new technologies in space robotics.

This is a crucial time in Canada for robotics in space and automation. The International Space Station is being built and space robotics will play a major role for assembly, maintenance and scientific payload manipulation. The exploration of planets and their moons, asteroids, and comets commands more and more our attention. Space servicing of satellites and space construction of large structures present new opportunities. The focus for robotics and automation technologies for space applications in the near and medium term is on R&D and projects associated with MSS operation and evolution (including Ground Facilities), Planetary Exploration, and Space Servicing.

The CSA, along with Canada's space industry, must continue to carry out extensive R&D in space robotics and automation as it anticipates a growing presence of Canadian technologies that go beyond classical manipulator applications. Continued investment by CSA and the space industry in cutting edge technology development reinforces Canada's leadership and innovation in space robotics, and opens up growing opportunities in commercial markets requiring this advanced technology. It will prepare Canada to play a key role in international missions as the world space community focuses its attention on the exploration of Mars and other targets in our solar system.

The list of actions that the Canadian Government and Canadian industry need to undertake in the near-term were outlined in Global Trends 2001. They are reinforced here as still applicable:

1. Effectively manage resources (human, financial, and facility) during the current lull in the application of space robotics and automation technologies.
2. Maximize utilization of current Canadian technology (MSS, robotic simulations, tele-operation, ground infrastructure, etc.) to continue to underscore the effectiveness and importance of Canadian capabilities in the area of space robotics and automation.
3. Prepare niche technologies for Canada to apply in the future.
4. Pave the way for these niche technologies to be used profitably in terrestrial applications.
5. Ensure that Canada is at the international forefront in providing these niche technologies.

The development of a high-level strategy for space robotics and automation in Canada is critical to accomplish these actions. Canada has attained a good international reputation in the space robotics and automation industry but will not be able to take advantage of the technical advances it has made or the human resources it has developed, and will definitely not be able to maintain the forefront in space robotics without a solid strategy for the future. The development and implementation of a high level strategic plan should be led by the CSA in conjunction with government agencies, industry and academia and be geared towards quick implementation.

The Space Robotics and Automation strategy for Canada should encompass R&D areas that will provide the greatest benefit to both space and terrestrial applications, space and terrestrial robotics industries relationships, involvement of academia and plans for demonstrating Canadian innovation utilizing current resources (human and facility).

Acknowledgements
The author would like to acknowledge the contribution and support from Drs. Jean-Claude Piedboeuf and Erick Dupuis of the CSA Space Technologies group, as well as Dr. Michael Stieber and Mr. Eric White, of the CSA, Space Systems group for their participation in the preparation of this chapter.

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FIGURE B

TECHNOLOGY REQUIREMENTS

	0-10 years	10-20 years	20-30 years	30 years +
Miniaturization		• Micro-robots • Miniaturized sampling systems		
Sensors and Data Processing	• Artificial vision for unstructured environments interesting features	• Autonomous recognition of scientifically • Global localization on planetary Surface • High sensitivity optical detectors • High power solid-state laser sources	• On-board Remote Sensing Data Processing	
Spacecraft/ Space Exploration Vehicle Technologies	• Mechanisms Resistant to Planetary Environments • Planetary Protection Methodologies	• High-precision pointing (attitude control) • Formation Flying	• High-Performance, Radiation-tolerant Electronics	• Robotically serviceable systems
Robotics	• High payload/ mass ratio manipulators • Sample Handling and Processing Systems • Subsurface sampling/Drill • Wheeled mobile robots	• Alternative mobility concepts • Aerobots extraction	• Heavy and Long Duty Mechanisms • Drilling, resource end-effectors	• Human-friendly robotics • Dextrous

CONCLUSIONS

TECHNOLOGY REQUIREMENTS (continued)

	0-10 years	10-20 years	20-30 years	30 years +
High-Speed Data Communication		• Optical Inter-satellite and Broadband Deep-space Communication Links • High-speed modulator-demodulator (with coding) • Hyperspectral Data Compression Techniques		
Intelligent Systems	• Ground control with supervised autonomy • Navigation in unknown terrain	• Network robotics/ multi-agent collaboration • Resource sharing – Sensor Fusion • Autonomous operations planning and navigation	• Distributed Processing between Spacecrafts • Spacecraft Networking • Self-diagnostics • Fault-tolerant systems and repair	• Human-Robot Cooperation
Structures		• Very Large Membrane Antennas		
Innovative Technologies		• Alternate power sources	• In-Situ Resource Utilization/ Transformation • Space Manufacturing • Magnetic Propulsion	• Radiation Protection for Astronauts during Deep Space Missions

SATELLITE NAVIGATION

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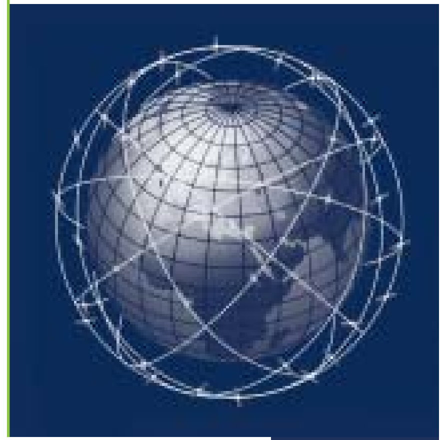
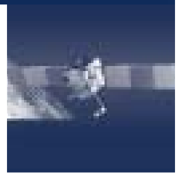


Prepared by:

Mark Burbidge,

External Relations



The 2002 chapter on satellite navigation provides an overview of the Global Navigation Satellite System (GNSS) sector, market estimates and drivers, headline news, the evolution of the satellite systems, and what to expect in the next few years. It is designed to provide Canadian industry with strategic and timely information on a sector that continues to expand in terms of revenues, technology advancements and converging applications.

INTRODUCTION

To cite a leading expert in the field: "Over the past 25 years, GPS has moved from a purely military satellite navigation system to an indispensable positioning and timing tool for hundreds of civilian scientific, engineering, navigation and positioning applications," adding that "GPS is now poised to play a leading role in the emerging *info-mobility* society[1]."

This chapter is divided into four sections, each intended to provide strategic market-oriented information for Canadian industry – the main stakeholder. Section One addresses market characteristics (trends, drivers and restraints) starting with the overall market and moving into the various SatNav fields – land, aviation, maritime, military and timing. Section Two lists newsworthy developments in the SatNav sector, with a particular focus on headlines involving Canadian companies. Section Three provides details on each of the global satellite navigation systems (GPS, GLONASS, Beidou and Galileo), key developments and potential opportunities. Finally, the chapter concludes with a snapshot of what to expect in the short and medium future.

For the most part, detailed technical information is avoided, although certain specifications on satellite navigation systems are provided as they may pertain to market and technology development issues. Readers are invited to refer to the footnoted sources for elaboration on technical, as well as political issues[2].

MARKET CHARACTERISTICS

The GNSS market remains strong as geospatial technologies become increasingly mature, converged, and integrated into conventional technologies (see FIGURE A). While complicating the life of market analysts, the technology convergence phenomenon translates into new products, value-added services and business models involving traditional and non-traditional users.

From a business perspective, the increased accuracy in the GPS signal, made possible by the U.S. decision to remove the Selective Availability (S/A) in May 2000[3], has helped to transform "P" for positioning into "P" for profit. Advancements to satellite-based augmentation systems are also improving the accuracy and ensuring the integrity of signals coming from GPS satellites.

In December 2001, (ABI) Allied Business Intelligence released a report entitled "GPS World Markets 2002: Prospects for Satellite Navigation and Locator Applications," in which they forecast an increasing role for GPS in what they termed the new "alert" society. The report states that one of the most important emerging GPS initiatives is the wireless E911 mandate. In addition, other GPS-based "people-tracking" devices are gaining in popularity, with technology as simple as a pendant tucked into a child's schoolbag or worn on an older person's wrist[4].

Similar to most estimates, ABI indicated that this growth trend will continue to move in a sharply upward direction, particularly in the area of higher volume consumer products including: asset tracking/fleet management, in-vehicle navigation, recreational vehicles and land markets.

Driving factors include:

- The integration into the cellular phone market, with E911 availability required by the U.S. Federal Communications Commission (FCC) to be in the hands of 95 percent of wireless users by the end of 2005, will bring GPS closer to the average citizen over the course of the next few years.
- GPS-enabled timing devices, used to mark and coordinate numerous functions, are being employed to an increasing degree by e-commerce and internet providers in addition to telecommunications and entertainment companies to manage broadcasts and "handoffs".
- Progress in Ground-based Augmentation Systems (GBASs) and Space-based Augmentation Systems (SBASs): LAAS and WAAS in the U.S.
- A heightened focus on military and national security operations, which led to the inception of GPS from the outset, are poised to drive positioning technologies to a new level due in large part to the post 9/11 market realities.

Although estimates fluctuate between analysts, there is a consistently rosy portrait of the GNSS market in the years to come:

- Frost & Sullivan estimated the North American GPS market generated US$3.19 B in revenues in 2001, an increase of 27% over 2000 which registered US$2.5 B in revenues[5]. They project revenues to reach US$7.4 B by 2006, compared to their estimate of US$4.6 B for 2006 just one year ago (see FIGURE B).
- Similar returns are recorded by Merryll Lynch who estimates that the GPS industry will rise to US$7 B by 2007, at an annual growth rate of 14%[6].
- ABI points out that although the U.S. currently dominates the GPS hardware and software market, with a 65% market share, non-U.S. producers will further capture a larger portion of the lucrative market and may account for half of the equipment by 2005. According to ABI analyst Bill Britton, the world market for GPS equipment will stand at US$34 B by 2006 and as much as US$41 B should the world economies recover from their current slump. The U.S. and Japan will continue their leadership roles in system development and manufacturing[7].

- The Office of Commercialisation of the U.S. State Department indicates a weakening dominance by U.S. suppliers (see FIGURE C). According to their reports, the U.S. held a 65% share of the total GPS market in 1996, down to 52% in 2001 and a further decline to 50% by 2002[8].
- ESA reported similarly strong growth in the GNSS marketplace: in 1998, the GPS receiver market alone was estimated at US$2 B with growth expectations as high as US$30 B by 2005[9].

1 Professor Vidal Ashkenazi, CEO of Nottingham Scientific Ltd. speaking at the Institute of Navigation (ION) GPS 2001 Conference, Salt Lake City, U.S.A. Reported in ION Newsletter (Vol. 11, No. 3, Fall 2001).

2 The author would like to thank those individuals who took the time to review and provide feedback on this chapter, notably Stéphane Corbin (CSA), Ray Guillemette (CSA) and Prof. Richard B. Langley (Department of Geodesy and Geomatics Engineering at the University of New Brunswick).

3 S/A is the intentional degradation of the civilian signal. It had been implemented by the U.S. in 1990 on all GPS Block 2 satellites, and had actually been set to zero in September 1990 [S/A was off between about August 10, 1990 and July 1, 1991] in support of Operation Desert Storm (not coincidentally the same time Europe saw the need for it to have its own global satellite navigation system). Turning off the S/A increased accuracy by as much as ten-fold and beyond.

4 Cited in "Terrorism Attacks Accelerate Interest in GPS Applications", SpaceDaily Web Site, 11 Dec. 2001. http://www.spacedaily.com/news/gps-01s.html

5 Market estimates sourced from Frost & Sullivan "North American GPS Markets" (© 2002).

6 Merryll Lynch Report; 9 April 2001.

7 "Terrorism Attacks Accelerate Interest in GPS Applications", ibid.

8 "Trends in Space Commerce", Office of Space Commercialisation, U.S. Department of Commerce. Prepared by Futron Corporation (©2001).

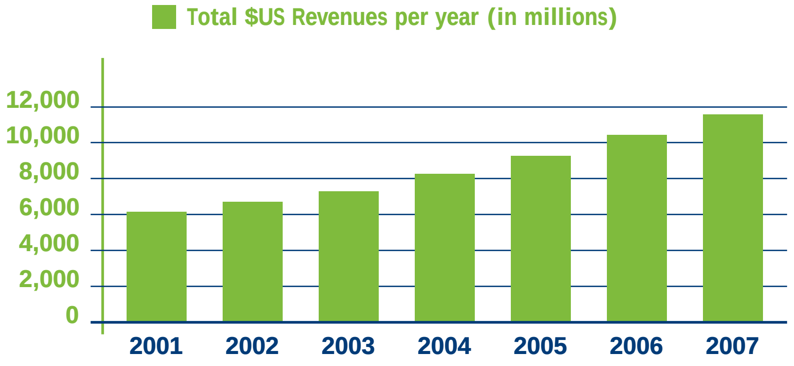
9 "Satellite Navigation and Location Systems, in: Space Benefits for Humanity in the 21st Century."European Space Agency background papers at UNISPACE III; 1999; pp. 101-104.

10 Trends in Space Commerce, Office of Space Commercialization, Department of Commerce, USA © 2001/2

11 "Availability Enables New Business Models in Tracking and Telematics Markets" by Ron Stearns, Senior Strategic Analyst, Frost & Sullivan (May 2002)

FIGURE A

GLOBAL REVENUES OF GPS EQUIPMENT AND SERVICES: 2001-2007



Source: Int'l Space Business Council© 2002

LAND APPLICATIONS

Among the main GPS markets (see FIGURE D), the Land market remains far ahead of the pack with close to 75% of total GPS market share in 2000[10]. The North American Land-based revenues grew 30% in 2001 with US$2.28 B in revenues. Within the land applications group, asset tracking, fleet management and in-vehicle navigation are among the largest GPS application markets in North America, with combined forecasted 2002 revenues of US$1.9 B. These two markets are expected to account for close to 60% of all GPS revenues in 2008, up from the current 50% in 2002[11].

L-Commerce

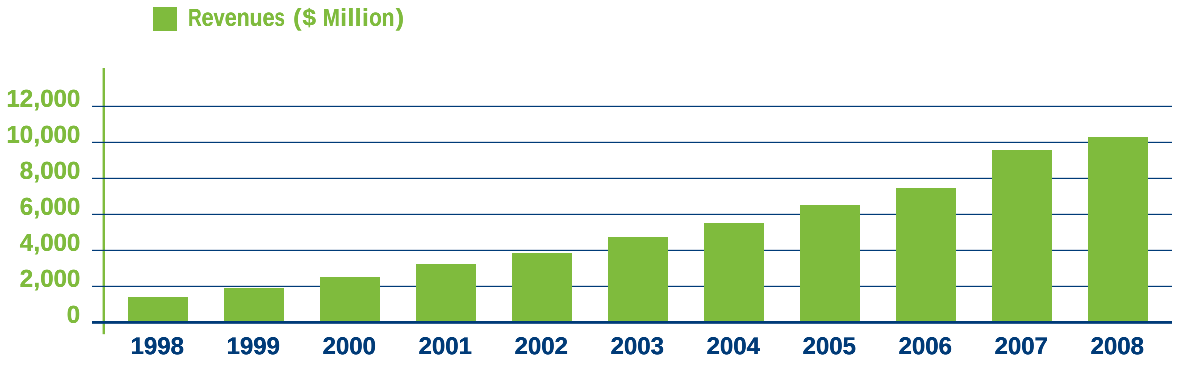
L-commerce (Location-based mobile commerce) is also well "positioned" to bring GPS-enabled technologies closer to consumers on the immediate horizon. In fact, some industry observers predict that it will exceed M-commerce (accessing the Internet using the cellular phone) in overall market presence. While the issue of Big Brother remains the subject of heated debate between consumer rights and privacy advocates, location technology vendors and wireless carriers, the technologies are ramping up to market.

In-Vehicle Navigation

Telematics – GPS/wireless-enabled location-specific security, information, productivity, and in-vehicle entertainment services to drivers and passengers – is projected to grow into an US$8 B global market by 2004. Some have even predicted that the sector

FIGURE B

NORTH AMERICAN GPS MARKET REVENUE FORECASTS: 1998-2008



Source: Frost & Sullivan© 2002

may be among the main driving forces behind overall economic recovery, given the forces of the automotive and communications industries and the converging of the two under Telematics[12]. Analysts point to the fact that only 1.5% of U.S. cars (typically luxury models) are equipped with vehicle navigation systems in 2002, compared with 7% in Europe and 25% in Japan.

In a recent Toronto Star article, Chet Huber, President of OnStar, a wholly-owned subsidiary of General Motors and a leading telematics provider in the U.S., explained that the company has seen a 250% increase in the subscriber base in 2001 alone, and anticipates ending the calendar year 2001 with almost two million subscribers[13]."

Still, recent news has taken some of the wind out of high-sailing expectations. In June 2002, Ford pulled out of Wingcast LLC, its joint venture with Qualcomm Inc. to produce telematics services in vehicles, due to what the company viewed as changing technology and changing customer desires. The President and CEO of Wingcast, Harel Kodesh, told a conference audience that "telematics is not a get-rich-quick proposition[14]," a statement echoed by other market observers; "The car companies envision that they would own and operate telematic services and bring in a huge stream of money… I don't know what will happen in the future… I'm also sure that while car companies may eventually make big profits on telematics, it won't be easy[15]."

12 "Will Telematics Be the Springboard to Recovery?" By David Bursky in Electronic Design, 24 June 2002, p. 20.

13 "Navigating the future of telematics: Canadian buyers slow to accept high-tech communications", by Max Wickens, Toronto Star, December 2001.

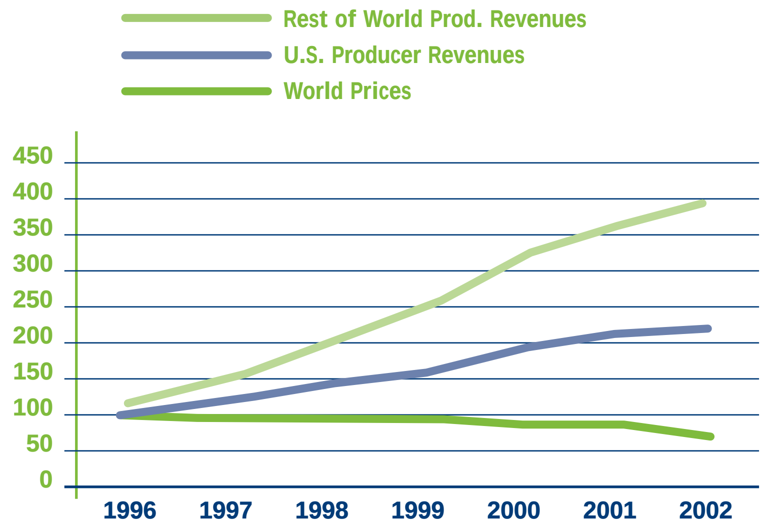
14 Quoted in "What is Automotive Telematics and Why Is It Sick?" by Dan Keegan on www. drivers.com (17 June 2002)

15 "Too Much Car Gadgetry?" by Jerry Flint at Forbes.com; 28 May 2002 (http://www.forbes.com/2002/05/28/0528flint.html)

16 "Navigating the future of telematics", ibid.

FIGURE C

GPS MARKET TRENDS: 1996-2002



Source: U.S. Dept. of Commerce© 2002

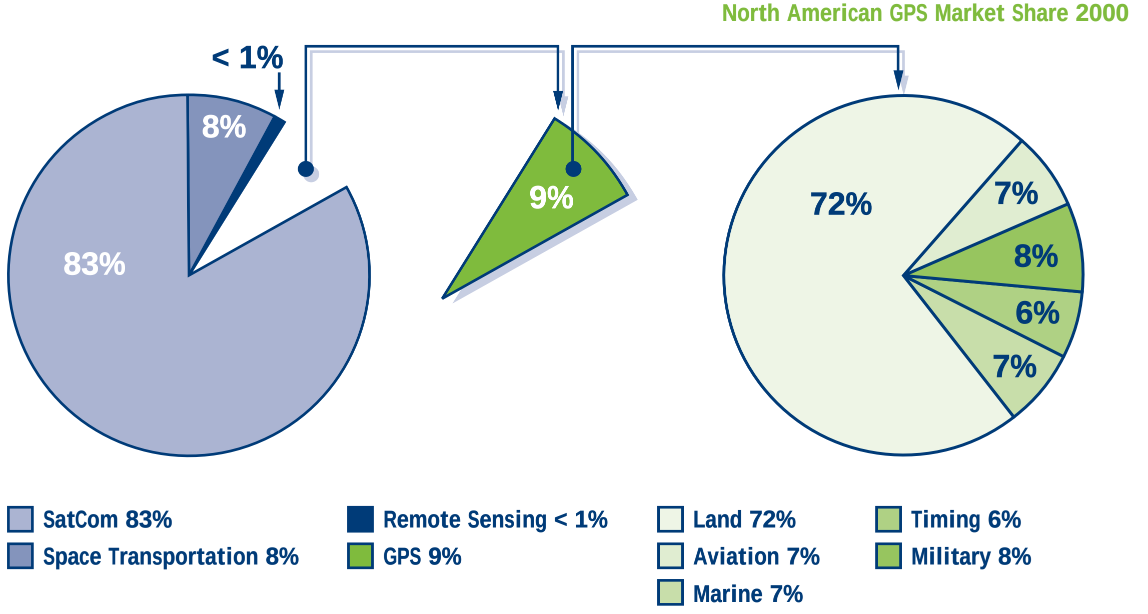
The situation is similar in Canada, Canadians being more conservative in terms of early market adoption of technology gadgetry. One reason forwarded by a market observer is that "perhaps [Canada's] road system is so simple that motorists have trouble getting lost. So they find it hard to justify spending CA$1,000 to CA$5,000 on an electronic navigation system when a few dollars will buy all the paper maps anyone could need to drive from sea to shining sea[16]." Bottom line, the article concludes, is that "carmakers aren't rushing to invest in navigational technology for the Canadian market, and Canadians aren't showing much interest, either. So it's likely to be a while before we see many cars with this equipment."

Drivers:

- Unrivalled land-based unit potential
- Affordable chip sets
- Integration into brand-name GPS-enabled products
- Miniaturization of GPS technologies
- Improved accuracy via DGPS (In Canada, it is referred to as the Canada-wide Differential GPS (CDGPS) Service, operated by the Government of British Columbia and sponsored by the Government of Canada, the ten Provinces, and the Territory of Nunavut; n.b. the Canadian Coast Guard also has a DGPS service, transmitted by terrestrial low and medium-frequency beacons. Also, various private sector companies offer services in Canada via terrestrial or satellite transmitters)

FIGURE D

GLOBAL SPACE SEGMENT REVENUE SHARE



Source: Global Segment: Trends in Space Commerce, Office of Space Commercialization, Department of Commerce, USA, 2001
North American Segment: Frost & Sullivan

17 see "GPS and Aviation Safety" in GPS World, 1 October 2001

Restraints:

- Advancements in GPS technologies face high levels of consumer ignorance
- High integration costs, notably in the automotive and asset tracking markets
- Slow pace of integration
- High costs of education and awareness initiatives
- In Canada, much of the country remains unmapped digitally and associated costs are prohibitive

AVIATION APPLICATIONS

The grotesque transformation of aircraft into weapons of mass destruction on September 11, 2001 heightened interest in how GPS could support airline safety and other issues related to national security. Among the priorities: applying GPS to regain control of an aircraft that has fallen into the wrong hands and to safely land the aircraft at the nearest suitable airport. Other considerations: equipping aircrafts with a "dead-man switch" that would allow the pilot to turn over navigational control to an on-board GPS-based autolanding system[17].

18 Canadian officials are examining the possibility of linking stations in Canada to the U.S. WAAS network using identical technologies to ensure seamless operations.

19 Frost & Sullivan (© 2002)

For any aircraft navigation system to function effectively using GPS, significant progress is still required in the ongoing field testing of the U.S. FAA's dual GPS-based navigational systems: the Wide Area Augmentation System (WAAS) that will enable aircraft to reach the so-called Category 1 decision point in an approach to an airport (to provide navigational accuracy to within 3.5 meters), and the Local Area Augmentation System (LAAS) that would enable aircraft to reach the ground in zero visibility, known as a Category 3B landing. The troubled WAAS program, the subject of much criticism, more studies and lengthy delays, is to be commissioned in late 2003 for precision navigation and landing, but a date for Category 1 operations is still unknown[18].

The arrival of GPS-enabled aviation is simply a question of time. GPS-enabled navigational initiatives will simply spur product development and thus revenue curves. On the whole, the North American GPS General Aviation market grew nearly 10% in 2001 with revenues of US$217.9 M[19]. Annual growth rates are forecast at close to 6%, with maximum future market revenues of US$323.8 M in 2006.

Drivers:

- GPS-enabled navigation initiatives spur product development
- Demand for GPS technologies to address aviation and national security issues
- Falling prices
- Gradual GPS data integration into avionic technologies and infrastructures

Restraints:

- Weak aviation market
- Costs of installation
- Slow pace of R&D and user adoption
- Unlikely adoption of GPS as sole navigation tool

MARINE MARKET

The GPS Marine Market, similar in size to the Aviation market, is awash with new products ranging from hand-held GPS/radio beacons to onboard marine positioning and navigation systems that provide impressive accuracy. The influx of new products continues to drive down prices while increasing use and consumer awareness – among the foremost constraints in the GPS marketplace. Frost & Sullivan noted an 11% growth in the N.A. GPS Marine market in 2001, at US$231 M, and forecasts a rise in revenues to US$417 M by 2008.

Drivers:

- Integration with other ship-board systems to spur growth
- DGPS infrastructure expansion ensures availability and accuracy
- Growth in recreational marine markets that use GPS technologies
- Hydrographic survey/mapping in continuing demand

Restraints:

- Low adoption rates for new GPS technologies
- Fixed number of water craft may hinder growth
- Price: marine handhelds can be more expensive than other recreational handhelds
- Low consumer awareness

MARKET CHARACTERISTICS

MILITARY MARKET

Underneath the world of civil GPS applications lies a system that began and remains a military space-based infrastructure designed to support warfighting activities. More than ever, advanced GPS-enabled weaponry is providing the military corps with the combative advantage in the field, for use in missile guidance to search and rescue of downed crews, to troop positioning.

The Gulf War in 1991 led military leaders to the realization that space-based systems provided an effective means of collecting and disseminating information to support command and control operations of frontline commanders. Not long after, military failures in Somalia further underscored the need for more advanced weaponry and equipment capable of pinpointing position and communicating movement. It resulted in a concerted effort, and increased budgets, among allied military leaders, particularly those in the U.S., to further integrate, operationalize – thus militarize – space systems into the battlefield.

When forces moved into Afghanistan in the campaign against Al Qaeda extremists, commanders and troops moved and communicated with a level of speed and precision simply unimaginable a decade earlier. One Marine general stated that, "[space]...made the big difference in this war. We used to measure our support with a calendar, and now we're using a stopwatch[20]." The testimonial was echoed by Peter B. Teets, Air Force undersecretary and director of the National Reconnaissance Office, who stated, "I'd have to say [GPS] is the single biggest contribution to the war. The very idea that a B-52 (Stratofortress) or a B-1 (Lancer) flying around at 50,000 feet altitude could provide close air support to troops on the ground is a remarkable thought. Even as recently as 10 years ago when we were involved in the Gulf War, such a thought would not have occurred."

Improvements, thus opportunities, are imminent. Gen. Ralph Eberhart, commander in chief of North American Aerospace Defense Command and U.S. Space Command, questioned at the February conference on National Defense Industrial Association's Science and Engineering Technology whether "[the U.S.]...realizes how very important GPS has been in this decade." In regards to improvements he said that "We're taking what's required and bettering it by half. That doesn't mean we're bettering bombs by half, but any errors that occur won't be due to GPS[21]."

As noted in a recent publication, "Most observers acknowledge that the military establishment as a whole lags far behind the commercial industry in the availability of state-of-the-art GPS receivers. The fielding of military Precise Positioning Service (PPS) receivers has improved recently, but equipping of U.S. and allied military forces with the new Selective Availability Anti-Spoofing Module (SAASM) hardware needs to be expedited[22]."

The increased role of space-based systems in battlefield management has translated into a robust GPS military market poised for growth. In 2001, the market was forecast at US$265 M with revenue growth of 22%. It is forecasted to rise to US$878 M by 2008. Driving this revenue growth are advancements in existing military GPS applications, and the R&D of next-generation systems.

20 "Milspace Comes of Age In Fighting Terror: Space takes center stage in combat operations and becomes a laboratory for military transformation", Aviation Week & Space Technology, 8 April 2002.

21 "US Space Commander Charts Future Course", SpaceDaily, 8 Feb. 2002, http://www.spacedaily.com/news/milspace-02d.html

22 "SAASM and Direct P(Y) Signal Acquisition", GPS World, July 2002, Vol. 13, No. 7.

23 A comprehensive overview of GPS military products and initiatives is outlined in " Guiding Weapons, Finding Soldiers" in GPS World, August 2002 Showcase issue, Vol. 13, No. 8.

Current and future GPS-related applications include[23]:

- Assisted-GPS for tactical indoor applications, e.g. in counter-terrorism
- Anti-submarine warfare
- Common grid (Military Grid Reference System/ US National Grid): facilitate its nationwide use for joint operations with civil emergency responders in homeland security environment
- Determination of remote locations by forward observers — e.g. by using field glasses equipped with GPS and laser telemeters — for determining enemy target coordinates, precision insertion and operation of special forces, etc.
- Electronically steered antennas
- Joint Stand-Off Weapon (JSOW, a glide or glide-boosted air-surface weapon).
- Land Warrior: a U.S. Army program that provides dismounted soldiers with up-to-date technology for wireless communications, navigation, and data sharing to improve battlefield situation awareness.
- Legacy maps: fixing inconsistencies between different maps
- M-code receiver development and testing
- Mine location, for safe passage or disposal
- Precision all-weather navigation of military ships, vehicles, and aircraft
- Pedestrian navigation
- Rapid mapping prior to military actions
- Remote control of unmanned land vehicles
- Selective Availability Anti-Spoofing Module (SAASM)
- Satellite orbit determination (future)
- Silent rendezvous
- Synchronization/orientation of communication/ relative navigation networks (EPLRS-Army, JTIDS-Navy/AF)
- Tracking radiosondes for weather forecasting and sea state determination
- Unmanned Aerial Vehicles (UAV) — e.g. Global Hawk

Drivers:

- Escalating reliance on GPS-enabled technologies
- GPS increasingly meeting military demands for location and targeting capabilities
- Increased rate of integration of GPS into battlefield managemenflt systems

Restraints:

- Uncertainty surrounding stable/growing military budgets
- High integration, installation and testing costs
- Challenging correlation between commercial off-the-shelf (COTS) equipment in military applications and purely military acquisitions, particularly longer-term supply arrangements.

TIMING MARKET

With timing so closely associated with money, it comes as no surprise that accuracy of the former influences one's control over the latter. GPS plays a critical role in ensuring such high levels of accuracy, and as many would agree, has become a crucial element of computing networks and the very networks driving time-sensitive financial markets.

GPS satellites continuously communicate position and time codes to earth reception stations. Positions are calculated by measuring the arrival times of signals from a formation of GPS satellites (ideally four or more satellites in view), thereby necessitating near precise timing data. To meet such requirements, the GPS control system's composite master clock (i.e., "paper clock") is kept within 1 microsecond of the U.S. Naval Observatory's Master Clock which is the official time-keeper for the U.S.

Block 2/2As each have four atomic clocks on board; Block 2Rs have only 3 clocks. Each clock is closely monitored by the U.S. Air Force Space Command at Schriever Air Force Base in Colorado[24] to determine the precise position of each satellite through the network of monitoring stations located around the world. They then compute and broadcast corrections to keep these clocks so accurate that they are almost always within 250 nanoseconds[25]. International clock comparisons are now routinely performed via GPS with accuracy on the order of 50 nanoseconds or better.

The need for precise timing accuracy has led to a growing industry of GPS equipment manufacturers working in a market forecast at US$197 M in 2001, reflecting 25% revenue growth[26]. Frost & Sullivan expect this segment to continue to grow within telecommunications markets, with new growth in e-commerce and internet service provider applications, where GPS timing signals are used to mark and coordinate a variety of functions.

Drivers:

- Regulation will increasingly require precise timing capabilities[27]
- Bandwidth expansion broadens potential number of users
- Falling costs – availability of signal providers enables affordable subscription use
- Technology convergence expected to expand services to the wireless marketplace

Restraints:

- Alternative options for timing: GPS-aided timing not always the first option
- Level of precision GPS can provide not always necessary
- High costs of integration, installation and training

MAJOR EVENTS OF 2001 AND EARLY 2002[28]

2001

August

THALES finalizes acquisition of SatNav firms Magellan and Navigation Solutions, an acquisition initially announced by Thales and Orbital Sciences on May 23, 2001.

PROFIT, The Magazine for Canadian Entrepreneurs, ranks SiGEM #1 of Canada's Fastest-Growing Young Companies and as Canada's "Hottest Start-up" based on revenue growth over two years: fiscal 2000 over fiscal 1998.

Release of The Volpe Report (Vulnerability Assessment of the Transportation Infrastructure.

24 In Canada, the Geodetic Survey Division, in conjunction with the Geological Survey of Canada, operates the Canadian Active Control System (CACS). It comprises a Master Active Control Station (MACS) and a network of 25 continuously operating GPS data acquisition stations, called Active Control Points (ACPs), which are distributed across the Canadian landmass and track all GPS satellites in view.

25 See http://www.gpsclock.com/gps/g2.html and http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=3123

26 Frost & Sullivan (© 2002).

27 see "GPS and the Legal Traceability of Time", GPS World, January 2001, Vol. 12, No. 1.

28 Particular focus was placed on news within Canadian GPS community.

Relying on the Global Positioning System) confirms that interference (unintentional and intentional) is a major concern, and that safety and economic risks associated with the loss or degradation of GPS signals have been underestimated.

September
Professor Elizabeth Cannon, Professor and NSERC/Petro-Canada Chair for Women in Science and Engineering (Prairie Region) at the University of Calgary receives the Johannes Kepler Award, considered the most prestigious in its field, for sustained and significant contributions to satellite-based navigation.

CSI Wireless receives prestigious Alberta Science and Technology (ASTech) for its "Outstanding Commercial Achievements", awarded to companies generating annual revenues of over CA$25 M.

SiGEM hails deal with RESPONSE Services Center for an in-vehicle system targeting cab owners and drivers, with the intent to increase safety.

October
Wireless providers miss deadline to begin implementing E-911 technology because the major national carriers said they aren't ready. The FCC agreed to tailor extensions for each of the six major cellular service providers under mandate to provide E-911 service.

NovAtel achieves a major milestone on the EGNOS RIMS-C receiver contract with the successful completion and approval of the Final Qualification Review (FQR). Following formal sign off of the FQR by THALES Avionics UK (RIMS-C contractor) and Alcatel Space Industries (EGNOS prime contractor), NovAtel ships the first batch of six production EGNOS RIMS-C receivers, to allow NovAtel to recognize CA$1.8 M in revenue.

PowerLOC Technologies, a subsidiary of Paradigm Advanced Technologies, sign an agreement with Distrel Spa for the distribution of its Destinator™ navigation system product throughout Europe.

November
ESA approves €550 M for Galileo at Ministerial Council Meeting. Canada announces intentions to invest €7.4 M.

EU Transport Ministers delay decision on Galileo, with notable holdouts by Germany and U.K. who want further study. Decision prompts the EU Heads of State to deliver consensus political support to Galileo at subsequent Laeken Summit. U.S. opposition mounts.

PriceWaterhouseCooper release business case on Galileo, forecasting total cost to develop and deploy Galileo as €3.4 B with a projected a benefit-to-cost ratio of 4.6 for the program from 2008 to 2020, generating close to €17.8 B in revenues.

SiGEM sells its wholly owned subsidiary, Auriga Communications, to Tait Europe, to allow SiGEM to focus efforts on achieving profitable growth from its existing taxi dispatch and telematics businesses.

NovAtel signs an agreement with BEELINE Technologies, of Fresno, California to supply the GPS and communications engine for precision agricultural guidance systems, positioning both companies to capture a significant share of this market.

MAJOR EVENTS
OF 2001 AND EARLY 2002

PowerLOC chosen by a large U.S. city to supply a turn-key specialized tracking system solution for a high security project which relates to the 9/11 terrorist attacks.

Daewoo Motor Co. launches "Dreamnet" in-vehicle information/navigation service for its vehicles, in collaboration with mobile communications giant Korea Telecom Freetel (KTF).

December
Russia starts restoring global satellite navigation system with launch of three Uragan GLONASS satellites.

SiGEM enters into distribution agreement with leading European distributor Broadband Technology to exclusively represent SiGEM's line of GPS and telematics products, including OEM receivers, antennas, and wireless tracking devices, in the UK and Ireland.

NovAtel and Raytheon sign contract for a long term, multi-phase development contract for a GPS receiver to be used in Raytheon's next generation satellite based landing system.

CMC Electronics selected by ACSS (Aviation Communication & Surveillance Systems) to supply GPS receivers for ACSS's new Traffic and Terrain Collision Avoidance System.

U.S Coast Guard contracts Raytheon ten years of engineering, technical, maintenance, and support services for the U.S. Nationwide Differential GPS, a contract valued at up to US$76 M.

ABI releases "GPS World Markets 2002: Prospects for Satellite Navigation and Locator Applications," that forecasts an increasing role for GPS in the new "alert" society.

In a new white paper, "Telematics Paradigm Shift: Industry Strategies Mature as Business Model Realities Sink In," The Strategis Group predicts that growth in the automotive telematics market will be catalyzed as auto companies and wireless operators partner to introduce more sophisticated hands-free voice solutions into cars.

NASA conducts groundbreaking research proving that GPS altimetry may be an inexpensive, effective tool to measure sea levels.

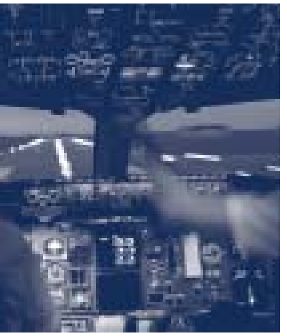
2002

January
U.S. Congress approves US$173 M for GPS satellite acquisition and US$78 M for GPS-3 modernization under 2002 Department of Defense Appropriations Act. US$181 M also allotted for space and control segment operations.

CSI Wireless unveils Asset-Link 100 Telematics Product - the first of what will soon be a family of innovative and cost-effective fleet-tracking, safety and security products.

NovAtel delivers an additional 12 WAAS receivers to Shenzhen Shenyuan Trading Company for use in the Chinese Satellite Navigation Augmentation System (SNAS). This order represents the first lot of receivers for Phase 2 of the Chinese SNAS program, and includes

29 See "Who's afraid of ultra wideband? An emerging wireless technology fights for its life" By Dan Briody in RedHerring (18 June 2002) http://www.redherring.com/insider/2002/0618/uwb061802.html



upgrades to mini-WAAS receivers previously delivered under Phase 1 in 2000. This latest sale has a value of US$1.3 M.

CMC Electronics launches a CA$56 M R&D initiative focusing on advanced vision systems for navigation, next generation aeronautical communications systems, and specialized GPS.

ePiNG tracking devices by SiGEM to be used by its reseller partner Synovia to provide a high-value tracking solution for school bus districts throughout North America.

February

Michael Gordon-Smith, a senior engineer specializing in air traffic management systems at CMC Electronics, receives the Volare Award from the Airline Avionics Institute. He was cited for his work on advancements in cockpit avionics systems, particularly in the application of state-of-the-art navigation systems to the real environment of airplane operators. His crowning achievement was his concept and architecture for a fully integrated, triple GPS/Flight Management System as the heart of the Boeing 747 "Classic" Cockpit Upgrade Program.

NovAtel appoints new president and CEO, Jonathan W. Ladd. The company also signs strategic co-operation agreement with Leica Geosystems on common development of new technologies for GPS and its advancement in the high-accuracy segment.

Trimble and ESRI form a strategic alliance to work on mobile Geographic Information System (GIS) solutions.

FCC permits the marketing and operation of certain types of products incorporating Ultra-wideband (UWB) yet protects GPS signals from intentional UWB emissions. Use of the devices must remain above 1.99 GHz or below 960 MHz, depending on the specific application. Opposition groups, composed of major wireless carriers, the U.S. DoD, satellite radio companies, and the GPS community, reiterate the argument that if UWB is allowed to operate as originally planned across spectrum used by the GPS and other authorized services, it could put the public at risk. Even so, the decision kept the door open for the UWB community to proceed with development: "We look at this as an excellent opportunity," expressed Jeffrey Belk of Qualcomm. Other possible benefactors are equipment makers that incorporate UWB chips into their new products, like cell phones[29]. General consensus is that considerable time will lapse before UWB reaches the market.

Germany approves €160 M for Galileo thereby setting the stage for favourable EU decision in March.

March

EU Transport Ministers approve the release of €450 M for Galileo, dismissing U.S. opposition.

SiGEM changes name to Mobile Knowledge.

Following The Volpe Report indicating that GPS is susceptible to unintentional disruption, U.S. Department of Transportation (DoT) responds with action plan to maintain the adequacy of backup GPS systems used for critical transportation applications.

Boeing receives approval from the U.S. Air Force to move forward with space vehicle production for the GPS 2F Modernization program.

Aerospace Corporation releases study on mitigating collision risks of decommissioned GPS satellites in orbit.

CSI Wireless launches Location-Sensing GPS-Enabled Wireless Phone.

Following the 9/11 attacks, Canadian Coast Guard (CCG) reconsiders decision to shut down aging Loran-C navigation system used by a dwindling number of mariners and pilots in favour of a single, more efficient GPS technology. The CCG, which spends CA$2 M annually to operate five Loran-C beacons in Canada, will again assess the long-term need for Loran-C in 2004.

May

CSI Wireless enters CA$6.5 M contract with AirIQ for commercial transport, rental vehicle fleets and service companies.

Zyfer releases "White Paper on Military GPS SAASM Technology," the new generation of military GPS navigation and timing functionality said to enhance the entire GPS infrastructure.

Scientists at NASA's Jet Propulsion Laboratory examine new, cost-effective GPS technology to monitor the Earth's atmosphere.

Lockheed Martin Missiles and Fire Control and the U.S. Army again successfully test the new Guided version of the Multiple Launch Rocket System (MLRS) rocket using GPS-aided guidance.

June

Ford Motor Co. pulls out of Wingcast LLC, its joint venture with Qualcomm Inc. to produce telematics services in vehicles.

NASA reports successful use of GPS for attitude, position and speed of the International Space Station.

Robert G. Bell, NATO assistant secretary general for defense support, states that NATO has not taken a position for or against Galileo, yet wants assurances that Galileo does not interfere with or impair NATO's access to the significant military advantages afforded NATO forces by GPS.

July

NovAtel awarded a contract by Raytheon Navigation Landing Systems for the next phase of development and qualification of LAAS receiver.

August

Researchers at the University of New Brunswick (UNB) launch GPS guidance software to steer giant port cranes manipulating shipping containers.

FAA awards NovAtel a contract to develop the next-generation WAAS receiver. The US$2.4 M contract covers receiver development and qualification work over a 21-month period and also includes an additional US$835,000 option for development of a new broadband WAAS antenna.

THE UNIVERSITY OF NEW BRUNSWICK: A SHOWCASE FOR GNSS R&D

The Department of Geodesy and Geomatics Engineering at the University of New Brunswick is one of Canada's leading centres for research in positioning and precision navigation using global navigation satellite systems (GNSS). The department has a long history of making important contributions in satellite-based positioning, stretching back to the early 1970s when it pioneered the use of the U.S. Navy Navigation Satellite System in geodetic studies. By 1980 or so, interest turned to the Global Positioning System even though only a few prototype satellites were in orbit at that time. Working with government agencies and industry, the department researchers tested some of the first commercially available GPS receivers and developed software for the planning, execution, and analysis of GPS surveys.

GPS research activity grew in the 1990s and into the new millennium with contributions in many application areas including hydrographic surveying, engineering and deformation surveys, geodetic positioning, aviation, machine control, augmentation systems such as WAAS and the Canadian Differential GPS Service, atmospheric science, and the use of GPS on low-Earth-orbiting spacecraft. The work in these areas was made possible, in part, through expertise in such topics as transatmospheric signal propagation, GPS signal bias and error mitigation through stochastic and functional modeling of the GPS observables, and the integration of GPS with other mensuration systems. Recently, the department inaugurated work on aspects of Europe's future Galileo system. UNB's targeted GNSS research is helping to provide accurate, reliable, and cost-effective positioning and navigation for Canadians and others around the world.

UNB's ongoing work is also geared towards the business end of the spectrum, namely to push GNSS technology further into practical – and profitable – commercial applications. For example, two UNB researchers recently developed guidance software to simplify the enormous task of accurately stacking large shipping containers within decimeters of each other. Standard mechanisms currently used to guide port cranes use cameras mounted on the sides of the cranes. The cameras rely on lines manually painted on the ground to keep the crane from running into stationary containers. To overcome the inaccuracies and other problems associated with the lines, the researchers developed and successfully field-tested new software that digitally maps the port and uses GPS to control the crane's actions to within a few centimeters. Such a development is one of many that exemplify the promising business opportunities being created through UNB's advancements of GNSS technologies.

SATELLITE NAVIGATION SYSTEM: MARKET TRENDS AND OPPORTUNITIES

U.S. GLOBAL POSITIONING SYSTEM

The world's principal space-based navigation system, the U.S. Global Positioning System (GPS), is a dual-use system supporting both civil and military users. Although it is operated by the US Air Force, the system is managed by an Interagency GPS Executive Board (IGEB). The IGEB, established in 1996, is chaired jointly by the Departments of Defense and Transportation, whose membership includes the Departments of State, Commerce, Interior, Agriculture, and Justice, as well as NASA and the Joint Chiefs of Staff.

The nominal constellation of GPS satellites consists of 24 satellites in 6 orbital planes (four per plane), at an altitude of 20,200 km and an inclination of 55 degrees. Historically, the system has 26-28 satellites in operation at any given time. The GPS civil signals are provided free of direct user fees, in accordance with government policy established in 1983.

Developments

The launching of the first block of GPS satellites began in 1978. Over the course of the next seven years, ten Block 1 satellites were successfully launched (one launch failure). Built by Boeing under a US$1.35 B[30] contract, all have since ceased operations.

In 1980, Lockheed Martin became prime contractor for the Operating Control System (OCS) to develop the mission software, ground antennas, the Master Control Station, and monitoring stations (located in Hawaii, Colorado, Cape Canaveral, Diego Garcia, Ascension Island and Kwajalein) that track the satellites' navigation signals and relay the information to the MCS at Schriever AFB, previously called Falcon.

The launch of the Block 2 and 2A series, also awarded to Boeing, began in 1989 and involved 28 satellites. Of the Block 2 satellites, four remain operational today. All but one of the Block 2A series are operational (2A-13 was decommissioned in 1997). In total, 22 satellites from the 2 and 2A series make up the current constellation.

The contract for Block 2R (R for Replacement Operational Satellites) was awarded to GE AstroSpace (now Lockheed Martin Space Systems) in 1989 and stipulated 20 satellites in the order of US$2.5 B, with an option for six more (a total of 21 satellites were eventually built). The first of the series of Block 2R satellites was launched in January 1997, the most recent on January 30, 2001. To date, six Block 2R satellites have been successfully launched (the first launch in January 1997 failed).

As of July 2001, the operational GPS constellation consists of 28 Block 2/2A/2R satellites. Replenishments should continue through 2002 or beyond, followed by the Block 2F (Follow-on) satellite series being built by Boeing, then by GPS-3, currently in the study phase. The next launch of a GPS satellite to join the constellation is 2R-8, scheduled for Fall 2002 on board a Boeing Delta II launch vehicle out of the Cape Canaveral Air Force Station (wiring problems found on the Delta II fleet in July 2002 may push the rescheduled launch to an even later date).

30 All figures in U.S. denomination unless stated otherwise.

MARKET TRENDS AND OPPORTUNITIES

31 For a more detailed article on the technical improvements to Block 2RM, see "M is for Modernization: Block IIR-M Satellites Improve on a Classic," by Willard Marquis (GPS World, September 2001; pp. 36-49).

GPS Modernization

Since its inception, GPS technology has evolved most considerably in terms of the system's reliability, availability, power and application. For the civilian market, a milestone event occurred in May 2000 with the discontinuation of Selective Availability (S/A), the process whereby the civil signals were intentionally degraded. This improved the accuracy of the GPS civil service from a specified 100 meters to 10-20 meters and thus spawned a boom of new-generation position-based services and applications.

Like all satellite systems, however, GPS has a limited lifespan. For this reason, the US has embarked on an extensive modernization plan of the 2R, 2F and the eventual third generation GPS-3 that is expected to bring the technology to a new plateau.

In April 1996, Boeing was selected by the U.S. Air Force to design and construct Block 2F, the Follow-on series to Block 2R/M (still being defined). The contract's potential value is approximately US$1.3 B and encompasses the construction of up to 33 space-craft through 2012 (six had been purchased by 1998). The Block 2F satellites will feature greater flexibility to incorporate evolving mission requirements and have a design life of nearly 15 years. Under the terms of the GPS Block 2F contract, the Boeing team is initially building the satellites, modifying the GPS ground control segment and providing launch processing and on-orbit support.

In September 2000, Lockheed Martin was awarded a US$53 M contract to begin development of modernization changes for the twelve remaining Block 2R satellites, now dubbed 2R/M for Modernized. Under the initial plan, all twelve modernized 2Rs, are to be upgraded by 2006, eight years earlier than initially planned. Previously, modernization of the GPS was not to begin until 2005. Under that schedule, a fully modernized constellation would not be available to users until 2015. Under a revised plan, modernization is to begin in 2003 with the first Block 2F launch projected for as early as 2005. All twelve modernized 2Rs are scheduled for service by 2006.

The modernization phases of Block 2R/M and 2F will introduce four new signals: two military signals on the L1 and L2 frequencies, and two new civilian signals, L2 and L5. While the first block of 2R/M satellites will carry the new L2 signal, users will have to wait until late 2009 before there are a sufficient number of satellites in proper orbital position to fully use the new signals. As for L5, the signal is being added to the Block 2F series since it was not feasible on Block 2R/M. A reliable L5 signal could be available as early as 2012, although some experts predict more likely around 2015 given that the roll-out is contingent on the sequential decommissioning of the 2R/M satellites.

From the users' perspective, the additional signals will provide a more robust civil service, improved accuracy to up to 3-5 meters, enhanced signal security, improved acquisition options and enemy jamming resistance[31]. Ground controllers will also have the ability to reprogram spacecraft signals and power while on orbit, called the Flexible Power Plan. The boosting of the satellite power capacity is most significant in the modernization process: the upgrades to 2R/M translate into a five fold increase in power over the 2R satellites. For the 2F series, the power surges ten fold. Under GPS-3, the power is expected to surge well over 100 fold.

GPS-3

In November 2000, two separate contracts valued at US$16 M were awarded to Boeing and Lockheed Martin, to perform a comprehensive 12-month GPS-3 architecture study to assess the mission needs and requirements of the existing system, and validate their achievability by developing innovative architecture recommendations. A third company, Spectrum Astro, was not awarded a contract but decided to participate using its own funds.

The result of the study will provide a complete life cycle cost and cost-benefit assessment of the navigation system for the next thirty years. As part of the process, meetings between the military and civilian communities, over the summer of 2002 and beyond, are defining the specific requirements for GPS-3. The Air Force had initially planned to award the winner-takes-all contract, estimated at US$2 B, in the fall of 2002 but has since pushed this date to early 2003. Deployment of the system is officially scheduled for 2010/11, yet, as described below, could be pushed further to the right due to budget issues (for overview of Evolution of GPS, from Block 1 to GPS-3, see FIGURE E).

Impediments to Modernization

Current budgetary issues risk derailing the planned modernization process. Budget cuts to cover cost growth incurred in the non-GPS related U.S. Air Force's Space Based Infrared System High Missile warning system are already being felt on plans to upgrade the 2R/M and 2F series.

A plan proposed in early 2002 that would speed up the GPS-3 schedule for delivery in 2009, a welcomed rumour in the civilian marketplace, was dropped in favour of enhancements to the GPS-2 blocks. Unfortunately, the plan also required a boost in funding which has yet to make it through the government process. This means that not all twelve of the GPS-2R satellites may reach modernization, possibly only eight to ten. If no funds are allocated on the immediate horizon, the 2R/M satellites will be launched under their initial specifications without the desired modifications.

Of equal concern is the impact such cuts would have on the GPS deployment sequence. The transfer of funding from the GPS-3 budget to cover non-GPS cost overruns would likely push the start date further to the right, to as late as 2007 depending on the depth of the cuts. If this is the case, deployment would shift from the 2010/11 timeframe to beyond 2015 (see FIGURE F). As expected, the user communities are lobbying for reinstatement of funding in order to optimize the advantages associated with the upgrades in power and signals.

GPS Modernization Opportunities for Canada

In the space segment, Canadian industry has not been an active participant in the construction of the GPS satellite system. To date, the US DoD has dealt primarily with the two largest US space companies, Boeing and Lockheed Martin, who have developed the full end-to-end system within each company's vertically-integrated infrastructure. Some outsourcing has occurred to lower-tier US firms. For example, ITT Industries Aerospace & Communications Division (A/CD) is working under

FIGURE E

EVOLUTION OF GPS

Satellite Block	Launch	Status	Prime
Block 1: 10 sats	1978	Decommissioned	Boeing
Block 2: 9 sats	1989	4 operational	Boeing
Block 2A: 19 sats	1990	18 operational	Boeing
Block 2R/M: up to 20 sats	2R: 1997 2RM: 2003	6 operational; 12 launch-ready sats for modernization	Lockheed Martin
Block 2F: up to 33 sats	2005	6 under construction.	Boeing
GPS-3	2010+	Architectural study phase	Boeing and LM

a US$39 M sub-contract to Lockheed Martin as part of the Block IIR upgrade and is also involved in the architecture study of GPS-3.

Military's lead on GPS, regardless of its strong civilian focus, renders it a defense technology and thereby subject to stringent licensing arrangements. Moreover, GPS is not part of the current Canadian exemption under the International Traffic in Arm Regulations (ITARs).

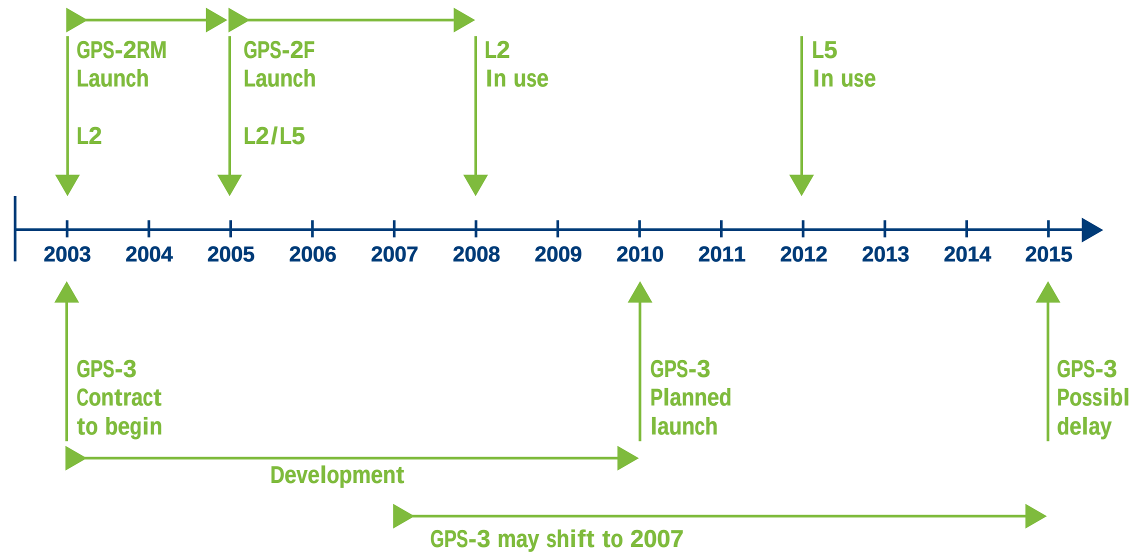
Just the same, quick resolve of the Air Force budget difficulties, resulting in a replenishing of GPS funding to expedite the upgrades of satellites under the Block 2R and 2F modernization initiative, could enhance interest by the American primes for launch-ready off-the-shelf components provided by suppliers, including those in Canada.

On the terrestrial applications side of the spectrum, the introduction of new signals opens opportunities in the testing and simulation markets, notably the need to ensure compatibility between the new signals and existing GPS signals and equipment. In fact, such a requirement has prompted the U.S. Air Force to revive their GPS test range at Yuma Proving Grounds, Arizona, for military and legacy system capability (testing to begin in September 2003). The range was first set up in 1977 and dismantled once the Block 1 and 2 GPS satellites became fully operational. Firms capable of providing such services to commercial GPS equipment manufacturers are in a position to help such companies expedite their upgraded equipment to market.

MARKET TRENDS
AND OPPORTUNITIES

FIGURE F

GPS DEPLOYMENT: 2002-2015+



32 Further technical and political insight into GLONASS at: http://www.fas.org/spp/guide/russia/nav/glonass.htm

33 Go to http://www.oso.chalmers.se/~geo/gg_comp.html for a comparison of GPS and GLONASS network specifications.

Russian GLONASS

A fully deployed Russian GLObal NAvigation Satellite System (GLONASS) constellation is composed of 24 satellites in three orbital planes. Eight satellites are equally spaced in each plane at an altitude of 19,100 km at an inclination angle of 64.8 degrees.

Conceived and promoted in the early 1970's by the former Soviet Ministry of Defense, GLONASS was officially placed under the auspices of the Russian Military Space Forces (VKS). This organization is responsible not only for the deployment and on-orbit maintenance of GLONASS spacecraft (the latter through the Golitsino-2 Satellite Control Center) but also, through its Scientific Information Center, for certification of GLONASS user equipment. Interests of civil users, as well as for international cooperation for application and development, are the responsibility of the Russian Space Agency[32].

Years ago, GLONASS rivalled GPS with a planned constellation of 24 satellites on three orbital planes compared to six for the GPS[33] (see FIGURE G). First launched in 1982, four years after the first GPS satellite, the system initially proved worthy as a complement/backup to the GPS system yet continually struggled to achieve the critical numbers that allow for reliable positioning capabilities.

MARKET TRENDS AND OPPORTUNITIES

34 See "GLONASS Contributions to Space Geodesy" by Jörgen Börjesson (Department of Radio and Space Science; Chalmers University of Technology; Göteborg, Sweden 2000).

35 Additional references: "GLONASS Spacecraft", GPS World, November 1994, Vol. 5, No. 11; "GLONASS: Review and Update", GPS World, July 1997, Vol. 8, No. 7.

36 "Russia Commits to Funding for New Glonass Fleet" by Peter B. de Selding in SpaceNews (Dec. 17, 2001; p.6)

37 As of September 2002, the GLONASS-M satellite is still set as "unhealthy" but recently started to transmit valid data.

At the time of its launch, GLONASS was the only satellite navigation system that did not have an intentional degradation of the civilian navigation code as was the case with GPS prior to the discontinuation of S/A in May 2000. Another advantage for GLONASS is the higher inclination of the satellite orbits, implying better satellite availability at higher latitudes[34].

Dual GPS/GLONASS receivers are currently available in the market place. Even with a reduced constellation, GLONASS can be helpful in some applications augmenting GPS. GLONASS is monitored by a sub-network of International GPS Service sites, including UNB – the only Canadian GLONASS monitoring site.

Developments

Since its inception in 1982, four models of GLONASS spacecraft have been flown. Eleven Block I satellites were launched between 1982-1985 with an average actual lifetime of just over one year. Six Block IIa satellites followed in 1985-1986 with new time and frequency standards, increased frequency stability and a 20% increase in lifespan. Block IIb spacecraft with 2-year design lifetimes emerged in 1987, and a total of 12 were launched, although half were lost in launch vehicle accidents over the course of two years. The remaining spacecraft worked well, operating for an average of nearly 22 months each.

The launch of Block IIc satellites beginning in 1991 allowed Russia to attain full constellation status consisting of 24 satellites by 1995 (21 operational and 3 active spares). Unfortunately the pinnacle was short-lived. Despite the launch of three new GLONASS satellites in 2000, the total number of operational GLONASS satellites soon slipped to eleven.

By mid-2001, this number was reduced to as few as six healthy birds and the system's demise was imminent unless funding was injected[35].

In August, Russia announced the much-needed influx of money for GLONASS replenishment. On this occasion, Russia announced plans to return GLONASS to full operational status well before the turn of the decade in what officials are referring to as a transition between the old and the new designs[36].

In December 2001, the launch of three GLONASS satellites, one of which was the GLONASS-M series, came on the heals of the announcement[37]. Current plans include another three satellites on a Russian Proton rocket in 2002 and more in 2003, for a total of 10-12 operational satellites. Capable of intersatellite communication and of autonomous operations for as long as 60 days comparable to Boeing's GPS Block 2F satellites[38]. By 2006, the Russians expect to have an 18-satellite constellation, and a complete constellation by 2007 which will include a third generation of satellites, GLONASS-K, to begin in 2005. GLONASS-K will have an orbital life expectancy of ten years, up from seven and will be phased in through 2010 (for overview of Evolution of GLONASS, see FIGURE H).

Developments aside, the GNSS community has ample reason to remain doubtful given the inadequate progress to date. As one observer commented, "Will the Russian government abandon GLONASS? The answer is probably not, but it is difficult to predict how the future political environment will affect funding for the program[39]."

FIGURE G

COMPARISON OF GLONASS AND GPS SPACECRAFT

	GLONASS	GPS
Sat bus width X height [cm]	101 X 327	152 X 191
Sat mass [kg]	1415	1066
Onboard power [W]	1600	1136
# of orbital planes	3	6
Orbital inclination	64.8°	55°
Orbit altitude	19,130 km	20,180 km
Nominal # of sats	24	24
Current # of operating sats	7-8	28

Source: GPS Satellite Comparison: http://www.oso.chalmers.se/~geo/gg_comp.html

38 "GLONASS Contributions to Space Geodesy" ibid. p. 11.

39 "Glonass: Still Out There"; Gerald L. Cook, Sequoia Research Corporation; Presented at ION 2001, 11-14 Sept. 2001 (Salt Lake City, USA).

Opportunities for Collaboration

For Russia, authorities have been in close discussions with the Europeans over possible collaboration in the upcoming Galileo system. Russian officials are seeking to use their experience from GLONASS to participate in the development and deployment of Galileo and may be in a position to provide launch services on board a Starsem Soyuz-ST rocket, a joint Russian-French partnership. Discussions also address the interoperability of the two systems thereby enhancing accuracy and coverage. Calls have also been made for more formal discussions involving Russian, U.S., and European officials to reach a common view on each of their respective navigation systems.

From Canada's perspective, Russia and Canada have enjoyed a long history of space cooperation in a variety of fields and continue to collaborate in various international ventures. Besides the notable partnership on the International Space Station project, other collaborative ventures include the COSPAS-SARSAT, a satellite based search and rescue system involving Canada, Russia, France and the US, in which Canadian industry played an important role. Russia's renewed efforts to expand and improve GLONASS could provide a basis for industrial opportunities involving various segments of the satellite infrastructure, from space to ground to application development, although certain trade issues persist.

MARKET TRENDS AND OPPORTUNITIES

40 "What is Galileo" http://www.esa.int/export/esaSA/GGGMX650NDC_navigation_0.html

Chinese Beidou Navigation System

In October 2000, China officially entered the satellite navigation system race with the successful launch of the Beidou Navigation System. A second satellite soon followed in December 2000, to make up a system designed and built by the Research Institute of Space Technology under the China Space Science and Technology Group. No other launches have been reported to date.

China expects its navigation system to play a progressive role in promoting national economic growth and is a key element to China's expanding list of space capabilities, particularly as it gears up for the Beijing Olympics in 2008. Outside of China, the navigation system is a topic of discussion between Russian and Chinese officials over possible cooperative space initiatives linked to Russia's GLONASS program.

By many accounts, China is becoming one of the most aggressive space-faring nations with high aspirations for satellite and manned space programs. In September 2001, Chinese officials reported that the country could launch 35 or more science and application satellites over the next five years. Additional navigation and positioning satellites are part of these plans.

OPPORTUNITIES FOR CANADA

For Canadian industry, current opportunities to participate in the Chinese navigation system remain limited given the limited scope of the project and restricted market access. This is unlikely to change over the course of the next few years.

Galileo

Galileo will be Europe's own global navigation satellite system, providing a global positioning service under civilian control. Once operational in 2008, the system will be interoperable with both GPS and GLONASS. The fully deployed Galileo system will consist of 30 satellites (27 operational + 3 active spares), positioned in three circular Medium Earth Orbit (MEO) planes at an altitude of 23,616 km and at an inclination of 56 degrees[40].

The first experimental satellite, part of the so-called Galileo System Test Bed (GSTB) is scheduled for launch in late 2004. Thereafter, up to four operational satellites will be launched in the timeframe 2005-2006 to validate the basic Galileo space and related ground segment. Once this In-Orbit Validation phase has been completed, the remaining satellites will be installed to reach full operational capability in 2008.

The Galileo system would be similar to the GPS and Russian GLONASS systems. The difference lies in its claim to be the world's first satellite positioning and navigation system specifically for civil purposes, designed to track aviation traffic across the European continent and provide search and rescue services.

EUROPE MOVES ALONG THE TECHNOLOGY LEARNING CURVE

EGNOS, which stands for European Geostationary Navigation Overlay Service, provides a unique opportunity for validating and demonstrating new service and application developments in a realistic environment using navigational signals from GPS and GLONASS satellites. As a forerunner to Galileo, EGNOS will eventually be folded into Galileo once operational. It is being developed by ESA in conjunction with the European Commission and Eurocontrol, the European Organization for Safety of Air Navigation.

The infrastructure will consist of three geostationary satellites and a network of ground stations to transmit critical information while informing users of the errors in position measurements and signal disruptions.

In February 2000, the EGNOS System Test Bed (ESTB), the first EGNOS prototype, began broadcasting signals from space, making the system available for navigation demonstrations and service trials. EGNOS currently relies on navigation transponders on board the Inmarsat-III Atlantic Ocean Region East (AOR-E). The test bed will also rely on ESA's Artemis satellite, which is on its way to geostationary orbit due to a failure in the upper stage of its launch. It is expected to reach geostationary orbit by the end of 2002.

In May 2002, EGNOS achieved the successful closure of its Critical Design Review (CDR) and subsequently moved into the manufacturing phase over the summer.

YELLOW LIGHT. GREEN LIGHT. YELLOW LIGHT?

Politically, the road to launching the Galileo constellation, like the vast majority of space projects at this current juncture, has been a difficult one. Despite successfully reaching the development and validation phase in 2001, Galileo found itself in what could be described as an erratic decision-making process involving the European Commission (EC) and the European Space Agency (ESA), that lead it close to the brink where it still lingers under a cloud of political wrangling.

FIGURE H

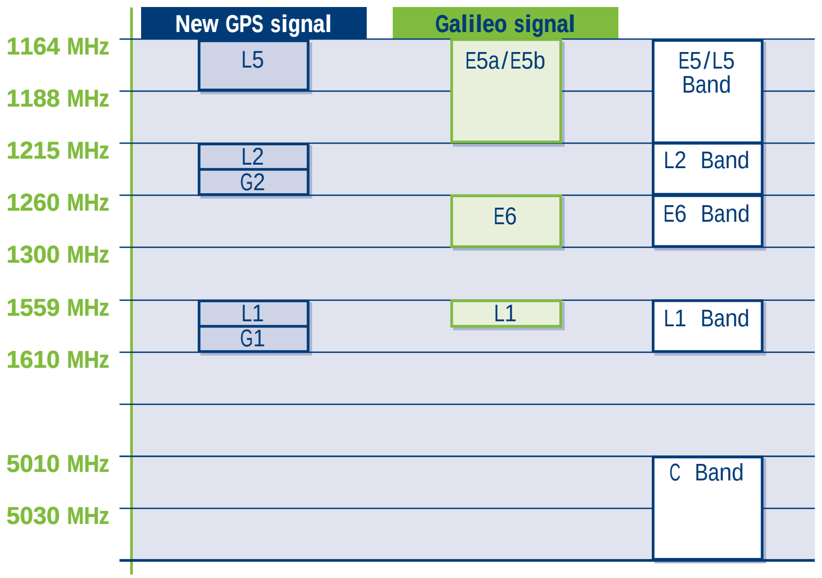
EVOLUTION OF GLONASS

GLONASS Blocks	Launch	Status
Block I: 10 sats	1982	Decommissioned
Block IIa: 6 sats	1985	Decommissioned
Block IIb: 12 sats	1987	Decommissioned
Block IIc: 51 sats	1991	5-6 operational
Block M: >5	2001	0 operational
Block K	2005	Under construction

41 Report: http://europa.eu.int/comm/energy_transport/library/gal_exec_summ_final_report_v1_7.pdf

FIGURE I

COMPARISON BETWEEN GPS AND GALILEO



Allocations decided by WRC-2000

10 navigation signals and
1 Search And Rescue signal.

- 4 signals in 1164-1215 Mhz (E5a-E5b)
- 3 signals in 1260-1300 Mhz (E6)
- 3 signals in the frequency range 1559-1591 Mhz (L1)

Following an EU allocation in April 2001 of €100 M, matched by ESA, to take Galileo to the next level, the two organizations proceeded into the summer with efforts to secure significant funding envelopes within each of their memberships. ESA's contribution of €550 M was unanimously approved at the ESA Council Meeting held in Edinburgh in November 2001, representing a decisive step in the evolution of Galileo into the development and validation stages (C/D). Canada also announced its intentions to participate with funding in the order of €7.4 M.

Coming on the heels of the ESA decision, and just prior to the upcoming EU Council meeting, was the release of an independent study on the business case of a European satellite navigation system[41]. The report concludes that there is a strong economic case for Galileo, far beyond the €3.6 M. The study estimates the total benefits at close to €18 M, including operations, representing a cost-benefit ratio of 4.6. Among the main beneficiary is the transportation industry, poised to reap substantial savings as a result of improvements to air traffic control, marine navigation and route guidance for motor vehicles. Significant revenues are also in store for chip-set sellers and value-added service providers.

MARKET TRENDS
AND OPPORTUNITIES

The EU believes Galileo will create a market for equipment and services for European companies totaling some US$71 B over 15 years along with 140,000 jobs. All this at a minimal cost: the EU equates the price tag to that of some 150 kilometers of semi-urban motorway or the cost of just one track of the main tunnel for the future high-speed rail link between Lyon and Turin.

Those working in the GNSS industry are equally supportive: Lyn Dutton, Business Development Manager at Thales UK (formerly Thomson-CSF), estimated that in Europe alone, Galileo is expected to boost the GNSS market to more than US$60 B between 2010 and 2020[42]. Richard Langley, a professor in the Geodetic Research Laboratory at the University of New Brunswick, said plans tentatively call for Galileo to mesh with GPS frequencies to simplify the development of dual-system GPS/Galileo receivers and drive down prices (see FIGURE I for GPS and Galileo frequencies).

Langley added that dual-system receivers would not only provide greater positioning accuracy, "but would also provide the three other key performance measures of a navigation system: availability, continuity and integrity." The "use of a dual constellation will be particularly beneficial in situations where the performance of GPS alone is marginal, such as in urban canyons and other restricted environments." Langley predicts that the cost of a dual-system receiver would not be much higher than that of a GPS-only receiver. And once Galileo becomes operational, GPS-only receivers will be relegated to the technology junk heap, he added[43].

Despite the list of supporters, with studies and statistics in hand, EU officials maintained a cautious position leading up to the December 2001 council meeting. At this meeting, Transport Ministers from Germany, Denmark, Austria, the Netherlands, Sweden, and Britain once again called for further delays to committing more money to Galileo until a stronger argument of the ensuing economic benefits was made. The respective ministers concluded that more "detailed consideration" was required, to help ease the burden on European taxpayers, before they could sign off on the European project. They also expressed concerns over the overall infrastructure and the role of private industry therein.

In February 2002, the scales tipped in favour of Galileo with Germany's decision to approve €160 M. One month later, EU Transport Ministers approved the release of €450 M that matched the previously-approved ESA funds. The go-ahead, however, was conditional on ensuring private investors would also come on board under the proposed, and contentious, Public-Private Partnership (PPP) arrangement. The ministers insisted the EU would meet no more than one third of the costs of Galileo's deployment, with the remainder met by the private sector. They agreed to set up a new committee – a Joint Undertaking (JU) structure – to co-ordinate the project's security-related issues.

The Joint Undertaking is designed for a period of four years, ending in 2005. Founding members are the EC and ESA, joined by the European Investment Bank and private enterprises subscribing to the initial funding of the JU. In response to EU concerns over a possible conflict of interest that could arise in allocating the private sector a role in implementing

42 Speaking at the ION GPS 2001 Conference, Salt Lake City, U.S.A. Reported in ION Newsletter (Vol. 11; No. 3; Fall 2001)

43 Quoted in CNN Communiqué "European Space Agency Backing GPS System"; 22 Nov. 2001; http://europe.cnn.com/2001/TECH/ptech/11/22/euro.space.galileo.idg/

MARKET TRENDS AND OPPORTUNITIES

44 See ESA Legal Notices, posted on http://europa.eu.int/comm/energy_transport/en/gal_who2_en.html

45 Cited in "Officials Say No Solution in Sight for Galileo Dispute" SpaceNews, 9 Sept. 2002 (http://www.space.com/spacenews/spacenews_businessmonday_020909.html)

46 GPS World Global View; April 1, 2002 (http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=14147)

47 "Europe's New Air War", Oliver Morton in Wired (Aug. 2002) http://www.wired.com/wired/archive/10.08/airwar.html

and administrating the infrastructure, private enterprises will not be allowed to become members before the finalisation of the tendering procedure with a view to selecting the future holder of the concession to deploy and exploit the system[44].

New political hurdles arose once again by early summer 2002 due to differences between Germany and Italy on which country will be considered the leader of Galileo. As of July 2002, ESA was continuing bilateral discussions with the respective governments in hopes of brokering a deal.

New financial matters also crept onto the table – this time, however, the issue dealt with over funding, not lack thereof. As of July 2002, ESA member states have approved a total of €730 M, an over subscription of some 30% of the funds requested from each government. ESA hopes to resolve the subscription rates and therefore the rates of industrial returns by the end of 2003, although SpaceNews reported in early September 2002 that multiple rounds of negotiations between the nations concerned - Germany, Italy, France and Britain - have come up empty. Apparently, there is no solution in sight, officials were quoted as saying: "We are now all looking toward the national elections in Germany as a future event that may produce a breakthrough. At the very least it will make ministers and the (German) chancellor more available to negotiate[45]."

U.S. RESISTANCE

As Europe dealt with its own internal wrangling, the U.S. GPS/military lobby maintained a less-than-subtle presence in the entire affair. In a statement released on March 7, and quoted in GPS World, the State Department stated that "The United States Government sees no compelling need for Galileo, because GPS is expected to meet the needs of users around the world for the foreseeable future[46]."

While recognizing the strength of a combined Galileo-GPS system, and the need for cooperation to address interoperability, many in the U.S. have openly expressed concerns over encryption plans, management framework, and Galileo's potential military use. The already tenuous relationship was exasperated in December 2001, between the ESA and EU meetings, with an open letter from U.S. Deputy Defense Secretary Paul Wolfowitz to his counterparts in NATO expressing apprehension over sharing of signals. As one observer noted: "To Wolfowitz, GPS...is also a crucial element of US military power, enabling new forms of precision warfare. The establishment of new location-based services outside the United States...would open up the possibility of outside parties using precision weapons for purposes that undermine US foreign policy. It could even, conceivably, lead to satellite navigation being used directly against the US[47]."

NATO officials were soon after echoing the concerns. In a leading navigation publication, Robert G. Bell, NATO Assistant Secretary General for Defense Support, spoke at length regarding what he perceived as the "serious military issue related to the ... placing one of the four services proposed by Galileo directly on top of – or 'overlaying' – the 'M-Code,' the encrypted future military GPS capability that will be used by U.S. and NATA forces for crucial military operations[48]."

Nonetheless, opponents are coming to the realization that Galileo is imminent and the extent of the investments appears far too along the development path to justify its cancellation (see FIGURE 1 Galileo Timeline). More importantly, at stake is the new relationship of ESA and the EC/EU and the role both are playing in a system that symbolizes European independence via technology prowess. So much to say that formal negotiations continue between U.S. and European officials in order to iron out many of the outstanding issues and to ensure that respective states and users around the world benefit from a more robust GNSS infrastructure.

OPPORTUNITIES FOR CANADA

To date, Canada has actively participated in the European SatNav programs since 1998, having played an active role in EGNOS, and Phase A and B2 of Galileo. Among the Canadian participants to date include:

- NovAtel (EGNOS/Europe, WAAS/N.A., SNAS/Chine, MSAS/Japan, Galileo studies);
- CAE (GalileoSat System Simulation Facility);
- University of Calgary (study phase; support to industry);
- University of New Brunswick (study phase; support to industry; EGNOS monitoring);
- Telesat Canada (regional integrity network);
- EMS Technologies Canada (SAR system, power supplies);
- NavCanada (to host reference station in Moncton); GPS satellites orbit from west to east, so a station in Canada allows EGNOS to make an early determination of satellite clock and orbit errors, thereby increasing the overall accuracy of the system. Users in eastern Canada would be able to use EGNOS signals from the westernmost EGNOS GEO, so having a station in Canada improves service in that area[49].

In November 2001, Canada announced its intention to invest approximately CA$11 M[50] to the Development and Validation phases (C/D), from 2002/03 to 2006/08. The key rationale underlying Canada's participation in this, the most extensive satellite constellation program on the immediate horizon, points to the potentially beneficial industrial returns to a number of the country's leading space companies specializing in both space and ground segments.

Activities that could involve a more comprehensive Canadian participation include:

- Search and Rescue technologies
- Ground receivers
- Navigation signal generation technologies
- Antenna technologies
- Regional integrity ground infrastructure

Although a European design, Galileo is a global system providing global coverage – and thereby requiring ground stations placed outside of European territory for telemetry, reliability and integrity. According to ESA, the ground installations will

48 Reported in the Institute of Navigation (ION) Newsletter (Vol. 12; No. 3; pp. 1, 16).

49 Cited in NavCanada's "SatNav Transition Strategy" (May 2002).

50 CSA funds approved in Spring 2002.

FIGURE J

GALILEO TIMELINE

PHASE A: 1998-1999	• ESA: Comparative System studies • EC: Concept studies
PHASE B1: 2000-2001	• ESA: Baseline System Design • EC: GALA study
PHASE B2: 2001-2002	• ESA: Preliminary System Design • EC: GALILEI study
PHASE C/D/E1: 2003-2005	• Joint Undertaking: Detailed design, development and In-Orbit Validation
PHASE E2: 2006-2008+	• Full Deployment and Long-term Operations

be rather extensive, with possible locations for ground stations in India, Alaska, South America and Canada[51]:

- Two telemetry, tracking and control stations to monitor the constellation.
- Between 18-20 reliability and integrity monitoring stations to assure Galileo signal accuracy.
- Ten satellite-uplink station to feed C-band signals to the constellation.
- Numerous stations to collect information from the on-board atomic clocks.
- A Galileo control centre, and one back-up centre, to provide the codes needed to encrypt Galileo data that is limited to specific users, and to provide signal-integrity data.
- A Security Office responsible for management of the different categories of access to Galileo signals, and to coordinate the overall safety and security of the constellation.

By virtue of Canada's status as a Co-operating State of ESA, Canada is allowed to participate in the GalileoSat program, the space component of Galileo. On the other hand, Canada is not a member of the European Union, the co-sponsor of Galileo, and discussions continue to formalize Canada's participation in what is a joint ESA-EU venture.

Overall, the world-class level of expertise found in Canada's GNSS industry, particularly in the manufacturing sector (NovAtel, CMC Electronics, EMS Technologies), satellite operations (Telesat) and reference stations (NavCanada), creates opportunities for collaboration in Europe's navigation venture. Moreover, Canada is home to some of the world's most renowned experts in the field – at the University of Calgary, University of New Brunswick, and Université Laval – with established links with industry, particularly between the University of Calgary and the growing Calgary-based satellite navigation industry.

51 See "Special Report: Ground Systems" in SpaceNews, June 10, 2002; pp. 20, 21.

WHAT TO EXPECT IN THE NEXT FEW YEARS

Industrial Consolidation: The SatNav industry is made up of hundreds of small and medium sized companies in the GPS-enabled service industry, supported by a more modestly numbered equipment manufacturing sector. Anticipate more consolidation in both the service and manufacturing industry as GPS technologies encounter more acute integration.

On the Defensive: GPS is among the most strategic tools for the U.S. military forces who are relying more and more on space for a competitive advantage in the battlefield. Efforts to increase the power of GPS to improve intelligence, surveillance, deployment and weaponry should translate into growing market opportunities, not to mention R&D opportunities where public defense funds are more readily available. The events of 9/11 have only expedited these efforts, triggered new ideas using GPS, and created additional funding envelopes into which industry may be able to tap. (Interestingly, GPS was used to record with great accuracy where debris was pulled from at ground zero in New York City, lending to the clean-up efforts by a significant time factor)

Big Brother: Awareness and demand for GPS, an industry now driven much more by the civil market than the military counterparts, will continue to grow as its proven power to locate leads to more affordable and integrated products for consumers. The forces behind this new "alert" society have lead to the wireless E911 mandate and other GPS-based "people-tracking" devices for children, older people suffering from Alzheimer's, and offenders on probation, parole or work release.

Location-based Services: Estimated to bring GPS-enabled technologies more firmly into consumer's handhelds. The technology responds well to growing demand for "on-the-spot" information and purchasing opportunities.

The Long and Winding Road: Full integration into the mass market of automobiles, as in the case of in-vehicle navigation, is a long-term process and one that will not result in instant cash-flow. At this stage, returns are most promising in the provision of GPS-enabled telematics in industries that rely on fleet tracking, as in the case of rental car agencies, taxis and companies that provide on-site servicing using company vehicles (i.e., public utilities).

Ongoing Turbulence: FAA's dual GPS-based navigational systems: WAAS and LAAS continue to experience some turbulent times, despite reports of good progress as of late. Anticipate the reaching of key milestones in 2003 and 2004, when the system is scheduled to be commissioned for precision navigation and landing (although a date for Category 1 operations is still unknown). The initiative has provided good opportunities for some of Canada's leading GPS suppliers and forecasts are positive as more progress is made.

Smaller is Better: Adoption and commercialization will rely heavily on the GPS industry's capability to achieve (1) technology miniaturization and (2) merging synchronization with other basic mass market services. Further design enhancements and market awareness will lead to increased cross-segment usage and adoption.

WHAT TO EXPECT
IN THE NEXT FEW YEARS

Timing is Everything: The need for precise timing accuracy, principally in the global computer network, will drive opportunities in the GPS equipment manufacturers industry. Regulation will increasingly require precise timing capabilities among the increasing number of current and potential clients, thereby leading to decreasing costs and expanded service.

Under the Microscope: Scientists are finding new and exciting ways to use GPS for such things as environmental monitoring and atmospheric science. The potential of using GPS for scientific ends remains largely untapped and should be the subject of promising developments over the next few years as the GPS system is modernized.

Launch of Europe: Galileo has helped to thrust the European SatNav industry into the marketplace. In fact, Galileo – one of the only multi-satellite constellations currently on the books in the entire space industry – has brought about unwieldy competition among European nations and back-room positioning by U.S. companies. European and non-U.S. GNSS industry are expected to increase their share of the global SatNav market.

Securing GPS Modernization Funding: Despite the renewed focus on increasing US defense capabilities, and the role of GPS therein, GPS modernization remains vulnerable to budget reallocation in the U.S. Plans for the next-generation GPS-3 constellation will likely slip to the right unless long-term stable funding is committed. Upgrades of existing blocks may also be affected. The rate of modernization may also be expedited and companies capable of delivering flight-ready off-the-shelf components may be positioned to benefit from accelerated upgrade initiatives.

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SPACE SCIENCE

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EXECUTIVE SUMMARY

The years 2001 and 2002 has definitely been challenging for the space sciences. Following the events of September 11th in the United States and their ensuing repercussions all over the world, governments are re-focusing their attention on security, infrastructure and rebuilding efforts. The redirection of government funds towards these issues bears an impact on activities of a more exploratory or research-based nature such as space science.

Nevertheless, it remains true that economic prosperity is directly correlated to the advancement and use of knowledge. In such a knowledge-based economy, continued evolution in scientific understanding is considered essential. For the most part, nations still rely on their governments' sustained recognition and support of scientific progress to achieve this understanding. Currently, the space sciences are undergoing a transition, by virtue of increased pressure for the transfer of scientific knowledge into direct earth-based applications and benefits for humanity. Today, many space agencies are considering placing more emphasis on commercialization of space science and technologies in order that these activities become a more integral part of their programs.

Although there have been some new developments worthy of mention, one should keep in mind that by its very nature, the space science environment entails long-term missions. This year's chapter will therefore provide an update of the information provided in Global Trends 2001, highlighting specific events from the last year and highlighting additional trends to monitor in the near future. These trends include:

Quest for knowledge: The fundamental desire of humankind to gain a better understanding of the universe and our planet, and to predict the evolution thereof, remains an integral function of all space programs.

Funding structure - role of government versus industry: Basic science will likely remain supported primarily by governments, but industry is increasingly contributing actively to the research and development of applied science.

Increasing public-private partnerships: By the public sector working jointly with private industry to develop technologies that have a use both in space and on Earth, it is hoped that development costs will decrease.

Commercialization of science: Agencies are eager to exploit the synergies existing between space and terrestrial research and development, and are exploring the commercialization possibilities of space science and technologies.

Synergies between the sciences: There is a growing realization that the boundaries between the various space science disciplines are becoming blurred. Research into Mars phenomena has a direct benefit on similar phenomena on the Earth; research into the space environment can provide tools for astrophysics and weather forecasting; etc.

Benefits of international cooperation: International cooperation leads to several benefits, including greater opportunities to participate in missions, access to international databases and facilities, potential access to foreign markets, political goodwill, and prestige.

Increasing pressure to consider global issues: There is building consensus that space science and space applications can contribute to solutions or alleviate problems related to issues such as the consequences of population growth, access to education and health care, environmental and ecological changes, and disaster prediction and relief.

Smaller missions: As space agency budgets have remained stable or declined in some cases, there has been, over the past several years, a tendency towards smaller, more flexible missions. It is expected that small-and micro-satellite single-focus science missions will increase in the future and that the number of larger, complex, multi-instrumented and expensive missions will remain steady or decrease.

Partnerships with other government departments: As science becomes scrutinized more heavily with respect to its role to provide direct benefits for Canadians, there will be an increasing trend to partner with other federal government departments who have an operational role. These will include Natural Resources Canada, Environment Canada, as well as the Department of Fisheries and Oceans to name a few.

For the purposes of this chapter, we will abide by the generally accepted definition of space science as being scientific research conducted from, in, or on space.

Note: The reader is invited to consult the appendix to this chapter for an updated profile of the Canadian space science community.

MARKET CHARACTERISTICS AND MAJOR EVENTS OF THE RECENT PAST

Space Science Budgets

The estimated Canadian Space Agency (CSA) spending in 2001-2002 for science activities was approximately 11% of its annual budget, which represents about CA$30 M. This amount is modest compared to some of our international counterparts. These numbers simply re-emphasize the Canadian space community's need for international cooperation. As stated in last year's Global Trends report, most governments of industrialized nations recognize the need to support international cooperation in science and technology, and therefore actively support and facilitate international Science and Technology (S&T) initiatives. For Canada, this has translated into an overall commitment of CA$69 M annually to support international S&T initiatives, with approximately 34.3% of this amount dedicated to the space sector[1].

FIGURE A below presents selected civil government space expenditures in space science and micro-gravity for the period covering 1997 to 2002. (Partial updated information, as details were not available from all agencies at the time of this publication).

[1] Reaching Out: Canada, International Science and Technology, and the Knowledge-based Economy, Report of the Advisory Committee on Science and Technology, Government of Canada 2000 (ACST report available at www.acst-ccst.gc.ca).

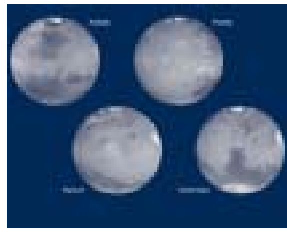


FIGURE A

SELECTED GOVERNMENT SPENDING ON SPACE SCIENCE*

	1997	1998	1999	2000	2001	2002 (estimates)
Canadian Space Agency (including life and microgravity sc.)	28.9	27.3	28.9	23.7	29.4	30.3
European Space Agency (including life and microgravity sc.)	725.0	830.35	805.98	696.03	768.0	671.74
Japan (ISAS + NAO)	310	302	280	276	258	N/A
NASA Space Science (including life and microgravity sc.)	3,035	3,380	3,538	3,772	4050	4220

*Amounts are in CA$ (Millions)

Note:

1) CSA: Figures based on year-end reports and planned spending estimates; include (microgravity and life sciences, exploration, astronomy). Numbers were revised from last year's publication to ensure consistency, basing numbers on the fiscal (April to March) versus calendar year.
NOTE: Re-organization into different service lines as of 1999 resulted in atmospheric environment and space environment being included in the Earth and Environment service line of the CSA. Should we include these numbers, the numbers would read for: 2000 = 46; 2001 = 49.6; 2002 = 48.8.
2) ESA: Numbers based on ESA Science Budgets (voted budgets) including microgravity (but excluding ISS columbus lab facility). Numbers taken from Euroconsult 2002 publication: "World Market Prospects for Public Space Programs, p. 129). The full numbers 1997-2002 have been updated for consistency, using budgets versus expenditure. Conversion rate EURO to CA$ (Annual Bank of Canada average).
3) Japan figures include Astronaut program (1999 to 2001 data from Institute for Space and Astronautical Science and National Astronomical Observatory ; therefore numbers include astrophysics, solar physics, space plasma physics, planetary science, science and balloon observation programs, astronomy). Conversion rate: 1 CA$ = 80 JPY. Data is not included for 2002 due to the current re-organization/amalgamation of the Japanese space organizations.
4) NASA: Numbers based on Presidential budget request (nasa webpage: http://ifmp.nasa.gov/codeb/budget2001)); Conversion rate: 1 CA$ = (approx.) 0.65 US$ (Bank of Canada average) - NASA budget includes space science as well as life and microgravity budgets (for all except 1997 which is NASA science budget only).
5) All numbers excludes military budgets.

Space Science Results

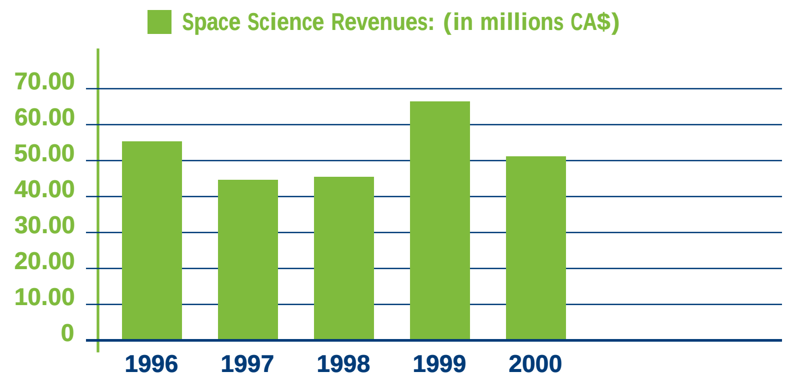
Based on results from an annual survey conducted by CSA on the State of the Canadian industry, revenues for the space science sector suffered a downturn during 2000, sliding 23%, or from CA$68 M in 1999 to CA$52 M in 2000. As a proportion of all space activities, revenues generated from Space Science activities in 2000 represented 4% of total revenues. Over the five-year period 1996 to 2000, revenues in the Space Science sector have declined by 9%. FIGURE B graphically demonstrates this variation[2].

[2] State of the Canadian Space Sector, 2000, External Relations Directorate, Canadian Space Agency.

MARKET CHARACTERISTICS AND MAJOR EVENTS

FIGURE B

TOTAL CA$ REVENUES PER YEAR



Source: State of the Canadian Space Sector, External Relations Directorate, CSA, 2000.

Due to Canada's involvement with the International Space Station, it was initially thought that many research opportunities would become available through this new platform. However, the current difficulties experienced by the partners of the ISS have resulted in a delay or postponement of certain scientific/research activities. This decreased level of science activity is unlikely to increase significantly over the course of the coming year, until the partners resolve the crew issue (3 versus 7), which limits the astronauts' availability for conducting experiments.

Regardless of these difficulties, the CSA's priorities remain unchanged. The results expected through the space science program over the coming years, include[3]:

- Improvement in the health of Canadians through gravitational biotechnology projects, osteoporosis experiments and extravehicular dosimetry;
- Improvement of medical knowledge, treatments and drugs by experiments using the effects of microgravity; and,
- Improvement of material processing techniques, including the understanding of fundamental physics and chemistry, proteins and biotechnology, fluid and combustion processes.

[3] Canadian Space Agency: 2001-2002 – Estimates (Report on Plans and Priorities).

4 Space Station will suffer, Sept. 17, 2001, www.space.com/news

Events/Announcements of 2001 - Early 2002

- ***International Space Station:*** There is increasing criticism over the situation with the ISS. Some journalists go as far as denouncing the ISS as a failure, with any potential for return from scientific research highly doubtful given current program cost overruns and subsequent budget cuts. "Given the prospect that schedule slips and scientific equipment delays continue to plague the mega-project, the ability to achieve the intended scientific goals off the ISS is seriously jeopardized[4]". Due to these difficulties, some of the ISS partners have realigned their science priorities, adapting their projects and timelines to the current constraints.
- ***Mars:*** The Canadian Space Agency has declared its intention for Canada to lead a future scientific mission to Mars in partnership with other key international players. The requirements for such a mission are not only to highlight Canada's scientific and technological capabilities, but also to inspire our youth and the general public. The mission is also expected to result in significant spin-off activities, as new instruments and techniques are developed for the harsh environment of the red planet. The recent discovery of water on Mars has only reinforced the current global interest in its exploration. Various international initiatives are underway or under development with several of these opportunities under consideration by CSA.
- ***International Living With a Star:*** Canada is positioned to play a major role in this large, international mission that has as its goal real-time forecasting of effects from the Sun (solar storms) in order to protect assets here on Earth (power systems, satellites, astronauts, communications, etc.). After initial studies conducted in 2000 on this program, NASA has now established the Living with a Star Program under the Sun-Earth Connection Theme, with the goal of understanding the changing Sun and its effects on the Solar System, life, and Society.
- ***OSTEO:*** The OSTEO experiment (1998) produced substantial results in synthetic bone biomaterials, testing and affirming the effectiveness of PTH (recombinant human parathyroid hormone). These results have led to growth in Millenium Biologix's primary terrestrial business and helped to secure a major global business partnership. Further research in this field will take place with the launch of OSTEO-2 (slated for 2002 – STS107).
- ***OSIRIS:*** The Swedish ODIN satellite was launched in February 2001, to which Canada provided the OSIRIS instrument to study ozone depletion. Through this mission and the forthcoming SCISAT mission, Canada has become recognized as the leading nation performing research into changes in the Earth's ozone layer, especially effects at high latitudes, where Canada is situated. OSIRIS is functioning well to date and yielding interesting results.

- ***SCISAT and MOST:*** Canada has started to take a significant step towards the development of small- and micro-satellites and associated technologies with these two innovative space science missions. This is an area where growth is expected in the next decade and these missions are positioning Canada to take advantage of this growing and dynamic sector.
- ***James Web Space Telescope (JWST)*** Canada has negotiated a 5% partnership in the Next Generation Space Telescope mission – the successor to the Hubble Space Telescope. This very large and complex mission is expected to place Canadian astronomers in the forefront of future discoveries about our universe, a subject of everlasting appeal to humanity.
- ***AURORA:*** On June 14, 2002, the CSA announced its commitment of US$700,000 (CA$1.1 M) over three years to participate in the European Space Agency's Aurora program. Participation in this program is key to creating international partnerships and collaboration with Canada on future missions to Solar system bodies, in particular those holding promise for traces of life. It will also allow Canada to demonstrate new space technologies and enhance its global recognition as a leader in key technologies, notably in Lidar (LIght Detection And Ranging), in robotics and in the development of scientific instruments[5].

MARKET TRENDS

Quest for Knowledge

Although there is a strong trend towards commercialization and development of earth-based applications from space science research and scientific instrumentation, the fundamental purpose of scientific research is to fulfill mankind's desire to gain a better understanding of the universe and to predict its evolution. This remains an integral function of all space programs. Some key projects proposed by or under development by the main contenders in space science are presented below:

- NASA's intent on launching the "James Web Space Telescope" (JWST) over the next few years, the next future large space astronomy observatory to which Canada has subscribed at a level of 5%;
- The European Space Agency's "exploratory" missions, such as Herschel-Planck to study the origin and evolution of the universe and of stars and galaxies, not to mention Mars Express scheduled for launch in 2003 and AURORA;
- Japan's interest in Lunar exploration through robotic or orbiting observatory missions;
- CSA's President, Dr. Marc Garneau's announcement that "Canada is going to Mars", a science driven although technology enabled initiative; and finally,
- The pending launch of Canada's SCISAT in 2003.

Funding Structure:
Role of Government and Industry

The necessity of public-private partnership is a reality. Under the current economic conditions, with decreasing budgets, the creation of synergies between science and earth-based applications, the pressures for science to yield economic returns, and the shift in focus to security issues, collaborative partnerships

5 Canadian Space Agency participating in two ESA programs studying the environment and exploring new worlds: GMES and Aurora, CSA press release, Saint-Hubert, Quebec, June 14, 2002).

MARKET TRENDS

between actors in the space science environment are increasing. Governments today still act as the main funding source for basic research, with an increasing expectation for industry to contribute or to become the main supplier of funds for science and research. The current economic slowdown in the United States, combined with the terrorism events of 2001 have placed new demands on Canadian government funding allocated to security issues. This, in combination with a number of other factors led to delays in the government of Canada's innovation agenda and availability of short-term funding for new initiatives. In such an environment, it is not surprising that the government's role increasingly becomes one of a catalyst for public-private partnerships, and less of a venture capitalist.

The Canadian government has identified its role in advancing science through funding of university research, enhancing the flow of knowledge, promoting excellence and relevance, policy making, and developing a science and innovation culture in Canada[6]. As stated in last year's report, government currently retains its primary role in funding basic research, often assuming 100% of the costs. However, while governments remain a principal funding authority in terms of applied science, especially in the early phases of research, there are more and more incentives for early transition of responsibility from government to industry. Joint-funding during the initial program/project development therefore becomes preferable. Researchers are encouraged to obtain industrial support and establish partnerships to share payload costs and maximize government leverage and economic benefits.

6 Vision, Imagination and Innovation, An update on the Benefits of Space Science in Canada, B.C. Blevis and Associates, January 1999, p.26.

Public-Private Partnerships

One of the main impediments to conducting space research has been the high cost with respect to placing experiments in space. Joint initiatives, where by space research is sponsored by organizations with the potential to further develop this research/technology for ground or Earth-based applications, are an interesting concept gaining increasing popularity. The concept of public-private partnerships (PPP) invites private industry to develop such double-use technologies, thus potentially reducing development costs. This concept also ties in with the following trends of commercialization of science and synergies between the sciences.

Commercialization of Science

More and more agencies are recognizing the synergies existing between space and terrestrial Research & Development, and as such, the need to further explore the commercialization possibilities of space science and technology. The potential transferability of space technologies to ground-based applications is increasingly a requirement and a potential cost-sharing opportunity.

Synergies between the sciences

There is a growing realization that the boundaries between the various space science disciplines are becoming blurred. As examples, it is foreseen that research into Mars phenomena will have a direct benefit on the research of similar phenomena on Earth and that research into the space environment can provide tools for astrophysics and weather forecasting. As the boundaries between disciplines become blurred, greater benefits in terms of advancement of knowledge and potential new developments or transfer of knowledge into different disciplines are expected. Identifying areas with potential applications or transfer across disciplines should lead to collaboration between scientists and their funding agencies.

International Cooperation

International cooperation remains a strong trend in the context of decreasing budgets, new competitors, difficult economic situations, and a limited pool of qualified space scientists. This also ties in directly with the pressure for focused research on global issues. Through pooling of resources, various benefits can be achieved, including greater opportunities to participate in missions, access to international databases and facilities, potential access to foreign markets, political goodwill, and prestige. Additional benefits/opportunities include the possibility to test hypotheses and the use of international databases and facilities.

The Canadian space community is well recognized globally for its highly qualified expertise in space science. In terms of international cooperation, Canada has built strong ties to the United States and Europe. This will remain true, although new space actors are consistently monitored for new and interesting opportunities. With respect to the International Space Station, although Canada has been able to perform experiments on the ISS, delays are expected to continue over the next year or two until a final decision is made on the exact configuration of the space station.

Pressure for Focused-Research on Global Issues

There seems to be a growing consensus that space science and space applications can contribute to solve or alleviate humanitarian, societal or global problems such as environmental and ecological monitoring, disaster management or measuring the consequences of population growth and mass movement. Interest has therefore been building in recent years for making use of space science and technology to monitor or combat such global issues, if/when they can be accomplished at relatively low cost. There is a growing expectation from the general public and international groups that space can provide benefits to Society and to developing countries particularly. The pressures for global solutions and benefits have resulted in the pooling of international resources and sharing of knowledge across borders. Canada is already involved in such types of activities, but is likely to increase participation in this line of research in coming years.

Smaller Missions

As space agency budgets have remained stable or declined in some cases, there has been over the past several years, a tendency towards smaller, more flexible missions. It is expected that small-and micro-satellite single-focus science missions will increase in the future and the number of larger, complex, multi-instrumented and expensive missions will remain steady or decrease. Such access to space has become essential in the context of the current situation with the International Space Station and the high costs typically associated with shuttle launches. Small and micro-satellite missions will hopefully ensure more frequent and cheaper access to space.

Partnerships with other government departments
Although there has been collaboration between various governmental institutions for basic research, partnering with departments with operational functions has gained impetus in the last few years. This role is in direct correlation with the increasing scrutiny with respect to space science's role in providing direct benefits for Canadians. Among the departments having such an operational role, partnerships with Natural Resources Canada, Environment Canada, Department of Fisheries and Oceans, to name a few, will likely be enhanced.

WHAT TO EXPECT IN THE NEXT FEW YEARS

Ongoing turbulence
As stated previously, issues with the ISS remain unresolved, government budgets are tight, and the scientific community is under pressure to produce results. This situation is unlikely to change significantly in the next few years. However, although this indicates a challenging road ahead, various alternatives are under consideration or development that may help smooth the path. These include increasing partnerships, new ways of conducting science, and new means of accessing space.

Innovative partnerships amongst actors of the space community
The trends clearly indicate the need for the space community actors to work in close collaboration. Although Canada has exceeded its own predictions of economic growth in 2002, the worldwide economic situation is such that governments are experiencing budgetary constraints that are forcing innovative thinking and partnering between the various actors in the space community to ensure their survival. Various factors are creating this environment, including not only the financial aspect, but also the need for space science to focus on Earth-based applications and pressures for humanitarian initiatives. This may include public-private partnerships, inter-governmental partnerships (space agencies working with governmental users) or increasing international partnerships.

Innovative "ways" of conducting science
The increasing overlap between the various space science disciplines, and requirement for transfer into Earth-based applications is leading the scientific community in reviewing how they conduct science, and how to work together to achieve greater return. Scientists from various sectors are increasingly collaborating together to complete complementary science. This new approach requires innovative thinking on the part of the space community. Should scientists eliminate the "invisible" barriers that typically exist between disciplines, it could lead to a decrease in overall launching costs, as cost is spread across various sectors and to many actors. Futher, these strengthened collaborations could also positively increase overall results from the science completed through data sharing amongst a wider scientific community.

Smaller is better
Could it be that smaller is indeed better? The difficulties and costs associated with the current means of conducting science in or from space are favoring the potential small and micro-satellite missions. Access to space is limited by two factors: cost and availability. This new approach of using small and micro-satellites is providing a cost-effective and timely alternative. The Canadian community participation in such missions is expected to increase in coming years. This is part of the rationale behind the CSA's initiation of small and micro-satellite program

Increasing interest in exploratory missions to Mars
The recent discoveries of water on Mars are reviving the international interest in the red planet. Should missions to Mars prove successful in identifying life, interest and investments for further missions to Mars and other planetary bodies will likely grow exponentially. Canada is well positioned to benefit from these missions, with a small team of experts currently studying options for involvement in international Mars initiatives.

CONCLUSIONS

Growth Potential
The space science community seems to be in a never-ending cycle of budget cuts or funding shortage associated perhaps with their strong quasi-dependency on government funding. Although governments recognize the need for scientific research, the financial resources are not always readily available due to a variety of constraints. Increasing private-public partnerships are therefore essential. Although these partnerships are increasing, the space science environment with long lead times and potentially many years prior to return of tangible benefits on Earth, is not always conducive to private sector involvement. Governments will therefore need to take a more proactive role, acting as catalysts for these private-public partnerships in order to ensure the success and survival of the space science community. The emergence of small-micro satellite missions may alleviate this situation somewhat, offering opportunities for more frequent flights at a reduced cost. It should be expected to see a growing interest in the Canadian community for these types of missions, which are more in line with our current financial capabilities.

Apart from the financial burden, the various trends in space science are pointing towards modest future growth in the field. The growing expectation for links between and across disciplines, along with the potential for humanitarian applications and successful spin-offs or transfer into Earth-based applications are indicative of continued interest and support for space science. Already Canada has positioned itself favorably in the space science community through participation in a variety of international missions. Again however, the main constraint to further international partnerships is tied to the financial limitations.

Canada
The Canadian government announced last year its desire for Canada to be recognized as one of the most innovative countries in the world, to be one of the top five countries for research and development performance by 2010.(Canada currently ranks 15th[7]). In February of 2002, The Government of Canada released Canada's Innovation Strategy[8] and followed quickly with an extensive consultation process intended to seek feedback from Canadians and secure the engagement and commitment to action of partners from the private, non-governmental, academic and government sectors. A National Summit on Innovation and Learning in November of 2002, will feature a national roll-up of the results of eight months of engagement with the

7 Speech from the Throne, Government of Canada 2001.

8 Government of Canada, New Release, February 12, 2002.

business communities, labour and Canadians across the country. The objectives of the Summit are to shape the priorities for Canada's Innovation Strategy and to seek the input and commitment from all sectors for a Canadian Innovation and Learning Action Plan.

There is great need for a clear strategy in space science. The CSA attempts to establish this strategy by working closely with the scientific community through consultation and feedback from the advisory boards. For the time being, space science missions/ opportunities continue to be evaluated on a case-by-case basis, through consideration of their merits and financial capability in the short-term, without necessarily seeking to establish a clear, longer-term strategy.

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APPENDIX - CANADIAN INDUSTRY PROFILE

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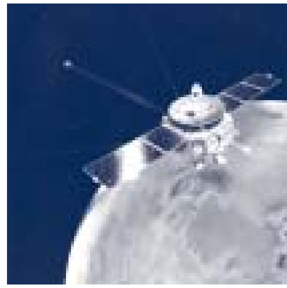
Suppliers

As demonstrated in the Global Trends 2001 report, there exists an extensive number of contributors to space science, with participants from the academic research, private and public communities. Increasingly, these actors are learning to collaborate in order to maximize their use of limited financial resources and expertise. The list below provides a few examples of Canadian suppliers and organizations that are actively contributing to space science. A more complete listing of Canadian suppliers and researchers can be accessed through the Canadian Space Agency's (CSA) Space Directory, available on the CSA web site at www.space.gc.ca.

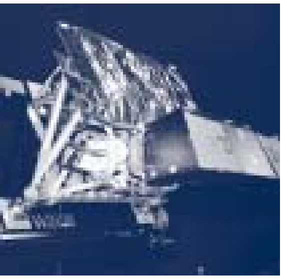
Private organizations (in alphabetical order)

- ***ABB Bomem:*** Bomem has been involved in various projects with the CSA, the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA) and National Space Development Agency of Japan (NASDA), related to the study of the atmosphere and atmospheric gases by developing instruments, for example, for SCISAT. The company's experience prompted it to establish a new commercial line of Fourier Transform Spectrometers based on space opportunities, profiting from its extensive experience in space science activities by transferring this knowledge to the design and manufacture of its commercial products, which are largely in the remote sensing area. The company has recently completed and delivered the Atmospheric Chemistry Experiment (ACE) instrument for the Canadian SCISAT satellite and is working on aspects of the future Planck mission, that will study the origin and evolution of the universe.
- ***Bristol Aerospace Limited:*** Bristol participates in space science research through the provision of sounding rockets, payloads and small satellites. The company is currently the prime contractor for the spacecraft bus component of the CSA's SCISAT program, a scientific satellite scheduled for launch early in 2003, which will study the chemical processes that control the distribution of ozone in the Earth's atmosphere. Bristol is also involved in the micro-vibration isolation system (MVIS) for the International Space Station.
- ***COM DEV:*** COM DEV designs, develops and manufactures scientific and remote sensing instrumentation for space. This company was the CSA's prime contractor for MOPITT (Measurements of Pollution in the Troposphere), providing systems engineering, detailed design, manufacturing, assembly and testing. Launched in 1999 on the Terra spacecraft for a 5-year mission, the instrument is collecting measurements on carbon monoxide and methane in the atmosphere. COM DEV also was prime contractor for the development of the CSA's Thermal Plaza Analyser (TPA) instrument that is flying to Mars on the Japanese Nozomi spacecraft, and developed the fine-guidance sensor for the NASA's Far-Ultraviolet Space Explorer (FUSE) mission. Currently, COM DEV is working on instruments and/or subsystems for the SWIFT, SCISAT, Cloudsat, James Web Space Telescope (JWST), and Hershel missions.
- ***Dynacon:*** Dynacon develops satellite control systems products and constructs complete microsats. The company was chosen by the CSA as the prime contractor to develop and build the world's smallest astronomical space telescope, scheduled for launch in 2003. Microvariability and Oscillation of Stars (MOST) is a CSA- program whose goal is to measure the ages of stars.
- ***EMS Technologies:*** EMS was the main industrial partner for the WINDII instrument that flew for over 10 years on NASA's highly successful Upper Atmospheric Research Satellite (UARS) mission as well as the plasma instruments for the Swedish Viking and Freja satellites. From these contracts, EMS developed the CALTRAC® star tracker product line that has been sold to several satellite customers. Currently, EMS is developing instruments and systems for the JWST, SWIFT, SCISAT, and the extended Polar Outflow Probe (e-POP) programs/missions.
- ***Guigné International Ltd:*** Guigné has developed a unique levitation technology based on work carried out for underwater acoustic imaging, used to study the ocean floor and Atlantic fish stocks. This innovative technology has evolved into space technology for use on the International Space Station (ISS). Developed specifically for use in the microgravity environment, the space DRUMS™ (Dynamically Responding Ultrasonic Matrix System) facility uses an acoustic levitation process that enables large fluid or solid material samples to be positioned and held stably in microgravity, while they are being processed on the space station. Called "containerless" processing, this leading-edge system of dynamic acoustic beam positioning prevents the samples from touching the walls of their containers, thus avoiding defects or contamination. Guigné is now benefiting from the commercialization of the product not only to space agencies but to other customers as well.
- ***MD Robotics:*** This company is a leading developer of space robotics having developed the Canadarm and Canadarm II. MDR is heavily involved with several partners in developing robotic and associated technologies for future planetary missions, especially Mars.
- ***Millenium Biologix:*** Millenium Biologix is a medical biomaterials company that partnered with the CSA and NPS Allelix Corporation for the OSTEO-1 experiment. The purpose of the experiment, launched in 1998 on board Space Shuttle Discovery, was to study the underlying process of bone loss and to evaluate possible treatments. Other partners included Mount Sinai Hospital, the University of British Columbia and the University of Toronto. As the results of the OSTEO-1 experiment were quite promising, a second OSTEO flight is slated for STS-107 in 2002 with similar partners. Millenium Biologix has also developed the Advanced Thermal ENvironment (ATEN) furnace, a major facility provided by Canada, designed to conduct fundamental studies on the International Space Station, including for example diffusion, Ostwald ripening, and particle pushing. Scheduled for launch in 2004, ATEN will also improve material processing techniques to grow semi-conductors, ceramics and glasses of better quality.
- ***NORCAT:*** The Northern Centre for Advanced Technology (NORCAT) based in Sudbury is developing advanced drilling technologies for future planetary missions.



APPENDIX - CANADIAN INDUSTRY PROFILE

- ***Optech:*** Optech is also involved in developing state-of-the-art LIDAR technologies for future space applications, including remote sounding of the Earth's atmosphere (ORACLE) and planetary missions.
- ***Routes AstroEngineering:*** Routes designs and builds space and environmental equipment and scientific instruments. This company has been involved in various CSA projects, including:
  - the CSA's Optical Spectrograph and InfraRed Imager System (OSIRIS), an imaging spectrograph on board the Swedish Odin satellite which is providing detailed data relating to ozone depletion;
  - the Microgravity Isolation Mount (MIM-II) which stabilizes experiments conducted in zero-gravity environments and prevents them from being affected by vibrations; as well as,
  - the Aquatic Research Facility (ARF) is a collaborative project between the CSA and NASA to study developmental biology under microgravity conditions. Following the success of the first flight of ARF, NASA asked the CSA to develop a Habitat for insect studies on the ISS.



Academic and research centers

The Canadian academic community and scientific research centres are responsible for most of the advancement and transfer of knowledge. Many Canadian universities actively participate in science projects funded by the Canadian government, which has led to the creation of various sub-organizations in specific fields. A few examples are provided below, identifying recent projects this community has been involved in:

- ***The University of British Columbia*** leads several projects involved in far infrared and submillimetre space astronomy, including Balloon Anisotropy Measurement (BAM), Balloon-borne Large Aperture Sub-millimetre Telescope (BLAST) and Planck.
- ***The University of Alberta*** is a leading centre for the study of the near-Earth space environment and is a leader in the Canadian Auroral Network for the OPEN Program Unified Study (CANOPUS)/ Geospace Monitoring programs, developing massively parallel computational algorithms to solve complex problems relating to the forecasting of space weather phenomena.
- ***The University of Calgary*** is leading various space science projects, such as the Thermal Plasma Analyzer (TPA), Suprathermal Mass Spectrometer (SMS), Ultra-Violet Auroral Imager (UVAI), Odin, CANOPUS, e-POP and Venus Climate Orbiter projects that have flown on or are being developed for several international satellite missions. Members of the Physics and Astronomy group are also partners in many other projects, such as Wind Imaging Interferometer (WINDII), VLBI Space Observatory Project (VSOP), Imager for Magnetopause-to-Aurora Global Exploration (IMAGE), Geoelectrodynamics and Electro-Optical Detection of Electron and Suprathermal Ion Currents (GEODESIC), Herschel, Hubble Space Telescope, Infrared Astronomical Satellite, etc. The university's success in space science and research has led to the creation of the Institute for Space Research.
- ***The University of Saskatchewan*** is the leading centre for the CSA's Optical Spectrograph and InfraRed Imager System (OSIRIS) instrument that is flying onboard the Swedish Odin satellite, providing the data centre for the analysis and distribution of results from this mission.
- ***The University of Western Ontario*** has been a long-standing partner in space research and is currently leading studies into a potential future mission to study gravity waves in the Earth's atmosphere (GWIM).
- ***The Centre for Research in Earth and Space Science (CRESS)*** is a York University Faculty-based Organized Research Unit, which focuses much of its research on Earth and space science, including geodynamics, remote sensing of the Earth's surface, troposphere, stratosphere, mesosphere and thermosphere, and plasma environment. It also includes research on planetary atmospheres, stars, and the interplanetary medium. Past involvement includes participation in the ODIN (OSIRIS) mission and MOPITT as well as being the lead institution for both the WINDII and future SWIFT wind measuring instruments.
- ***The Centre for Research in Earth and Space Technology (CRESTech)*** is a derivative of the Institute for Space and Terrestrial Science, which owes its origins to CRESS. Established in 1987, CRESTech is a Centre of Excellence of the Province of Ontario, which is at the forefront of research into how astronauts' perceptions and sense of balance are affected by space flight.
- ***The University of Toronto's (UoT) Institute for Aerospace Studies*** conducts research in the field of plasma materials. The UoT and the University of British Columbia are participating in the MOST mission. Within the Department of Physics are several scientists who are leading research into the study of the Earth's atmosphere from space, including the MOPITT instrument on-board NASA's Terra satellite, the MAESTRO instrument to be flown on SCISAT, and the MANTRA (Middle Atmosphere Nitrogen Trend Assessment) series of high-altitude balloon launches to study the Earth's middle atmosphere in relation to ozone depletion.
- ***The University of New Brunswick*** is rapidly developing into a major centre of space science activity with involvement in future planetary research, the Geospace Monitoring program and atmospheric studies.
- ***C-CORE*** is an applied engineering research institute located at Memorial University. Funded by industry and government, the Centre undertakes research that contributes to the safe and economic development of Canada's resources, particularly in industry-related activities and commercialization of space for enhanced oil recovery, contaminant transport, aerosol studies and environmental studies as applied to the microgravity environment.

Customers:

- Public sector: Governments remain the major buyers of scientific data, and the primary financial source of support for the development of scientific instruments and research. Departments mandated with public concern issues such as health and the environment make extensive use of the data and discoveries gathered through space science. Environment Canada, for example, makes extensive use of space science data for meteorological applications and research on ozone depletion, atmospheric pollution and climate change.
- National Research Council: NRC is Canada's premier science and technology research organization, a leader in scientific and technical research as well as the diffusion of technology and the dissemination of scientific and technical information. The council works in partnership with industry, universities and international research organizations, expanding the frontiers of science and technology. The NRC is specifically involved in space astronomy research providing the lead scientific support for the FUSE and NGST missions, as well as helping to support a Canadian Astronomical Data Centre that receives all results from the Hubble space Telescope (HST).
- Natural Sciences and Engineering Research Council: NSERC is the major partner with the CSA Space Sciences Program in ensuring that results from the scientific missions and projects supported by the CSA are analyzed and published.
- Environment Canada (EC)/Meteorological Service of Canada (MSC): MSC is a major partner of the Canadian Space Agency in formulating and implementing the Atmospheric Environment element of the Canadian space science activities. The MSC are associated in many programs and missions, including CloudSat, MAESTRO/SCISAT and MOPITT.
- Natural Resources Canada/Geological Survey of Canada (GSC): GSC supports the space science program in its Space Environment and Planetary Exploration programs. In the former, the magnetometer chain provided by MSC is an important part of the CANOPUS and Geospace Monitoring programs, and GSC also has the lead to develop a Space Weather forecast program. In the field of planetary exploration, support is provided to the community through the meteorite and remote sensing programs of the Canada Centre for Remote Sensing.
- General public: The general public is the major beneficiary for many aspects of Canadian space science activities through spin-offs such as breakthroughs in medical treatments and instruments, improved weather forecasting, as well as fewer interruptions in power grids and communications to name a few. One example includes Canada's Hoffman Reflex experiment that measures the effects of microgravity on human reflexes. This experiment has important implications for the health and safety of astronauts but may also lead to improvements in managing balance disorders on Earth, particularly in the elderly. Another example involves NASA, and the potential of eradicating dyslexia in young children through physical exercises that were initially developed for astronauts.