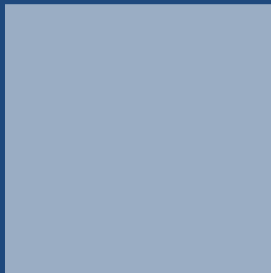
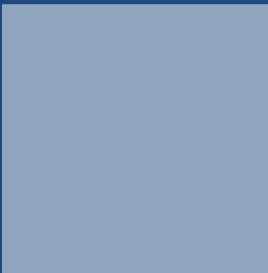
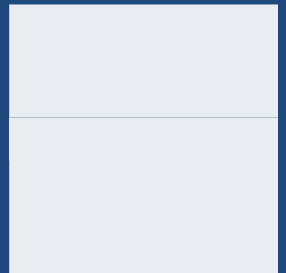
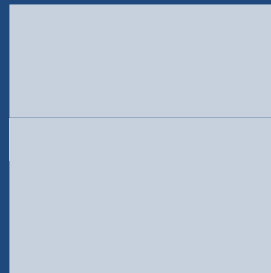
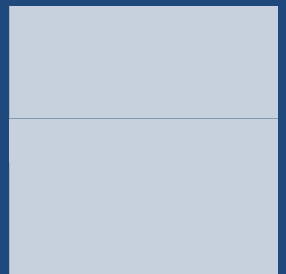
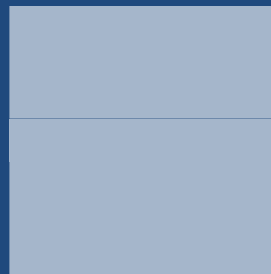
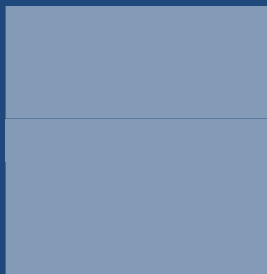
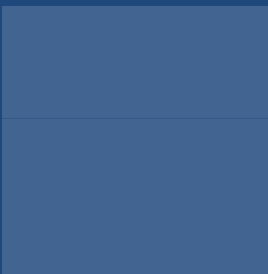
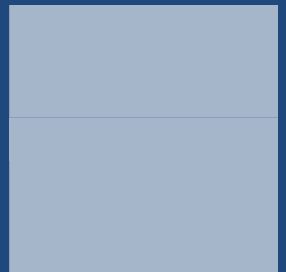
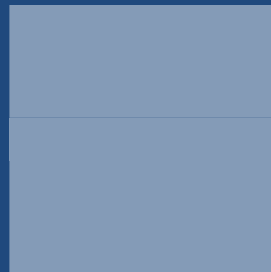
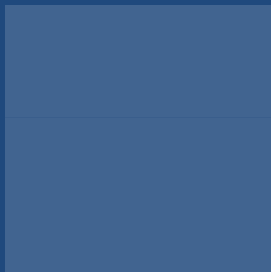


# Final Report

## The State of the Canadian Space Sector

Prepared for:  
**Aerospace Review**

2012 July 18



The logo for Hickling Arthurs Low, featuring the firm's name in a bold, blue, sans-serif font. Below the name is a stylized globe of the Earth. At the bottom of the logo, the tagline "INNOVATION POLICY ECONOMICS" is written in a smaller, blue, sans-serif font.

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# 1. Introduction

Canada has had a proud history in space. On September 28, 1962, Canada became the third country to design and build its own satellite when Alouette 1 was placed in orbit. Ten years later, Canada became the first country to have its own geosynchronous communications satellite with Anik 1. Subsequently, Canada gained international recognition and prestige from its work on the Canadarm for the Shuttle and Space Station and for its astronaut program. Perhaps less widely recognized is Canada's success with the RADARSAT 1 and 2 earth observation satellites, and science missions such as MOST.

However, a nation's capability in space provides more than just admiration and respect. Communications, earth observation, navigation, and scientific satellites have become essential to everyday life, even if users are often not aware of their role. For example, NASA documented that more than 12,000 lives have been saved by spinoff technologies such as cardiovascular medical devices and life rafts in the United States.<sup>1</sup> Every day, phone calls, weather forecasts, aircraft navigation, resource discovery, and protection of lives and the environment, depend on satellites for their success.

Further, Canada's investments in space have provided significant social and economic benefits. The Canadian Space Agency estimates that the Canadian space sector has revenues of \$3.4 billion per year. For example, CSA studies estimated the industrial economic impact of RADARSAT-1 alone to be \$1.2 billion in the period to 2020, with additional benefits to Canadian users of \$36 million per year.<sup>2</sup>

In addition, technologies that had their origins in space are making all sectors of the economy more productive. For example, NASA has estimated that improved aircraft design, robot submersibles capable of inspecting dams, and other technologies resulted in more than \$6.2 billion in cost savings in the United States.<sup>3</sup>

This report examines the state of the Canadian space sector and what will be required to continue Canada's past successes in space. We have examined various sources of space statistics and discussed Canada's situation with senior stakeholders in government and industry.

The next chapter reviews the major applications of space technologies and Canada's history and role in each. Chapter 3 examines the markets for space and Canada's performance. Chapter 4 looks at the role of policies and plans in supporting a space sector, the history of Canada's

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<sup>1</sup> Space Foundation (2012) The Space Report 2012, p30.

<sup>2</sup> Hickling Arthurs Low (1999) Assessment of the RADARSAT Program, prepared for the Canadian Space Agency; Hickling Arthurs Low (2007) RADARSAT-1 Benefits Assessment, prepared for the Canadian Space Agency

<sup>3</sup> Space Foundation (2012) The Space Report 2012, p30.

previous space plans, CSA's current plans, the technology development programs of the European Space Agency, and the technology competencies of Europe and Canada. Chapter 5 summarizes what we have heard from stakeholders about the needs of the Canadian space sector and the role of government. Chapter 6 presents our conclusions. Appendix A summarizes past and future Canadian space missions and Appendix B reviews Canadian space companies.

## 2. Space Technology Applications

Space is not a homogeneous industry and to understand the market's dynamics, it is necessary to consider the elements of the value chain within each of the major applications of space technologies.

In general, an operational space system consists of the space segment (the hardware in space), the ground segment (the hardware on the ground that is used to operate the space segment), and downstream applications and services that utilize the capabilities of the space and ground segments. A precursor of operational space systems is the research, development and demonstration of space technologies. These efforts also result in terrestrial applications of space technologies. While it is the space infrastructure that receives much of the attention, it is the applications and services that provide the majority of the economic benefits.

Depending on the space system, government, industry, academia, and consumers have differing roles to play in the development, provision and use of space systems and data.

The following sections briefly survey the major applications of space technologies – communications, earth observation, meteorology, navigation, surveillance, and scientific – and Canada's contributions and capabilities in each.

### Space System Components and Activities

- *Space Segment:* R&D, manufacturing, testing, integration and launch of platforms (satellites, spacecraft, and robotic systems), complete systems, subsystems and components.
- *Ground segment:* R&D, manufacturing, testing, and integration of facilities on Earth for controlling space-based systems and satellites, for linking satellites to operational terrestrial networks and for processing satellite-derived data.
- *Applications and Services:* Development and/or provision of services and value-added products and technologies that are derived from the use of space systems and/or data, and the provision of consulting and engineering services.
- *Fundamental Space Research:* Primarily research related to non-commercial or pre-commercial space activities.

Source: CSA

### 2.1 Communications

The satellite communications sub-sector is the most mature and commercial part of the space market, and by far the largest and financially successful. Most direct clients of satellite telecommunications services are telecommunications companies providing voice, data, and television services to consumers.

The first space systems were for communications and, driven by our need to communicate across vast distances, Canada was involved at the beginning. One of the issues highlighted by the Chapman report in 1967 was “the need for Canadian satellites for domestic communications by 1970 or 1971”. As a result, a new Department of Communications was created in 1969. As part of this DRTE was moved and renamed the Communications Research Centre (CRC). CRC survives today as part of Industry Canada, but no longer works in satellite communications. Telesat Canada was created to operate Canada’s new satellites, the first being Anik 1 in 1972. Subsequently, Canada has developed a strong indigenous capability in some parts of the satellite communications value chain.

Telesat Canada is now the fourth largest satellite communications provider in the world, serving broadcast, telecom, corporate and government customers. It has commissioned 21 satellites over the years and currently operates 11. All of these have been built outside of Canada. A summary of Canadian communications satellites is provided in Appendix A.1. A summary of Canadian space companies is provided in Appendix B.

COM DEV manufactures products and subsystems that are sold to major satellite builders for use in communications, space science, and remote sensing satellites. 80 percent of all commercial communications satellites ever launched include COM DEV components.

SED Systems is a developer and integrator of systems, products and services used by satellite manufacturers, operators and service providers in the global satellite communications sector. They also provide satellite operations services to control and monitor satellites for government and commercial clients.

While Canadian companies supply components to foreign satellite manufacturers and operate communication satellite systems, we do not have the indigenous capability to build large communications satellites. However, this may change with MDA’s recent purchase of the US-based satellite manufacturing division of Loral Space and Communications, the world’s largest maker of communication satellites.

While governments are significant users of satellite communication services, they do so for the most part as clients of private sector providers. However, there are exceptions to this in special cases. Militaries have some purpose built satellite communications satellites. For example, DND has paid \$350 M to participate in the Wideband Global Satellite (WGS) system. The constellation of WGS satellites increases the communications capabilities of the militaries of the United States, Canada, and Australia. There will, however, be no direct industrial benefits from Canada’s involvement.

In another case, CSA is examining a Polar Communications and Weather (PCW) satellite mission with a novel highly elliptical orbit to provide communications in the high north. There is the possibility of achieving this through a public private partnership with Telesat.



## 2.2 Earth Observation

By observing the Earth from space, satellites provide essential information on ocean, ice, land environments, and the atmosphere. Earth-observation (EO) satellites can help monitor and protect the environment, manage natural resources, and ensure safety and security. Satellite-borne EO systems have been providing imagery for more than two decades, and in recent years have seen a dramatic increase in data availability, quality, and access by end-users. EO is particularly useful for the monitoring of extensive, remote and isolated geographic regions that do not lend themselves easily to conventional, field-based data collection. As with communications satellites, because of the needs associated with a large land area, Canada was an early participant in EO research and development. A summary of Canadian EO satellites is provided in Appendix A.2.

EO systems measure the emanation of electromagnetic energy. They are broadly classified into passive and active sensors. Passive sensors register the amount of solar radiation reflected or thermal radiation emitted by the earth's surface and therefore they rely on an external source of illumination. Conversely, active sensors provide their own illumination by generating and emitting electromagnetic energy and measuring the proportion of that energy reflected by the targets of interest. Most EO satellites are in low earth orbit (LEO) so that they can be as close to the object they are imaging as possible. Some weather satellites (discussed separately below) are in geosynchronous orbit, which is much higher, so that they can monitor continental sized areas.

The utility of a remote sensing system for a particular application is determined by its spatial resolution, revisit frequency and spectral configuration. Spatial resolution determines the amount of detail that can be captured by the sensor. It is expressed as the size of a picture element (pixel) in ground distance units (e.g. metres). Today's operational EO systems deliver data at resolutions ranging from less than one metre to a kilometre. A related parameter is the swath coverage – the area on the ground covered by a single image – which is inversely proportional to the resolution. The revisit frequency of the sensor is defined as the time interval between the successive imaging of the same geographic area. Revisit rates of current systems typically range from less than 1 day to 30 days. The spectral configuration of a sensor includes the number of spectral bands as well as their positioning in the electromagnetic spectrum and their sensitivity.

Passive EO systems include panchromatic, multispectral, hyperspectral, and passive radar. Panchromatic optical satellite images, which are essentially photographs, are the easiest to interpret and the highest resolution, now as fine as 0.5 metres. High resolution optical satellites are the most common, fully commercial satellites, although such ventures usually have significant government anchor tenants. While Canada has no panchromatic optical satellites, Canadian companies distribute and work with imagery from satellites such as SPOT, QuickBird, WorldView, and GeoEye.

Multispectral imagers collect data in narrow spectral bands in the electromagnetic spectrum (i.e. ‘colours’, although the sensors may detect wavelengths outside of visible light into the infrared and ultraviolet). Multispectral and panchromatic sensors are often combined on the same satellite. In 2011, Blackbridge Geomatics acquired the assets of RapidEye AG of Germany. RapidEye’s five identical satellites, launched in 2008, provide five metre resolution, five band, multispectral imagery. The RapidEye satellites were designed and implemented by MDA. ABB Bomen was involved in the development of MERIS, an imaging spectrometer with 15 bands, on the ESA Envisat satellite. Envisat operated from 2002 until 2012.

Where multispectral systems detect tens of spectral bands, hyperspectral systems detect hundreds and as a result produce vast quantities of data. Canada has had an active hyperspectral program for the last decade. Much of that work was conducted by CCRS and supported by airborne systems. A planned Canadian hyperspectral satellite mission has now been abandoned.

The principal active remote sensing systems employ synthetic aperture radar (SAR) sensors. SAR systems do not rely on the sun to provide illumination and can therefore acquire imagery day or night. Moreover, the radiation used in SAR sensing can penetrate haze or cloud cover. These systems are therefore particularly desirable in areas, such as the North, that are characterized by significant levels of cloud cover or darkness throughout the year. By combining two or more SAR images and using differences in the phase of the waves returning to the satellite in a technique known as interferometry, surface deformation or digital elevation can be calculated to an accuracy of centimeters.

Canada’s major EO satellite investments have been in the design, development, and operation of radar satellites. RADARSAT 1 was launched in 1995, RADARSAT 2 was launched in 2007, and the RADARSAT Constellation Mission (RCM) is now being developed. Over 100 Canadian companies have contributed to that work, including COM DEV, and SED Systems, with MDA as the prime contractor. MDA and MPB Technologies also contributed to ESA’s Envisat Advanced Synthetic Aperture Radar (ASAR) instrument.

An EO system typically has three parts that may be fulfilled by three or more separate organizations. First is the satellite operator which controls the satellite and instructs it to fulfill certain tasks – i.e. to take images of particular locations at certain times, usually as requested by a customer. MDA operates RADARSAT 2.

Second is the ground station operator which receives the data as the satellite passes within range, provides some initial processing, and distributes it as required. Since most satellites have limited on-board data storage capacity, ground stations are distributed around the world so that data can be off-loaded to make room for new data acquisitions. Often a satellite operator will own some ground stations, but also work with others to access ground stations in other parts of the world.

For example, in the case of RADARSAT-2 ground segment equipment is housed in CSA facilities in Montreal and Saskatoon, in CCRS facilities in Gatineau and Prince Albert and MDA headquarters in Richmond, British Columbia. There is also reception, archiving, and processing

equipment in other facilities all over the world. The 2012 federal budget allocated \$23 million over two years to CCRS for new satellite data reception facilities and the development of a data management system.

Third is the value-added industry that takes the EO satellite data and performs further specialized processing and analysis to meet the needs of the end-user. For example, this might pertain to natural resource development, mapping, sea ice and iceberg detection, agriculture, forestry, or wide range of other applications. While Canadian firms are adept at using all types of EO data, they have developed particular specializations with SAR imagery. Examples of firms in the Canadian value-added industry include: MDA, C-Core, Hatfield, Noetix, Viasat, PCI, IES, and Enfotec (see Appendix B for company descriptions). Most of these firms are very small.

Meteorology satellites are in effect EO satellites, but dedicated to weather forecasting purposes. They can be used to measure a wide variety of phenomena such as cloud systems, wind, currents, and land and water temperatures.

Meteorology is unique in that the satellites are owned by public sector organizations around the world operating in a coordinated and cooperative manner. The most significant of these are NOAA in the United States, EUMETSAT in Europe, and agencies in Russia, Japan, India, and China

In addition to the dedicated meteorology satellites, a number of science missions (discussed below) provide information on parameters that contribute to weather forecasting, climate change research, and environmental monitoring.

While a voracious consumer of satellite meteorology data, Canada has not participated in these missions. Canada has, however, contributed to a number of weather-related science missions (discussed below). A proposed Polar Communications and Weather (PCW) mission is being investigated by CSA, DND, and EC to fill gaps in weather monitoring in the high Arctic.

## 2.3 Navigation, Position, and Timing

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Global Navigation Satellite Systems (GNSS) provide positioning, navigation and timing information to users with the appropriate receivers. GNSS are made up of three parts: a constellation of navigation satellites (space segment and augmentation facilities), ground infrastructure (control segment), and user receivers (user segment). The space segment is typically composed of about 24 satellites in medium earth orbit transmitting information over line-of-sight radio signals. The control segment ground stations track the satellites to determine satellite clock and orbit status and then update the navigation message of each satellite. The user segment consists of an antenna, receiver, and a processor which computes position, velocity and precise timing for the user. The GNSS in operation or planned for the future include:

- *Global Positioning System (GPS)* (United States) – Operational since 1995, GPS currently has 32 operational satellites in orbit, with about 8 visible at any time from nearly any place with a clear view of the sky.
- *GLobal NAVigation Satellite System (GLONASS)* (Russia) – Also operational since 1995, the system initially fell into disrepair for a number of years but has recently been restored to a full operational constellation of 24 satellites.
- *Galileo* (European Union or EU) – Galileo will utilize 28 satellites and is expected to be fully operational by 2017. It is intended to provide more precise measurements in more difficult environments than currently available through GPS or GLONASS.
- *Compass* (China) – By 2015 this system will have a constellation of 35 satellites, which include 5 geostationary orbit satellites and 30 medium Earth orbit satellites that will offer complete coverage of the globe.
- *Regional Systems* – Include Beidou 1 (China), DORIS (France), IRNSS (India) and QZSS (Japan)

The accuracy and integrity of a GNSS can be improved through the use of space-based augmentation systems. Government operated systems include: North America Wide Area Augmentation System (WAAS); European Geostationary Navigation Overlay Service (EGNOS); Japanese Multi-Functional Satellite Augmentation System (MSAS); and Indian GPS Aided Geo Augmented Navigation (GAGAN). Industry operated systems covering Canada include John Deere's StarFire and Trimble's OmniSTAR.

Canadian uses of GNSS include:

- Air Transportation: aircraft navigation, aircraft surveillance
- Marine Transportation: vessel navigation, vessel position reporting and tracking, dynamic positioning.
- Road Transportation: in-vehicle navigation, automatic vehicle location
- Safety: location services for national security, public safety, emergency management, and law enforcement, corrections, and crime prevention.
- Government Services: natural resource management, meteorology, geodynamics, municipal services, official time determination, mapping, and hydrographic surveying.
- Energy and Utilities: time synchronization, positioning and monitoring of assets.
- Information and Communication Technology: time synchronization.

- Finance: transaction timing

Canada provides four WAAS reference stations operating in Goose Bay, Gander, Winnipeg and Iqaluit to help extend WAAS coverage over the North. One of the three WAAS satellites is actually a payload on a Telesat Anik satellite. Canada examined contributing to the European Galileo system, but that partnership did not happen.

NovaTel is one of the few Canadian companies manufacturing GNSS positioning products, including GNSS receivers, firmware, antennas, inertial augmented systems, and post-processing software.

## 2.4 Surveillance

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Surveillance satellite systems improve navigation safety, provide distress alerting, and allow authorities to monitor vessel movements. The following sections describe systems for search and rescue and vessel identification.

### 2.4.1 Search and Rescue

COSPAS-SARSAT (COSPAS is an acronym for the Russian words “Cosmicheskaya Sistema Poiska Avariynyh Sudov”, or Space System for the Search of Vessels in Distress, and SARSAT is Search and Rescue Satellite-Aided Tracking system) provides accurate, timely, and reliable distress alert and location information to help search and rescue authorities assist persons in distress. The system was established in 1979 by Canada, France, the United States, and the former Soviet Union, and today the system has 43 participating countries and has been instrumental in saving more than 28,000 lives worldwide.<sup>4</sup>

The system consists of:

- Distress radiobeacons (ELTs for aviation use, EPIRBs for maritime use, and PLBs for personal use) which transmit signals during distress situations;
- Instruments on board satellites in geostationary and low-altitude Earth orbits which detect the signals transmitted by distress radiobeacons;
- Ground receiving stations which receive and process the satellite downlink signal to generate distress alerts; and

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<sup>4</sup> David Affens, *et al*, 2011. Innovation: The Distress Alerting Satellite System, GPS World, January 1, 2011, (see <http://www.gpsworld.com/gnss-system/innovation-the-distress-alerting-satellite-system-10883>)

- Mission Control Centers (MCCs) which receive alerts and forward them to Rescue Coordination Centers (RCCs), Search and Rescue Points Of Contacts (SPOCs) or other MCCs.

The space system consists of both a low earth orbit constellation and geostationary satellites. For the LEO constellation, Russia supplies two Cospas satellites and the USA supplies two NOAA meteorological satellites equipped with SAR instrumentation supplied by Canada and France. The GEO constellation consists of satellites provided by the USA (GOES series), India (INSAT series) and EUMETSAT (MSG series).<sup>5</sup>

## 2.4.2 Space-Based AIS

In 2000, as a part of the Safety of Life at Sea (SOLAS) convention, the International Maritime Organization (IMO) added Automatic Identification Systems (AIS) to the shipboard navigational carriage requirement for a number of ship categories. All ships in service in the applicable categories are mandated to operate their AIS equipment continuously, except where international agreements allow navigational data to be protected.

AIS was conceived mainly as a terrestrial-based collision avoidance system using regular VHF transmission and reception of short binary messages containing information about the ship's identity, position, speed and course. Data such as the ship's name, IMO number, cargo type and estimated time of arrival (ETA) are also transmitted, but less frequently. However, the placement of an AIS receiver on a satellite has advantages for marine surveillance requirements. While space-based AIS services have been available for some time, there are still issues with signal collisions, interference, time latency and update frequency.

The S-AIS business consists of three components: 1) Construction of the AIS satellite system, including the AIS receiver, the satellite platform, the ground stations, and the data processing infrastructure; 2) Collection and processing of AIS transmissions, and 3) Distribution of value-added AIS information to end users. Currently, players in the AIS markets participate in some or all of these components.

S-AIS players exist in both the public and private sectors. Commercial S-AIS initiatives are being developed by ORBCOMM (USA) and exactEarth (Canada). They are working in cooperation with LuxSpace and SpaceQuest, respectively, for the provision of the satellites. Governments in Norway, India, Europe, the United States, and Canada are also experimenting with the concept.

The potential total market size is in the tens of millions of dollars, up to \$100 million per year. The ultimate market size will depend heavily on whether governments implement their own S-AIS systems rather than working with commercial operators.

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<sup>5</sup> <http://www.cospas-sarsat.org/en/system/detailed-system-description/satellite-configuration>

The primary market for S-AIS data appears to be government agencies, primarily those with security and enforcement mandates. The split between government and commercial markets is estimated to be on the order of 75% to 25%. Most of the potential government clients will be from the developed world with responsibility for large areas of ocean or interests in global security. This is probably primarily the G10 or G20 countries.<sup>6</sup>

## 2.5 Science

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Canadian scientists and companies have been involved in a number of satellite missions that address specific scientific objectives related to space weather, astronomy, and environmental science. While this work does not have significant economic impacts, it does exercise and advance Canada's space technology capabilities and contributes significantly to the advancement of science.

### 2.5.1 Space Weather

Space weather phenomena occur when energetic particles thrown out from the Sun interact with the earth's magnetic field producing magnetic disturbances and increased ionization in the ionosphere, between 100 and 1,000 km above the earth. While the Sun is the main driver of space weather impacts, other factors (e.g., radiation belt dynamics) also play an important role. Since the earth's magnetic field is concentrated at the poles, high latitudes are particularly impacted by these disturbances. Space weather has a variety of impacts on technology, both in space (satellites and manned missions) and on the ground (pipelines, power systems, communication cables).

The most visible manifestation of space weather is the aurora borealis. Canada's first satellite missions (and among the first satellites in the world) were created to study this phenomenon: Canada became the third country to design and build its own satellite when Alouette 1 was placed in orbit in 1962. A team of DRTE scientists was formed under John Chapman's leadership to design and build two identical Alouette models. Contractors such as RCA and Spar Aerospace Limited produced their first space hardware products during Alouette's construction.

Following the success of Alouette-I (1962), Canada and United States signed an agreement to launch further satellites under a new program called International Satellites for Ionospheric Studies (ISIS). Under the program, the Alouette II was launched in 1965 and two new satellites, ISIS I and ISIS II, were launched in 1969 and 1970 respectively.

Both ISIS satellites were designed and developed in Canada. The Defense and Research Telecommunications Establishment managed the project, while the private sector handled most

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<sup>6</sup> C-Core and Hickling Arthurs Low (2011) Automatic Identification System (AIS) Contextual Analysis, prepared for the Canadian Space Agency



of the hardware development. RCA Ltd. of Montreal largely built both satellites, with some of the work subcontracted to De Havilland and SPAR.

Since then, Canada has continued its leadership in space weather research. CAScade, Smallsat and IONospheric Polar Explorer (CASSIOPE) is a made-in-Canada small satellite planned to be launched in 2013. One of its payloads consists of eight high-resolution instruments used to probe the characteristics of near-Earth space. Partners in the mission include the University of Calgary, Bristol Aerospace, and MDA, the prime contractor for the overall mission.

Canada has also cooperated with Sweden on the Viking satellite (1986), with Japan on the Akebono satellite (1989), with Russia on Interball-2 (1996), and with NASA on the THEMIS mission (2007). Canadian organizations involved in these missions include: the University of Calgary, CRC, Bristol Aerospace, MDA. Summaries of these missions are contained in Appendix A.3.

### **2.5.2 Astronomy**

Canada has been a leader in astronomy for over a century, long before the advent of space-based astronomical sensors.<sup>7</sup> Much of that success has been due to Canada's important role in the development of ground-based observatories, but in recent years Canada has been very active in satellites used for astronomy research. In the absence of interference from the earth's atmosphere, space-faring facilities have the advantage of being able to detect portions of the wavelength spectrum that are blocked or filtered by the earth's atmosphere. As such they are an important complement to ground-based facilities.

The only Canadian astronomy satellite is MOST (Microvariability and Oscillations of Stars). It is the world's smallest astronomical space telescope and it measures the ages of stars in our galaxy. Dynacon Enterprises Limited (now Microsat Systems Canada Inc.) was the lead contractor. Other key partners included: the University of British Columbia, the University of Toronto Institute for Aerospace Studies (UTIAS), the Centre for Research in Earth and Space Technology (CRESTech), and COM DEV (formerly Routes AstroEngineering), and a team of scientists from across Canada and the U.S. led by the University of British Columbia.

Canada is currently building NEOSSat (the Near-Earth Object Surveillance Satellite) with a planned launch in 2012. It will be the world's first space telescope dedicated to detecting and tracking asteroids and space debris. NEOSSat applies key technology already demonstrated in Canada's MOST satellite. NEOSSat is jointly funded by CSA and Defence Research and Development Canada (DRDC). The satellite is built by Microsat Systems Canada Inc., with support from Spectral Applied Research and COM DEV (formerly Routes AstroEngineering). The science team includes DRDC, the University of Calgary, the University of British Columbia, the Planetary Science Institute, the University of Arizona, the University of Western Ontario, the University of Hawaii, NASA, and SAIC.

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<sup>7</sup> Hickling Arthurs Low (2011) Astronomy in Canada, prepared for the National Research Council.



Canada is a partner on other former, existing, and planned astronomy missions, including with NASA and France on FUSE (1999), with ESA on the Herschel and Planck space observatories (2009), with Austria and Poland on BRITE Constellation (2012), with Japan on Astro-H (2014), and with NASA on the James Webb Space Telescope (2018). Canadian organizations involved in these missions include: COM DEV, HIA, CSA, the University of Toronto, the University of British Columbia, the University of Calgary, the University of Western Ontario, the University of Victoria, McMaster University, the Université de Montréal, Saint Mary's University, the University of Waterloo, and the University of Manitoba. Summaries of these missions are contained in Appendix A.4.

### **2.5.3 Environmental Science**

In addition to general earth observation missions, satellites often have specific research goals that contribute to environmental science.

For example, SCISAT-1 is a Canadian satellite designed to make observations of the Earth's atmosphere to help improve the understanding of the depletion of the ozone layer, with a special emphasis on the changes occurring over Canada and in the Arctic. Its main instruments are an optical Fourier transform infrared spectrometer, the ACE-FTS instrument, and an ultraviolet spectrophotometer, MAESTRO. These devices record spectra of the Sun, as sunlight passes through the Earth's atmosphere, making analyses of the chemical elements of the atmosphere possible. SCISAT is a relatively small satellite launched in 2003. The Canadian Space Agency coordinated its design, launch and use. The team of Canadian and international scientists is led by the University of Waterloo. Contractors included Bristol Aerospace, ABB Bomem, EMS Technologies (now MDA), Routes AstroEngineering (now COM DEV), and COM DEV. The array detectors for the on-board cameras were contributed by Belgium. NASA provided the launch. There were also contributions by the Meteorological Service of Canada, the University of Toronto, and the Natural Sciences and Engineering Research Council.

Canada is also a partner on other international environmental satellite missions, including with NASA on UARS (1992), with NASA on Terra (1999), with Sweden on Odin (2001), with NASA on CloudSat (2006), and with ESA on SMOS (2009). Canadian organizations involved in these missions include: COM DEV, Array Systems Computing, Environment Canada, HIA, York University, Université du Québec à Montréal, the University of Toronto, the University of Calgary, the University of Waterloo, St. Mary's University, McMaster University, and the University of Saskatchewan. Summaries of these missions are contained in Appendix A.5.

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## **2.6 Human Space Flight and Space Exploration**

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Canada's involvement in human space flight and space exploration includes the development of robotics and space vision, the Canadian astronaut program, and participation in the Mars

expeditions of other countries. While this work does not have significant economic impacts, it does exercise and advance Canada's space technology capabilities and contributes significantly to the advancement of science.

### **2.6.1 Robotics and Space Vision**

Perhaps the space technology best known by Canadians is the Shuttle's Canadarm, technically named the Shuttle Remote Manipulator System. It first flew on the Space Shuttle Columbia (STS-2) in 1981. The Canadarm was retired along with the Space Shuttle program after mission STS-135, which marked the robotic arm's 90th flight.

Canadarm: The Next Generation, is Canadarm2, technically known as the Mobile Servicing System (MSS). The 17-metre long robotic arm has been located on the International Space Station (ISS) since 2001. It plays a key role in station assembly and maintenance; it moves equipment and supplies around the station, supports astronauts working in space, services instruments and other payloads attached to the ISS, and helps to capture spacecraft and dock them to the ISS.

The MSS is composed of the actual arm called Space Station Remote Manipulator System (SSRMS), the Mobile Remote Servicer Base System (MBS) and the Special Purpose Dexterous Manipulator (SPDM also known as Dextre or Canada hand). The system can move along rails on the Integrated Truss Structure on top of the US provided Mobile Transporter cart which hosts the MRS Base System. The MSS was designed and manufactured by MDA Space Missions (previously called MD Robotics; previously called SPAR Aerospace).

The station received a second robotic arm during STS-124, the Japanese Experiment Module Remote Manipulator System (JEM-RMS). The JEM-RMS will be primarily used to service the JEM Exposed Facility. A third robotic arm, the European Robotic Arm (ERA) is scheduled to be launched alongside the Russian-built Multipurpose Laboratory Module in 2013.

Related to the Canadarm is Canada's Space Vision System (SVS). It provides information on the exact location, orientation and motion of a specified target, helping to enhance astronauts' vision as they perform precise tasks in extreme lighting conditions. The Space Vision System was first tested by Canadian astronaut Steve MacLean during Shuttle Mission STS-52 in 1992. It is still in use with Canadarm2 on the ISS. SVS was conceived of at NRC and built by NEPTEC.

Although a technical and public relations success, the Canadarm has not resulted in significant economic spinoffs. Other countries have caught up with, and perhaps surpassed, Canadian capabilities in this area as evidenced by the Japanese and European arms for ISS. Attempts to find terrestrial applications for the technology have not been particularly successful. MDA is developing an in-orbit servicing capability that will involve a robotic arm, but that venture has been a difficult sell.

## 2.6.2 Astronauts

The Canadian Astronaut Program was established under the management of the National Research Council of Canada in 1983, when the United States invited Canada to fly an astronaut on the Space Shuttle. This invitation led to the creation of a permanent corps of Canadian astronauts.

Canada's astronauts' main job is to develop, support, train and fly on international space missions and take part in further scientific research and advanced technology development. They also play a key role in raising awareness about Canada's activities in space and inspiring youth to explore the fields of science and technology.

Canada has now undertaken three rounds of astronaut recruitment. As a result of the first call in 1983, six astronauts were selected, the second call in 1992 provided four more, and the most recent call in 2008 recruited two.

Since 1984, when Marc Garneau became the first Canadian in space, eight Canadians have flown on NASA Space Shuttles and on Russian Soyuz rocket in 15 missions. In May 2009, Robert Thirsk flew to the International Space Station (ISS) for a six-month stay, thus becoming the first Canadian to stay aboard the ISS for an extended period.

Astronaut Marc Garneau was appointed President of the Canadian Space Agency in 2001. In 2008, Astronaut Steve MacLean was appointed the current President of the Canadian Space Agency.

## 2.6.3 Planetary Exploration

Canada has no active planetary exploration program, but it has participated in a few international missions to Mars.

Japan's Nozomi satellite was designed to study the Martian atmosphere and its interaction with solar wind. It was launched in 1998 but did not successfully achieve orbit around Mars. Canada provided the Thermal Plasma Analyzer instrument for the mission.

NASA's Phoenix Mars Lander arrived near Mars' northern polar cap in 2008 where it operated for more than five months. Canada provided a meteorological station for the lander.

Launched in 2011, NASA's Curiosity Mars Lander is expected to arrive on Mars on August 6, 2012. Curiosity is carrying a Canadian-made geology instrument.

Canadian organizations involved in these missions include: MDA, Optech, Natural Resources Canada, CSA, York University, University of Alberta, Dalhousie University, University of Calgary, University of Guelph, University of New Brunswick, University of Western Ontario. Summaries of these missions are contained in Appendix A.6.

# 3. Space Markets

## 3.1 Canadian Performance

According to the Canadian Space Agency’s ‘State of the Canadian Space Sector 2010’,<sup>8</sup> the Canadian space sector generated total revenues of \$3.4 billion; an increase of 14% over the previous year. Those revenues were evenly split between domestic and foreign customers. The domestic customers were 82% from the private sector and 18% from government. Total employment for the sector was 8,256. 67.5% of the revenues went to Ontario, with the rest almost evenly split among the other regions. Figure 1 shows the trend in space revenues over the past ten years in both current and constant 2010 (i.e., corrected for inflation) dollars. Overall, the general trend is upward at about 7% per year.

**Figure 1: Historical Canadian Space Revenues**

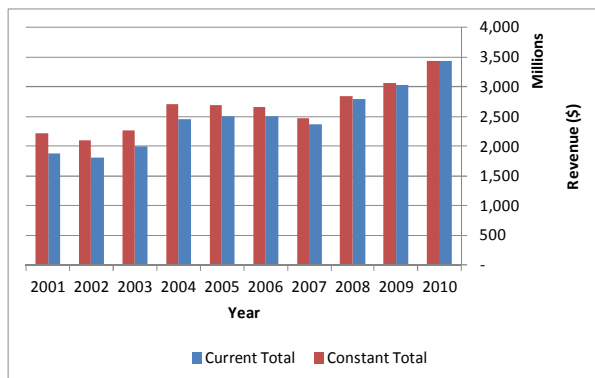
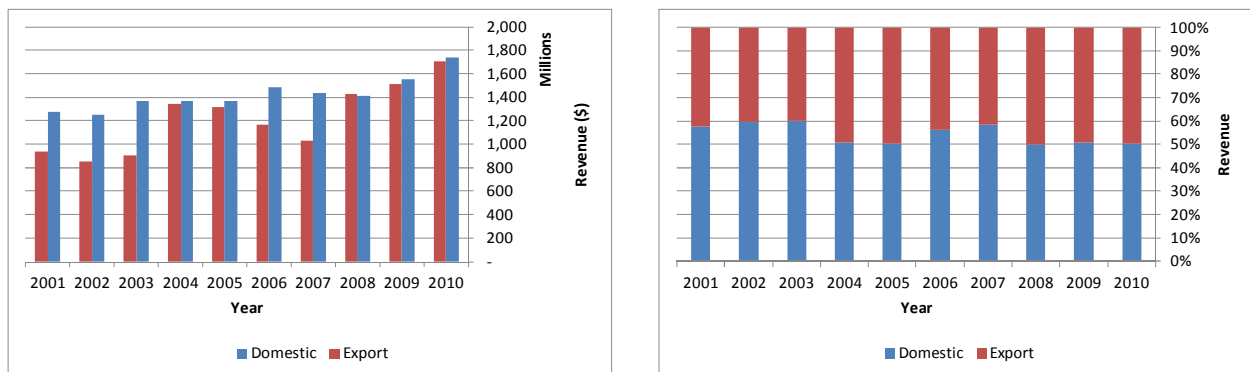


Figure 2 shows the portion of exports over the past ten years. Overall, exports have been 40% to 50% of revenues.

**Figure 2: Historical Export Portion of Canadian Space Revenues**



<sup>8</sup> Canadian Space Agency (2011) State of the Canadian Space Sector

Figure 3 shows the portion of domestic revenues that have been from the public sector. That portion is now about 20%, down from a high of almost 30% ten years ago.

**Figure 3: Historical Public Portion of Domestic Canadian Space Revenues**

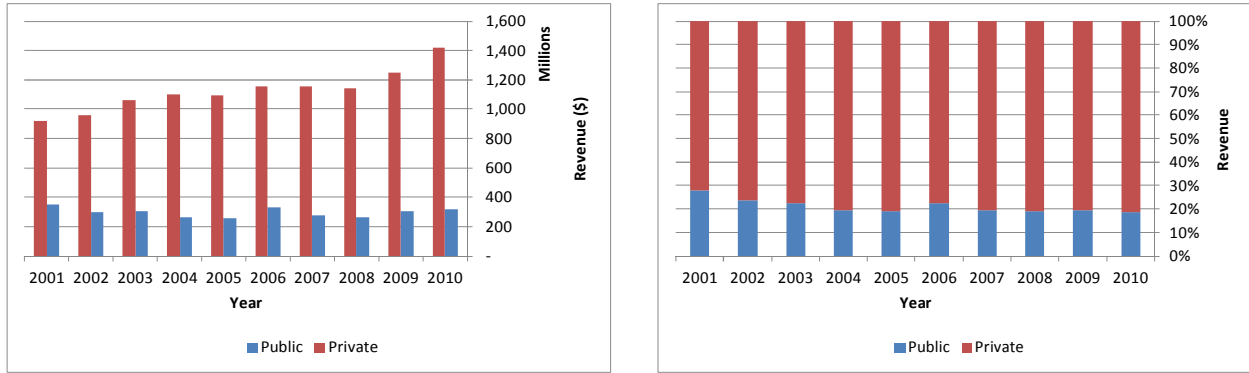
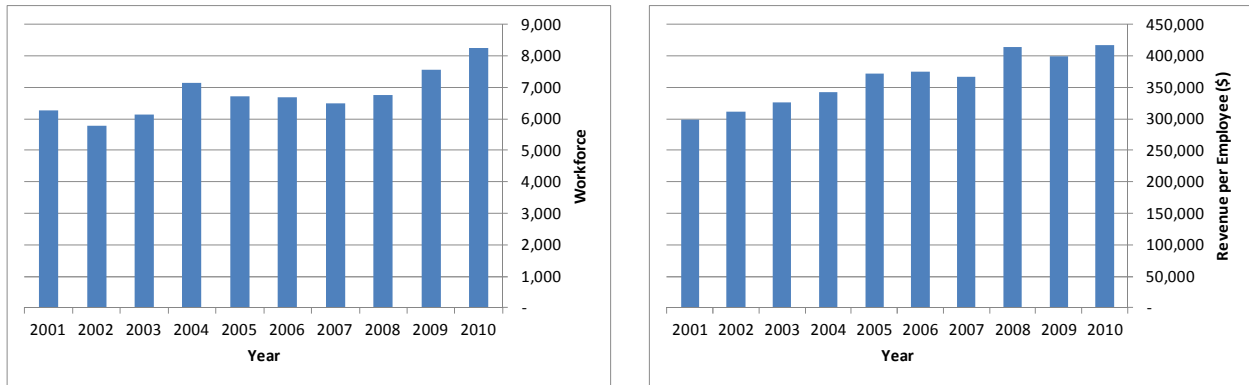


Figure 4 shows the historical Canadian space workforce which has been increasing. However, it has not kept pace with the increase in revenues as the productivity of the sector has increased from about \$300,000 revenue per employee to about \$400,000 over the last decade.

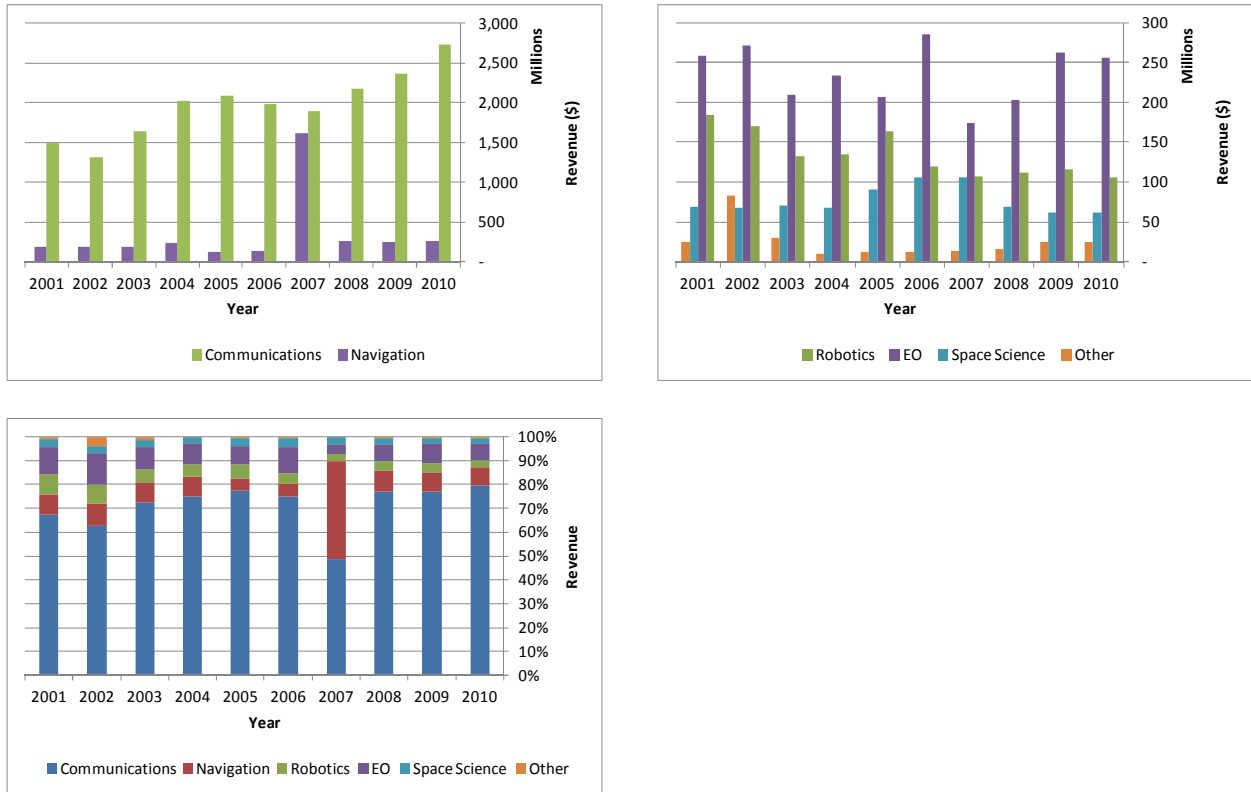
**Figure 4: Historical Canadian Space Workforce**



These total numbers hide a few important characteristics of the sector. First is the dominance of satellite communications. Communications revenues of \$2.729B were 79% of total space sector revenues in 2010 and accounted for 97% of the growth in the sector. This sub-sector was followed by navigation at 8% (\$260.4 M), earth observation at 7% (\$239 M), robotics at 3% (\$106 M), space sciences at 2% (\$68 M), and ‘other’ at 1% (\$25 M). Navigation and space sciences had minor growth and robotics and earth observation saw revenues decrease.

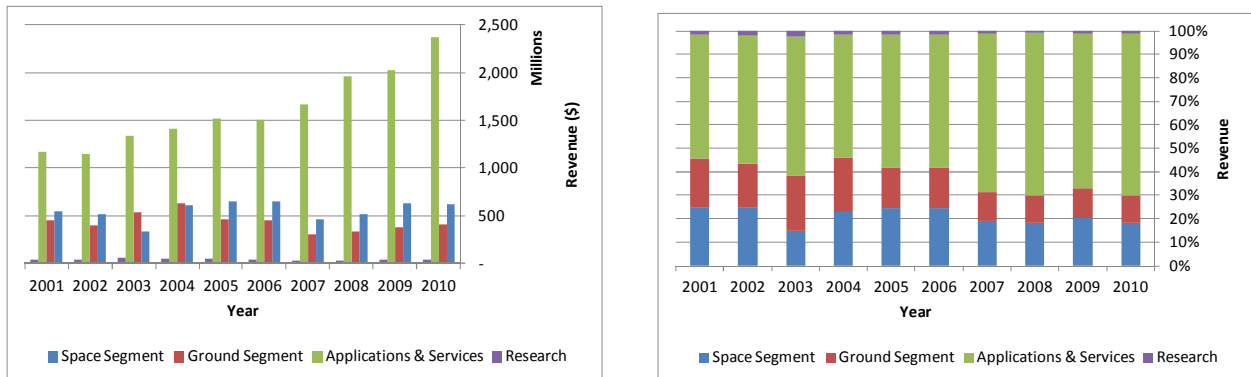
Figure 5 shows the historical trend for revenues by space sub-sector that indicates the increasing dominance of communications and the static or decreasing status of the other sub-sectors.

**Figure 5 Historical Revenues by Canadian Space Sub-Sector**



The second characteristic is the dominance of applications and services. Although space and ground hardware receives the most media attention, it is in fact the applications and services derived from that hardware that drives the economic benefits from the sector. This can be seen in Figure 6 which shows that applications and services currently account for about 70% of revenues, up from about 55% a decade ago. This disparity will only increase as revenues from the space and ground segments are flat and all of the increases in revenue for the sector are coming from applications and services.

**Figure 6: Historical Canadian Space Sector Revenues by Space Sector Segment**



The third characteristic of the sector is the high degree of concentration. While there are almost 200 Canadian organizations involved in the space sector, in 2010 98.3% of the total space revenues and 92% of the space sector workforce were accounted for by the activity of the top 30 organizations and growth was dominated by a few top earning companies.

Fourth, is the sector's low level of R&D; surprising, given the 'rocket science' perception of space technology. In 2010, space R&D expenditures totaled \$72 M, just 2% of revenues, with 50 organizations undertaking space R&D projects. This low level is partially due to the fact that much of the R&D in the sector is paid for by clients and is therefore the bread and butter revenue of many organizations.

The final characteristic is the important role of the public organizations in the space sector. In 2010, universities and research centres accounted for \$65M of domestic revenues, with \$54M coming from public funds, and \$4.4M of revenue from foreign sources.

### 3.2 Canada in the International Market

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The Space Report 2012 estimates that the global space market was \$258 B in 2010, growing 8.4% over the previous year<sup>9</sup>. Most of the growth was in the private sector as public sector budgets were stagnant in many economies, although public spending on space in some emerging economies is strong. The impact of the financial crises on the space sector has been attenuated to some degree by the long term planning nature of the development of space systems.<sup>10</sup>

Thus Canada has about 1.3% of the world market; comparing this to Canada's 2.5% overall share of the world's economy means that our space sector is performing at about half of what might be expected.

To a great extent this difference is due to what we don't do. For example, we have no launch capability and very little satellite manufacturing capacity; but these are relatively minor in the overall scheme of things. Most important is that Canada has essentially missed out on the whole GNSS market.

Canada has done relatively well in the communications market, and we have in the past held our own in earth observation, although that position is now slipping. As was discussed above, that performance can be credited to initiatives of the federal government early in the history of the sector. While Canadian government spending is not a large portion of the sector's overall revenues, it is critical to enabling the success of some portions of the sector.

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<sup>9</sup> Space Foundation (2012) The Space Report 2012

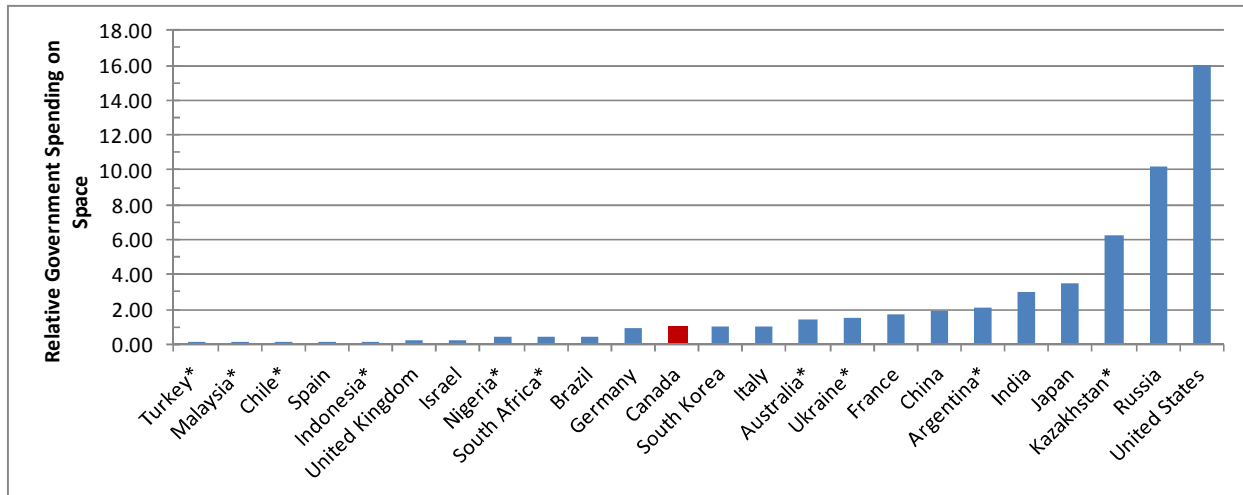
<sup>10</sup> European Space Agency (2011), European Space Technology Master Plan, page 12.

According to The Space Report, globally government spending on space increased even though its percentage of the overall space economy declined to 25% in 2011 from 27% in 2010. The aggregate growth rate for government space budgets was 6%, bringing spending to \$72.77 billion in 2011. The governments of Brazil, India, and Russia all increased their space budgets by more than 20%. Some space agencies experienced more modest growth, as was the case for the European Space Agency (ESA), whose budget increased by 7% in spite of the ongoing fiscal problems in some of its member states. Space agencies in other nations, such as the United States and Japan, operated under flat or diminished budgets.

That situation is important to note, as Canada’s future competitors in space are likely not to be our traditional partners, the United States and Europe, but emerging economies such as Brazil, Russia, India, and China.

Figure 7 shows Canada’s government spending on space adjusted for the relative size of each economy (i.e., dollars of government space expenditures per dollar of GDP). By definition, Canada is 1.0. As can be seen, the United States spends 16 times more than Canada for its size. However, more interesting are the emerging economies such as South Korea, China, and India, which are making space a priority.

**Figure 7: Relative Government Spending on Space**



\*2011 Data, otherwise 2010 Data.  
Source: The Space Report 2012



# 4. Space Policy and Plans

## 4.1 The Role of Space Policy and Plans

A space policy describes the context in which a government sees the international and domestic space environment, placing its own activities in relation to the activities of others. It can set goals for how government space projects and activities are to be developed in light of that environment and how those programs relate to other issues. The Space Report 2012 puts it well:

“As space activities across the globe become more dynamic – blending commercial, government, and crossborder activities – governments increasingly see a need for a formal space policy to provide a framework for coordination and integration of activities. Effective space policy can foster public interest in space activities, establish guidance for development of industrial capability, and set the stage for effective international cooperation. In the absence of clear and effective space policy, government space activities are likely to develop in a manner that may present long-term sustainability challenges.”<sup>11</sup>

As Figure 8 demonstrates, national space policies and plans are now common.

**Figure 8: Selected Major National Space Policy Documents, 2009-2011**

Country	Document Name	Release Date
Australia	Principles for a National Space Industry Policy	September 2011
China	China's Space Activities in 2011	December 2011
Europe	Towards a Space Strategy for the European Union that Benefits its Citizens	April 2011
Germany	German Space Policy	November 2010
Italy	Italian Space Agency Strategic Vision 2010-2020	October 2010
Japan	Basic Plan for Space Policy	June 2009
South Africa	National Space Policy	March 2009
Sweden	The Swedish National Space Board's Long-term Strategy Focused on 2011-2015	November 2010
United States	National Space Policy	June 2010
United States	National Security Space Strategy	January 2011

## 4.2 Canadian Space Plans

In the past, plans have been integral to guiding the development of Canada's space industry. Canada's first interests in space were scientific, relating to the ionosphere, space weather, and the

<sup>11</sup> Space Foundation (2012) The Space Report 2012, Page 141.

aurora borealis. Canada's first four satellites, Alouette 1 and 2 and ISIS 1 and 2 from 1962 to 1971, were created by a team from the Defence Research Telecommunications Establishment led by John Chapman for this purpose. In 1967, Chapman was the senior author of a report entitled "Upper Atmosphere and Space Programs in Canada", an extremely influential report now known as "The Chapman Report". In that paper, Chapman recommended a major change in focus for the Canadian space program. He suggested that rather than concentrate on space science, Canadian satellites should be used to decrease the difficulties in communications and resource management caused by the country's enormous size. Subsequently in 1968, the Government's White Paper entitled *A Domestic Satellite Communications System for Canada*, concluded that in view of Canada's particular geographic, economic and social features, "...a domestic satellite communications system is of vital importance for the growth, prosperity and unity of Canada, and should be established as a matter of priority." As a result, the Telesat Canada Act was introduced in the House of Commons and on September 1st, 1969, the date of Proclamation, the Telesat Canada corporation came into existence. This enabled the development of the the Anik A1 communications satellite which was launched in 1972, making Canada the first country with a domestic communications satellite in geostationary orbit and creating the foundation for Canada's satellite communications success today.

The first Long-Term Space Plan was released in 1985 with a funding of \$195 million for fiscal year 1985-1986. That plan resulted in Canada's participation in the International Space Station and mobile communications satellite, MSAT.

In 1994 the Second Long-Term Space Plan was released. Over the next ten years, the Canadian Space Program was allocated \$2.7 billion, including \$500 million as the Canadian contribution to the International Space Station Program and upgraded support facilities for the RADARSAT program. There were also provisions for an Advanced Communications research program, the development of space technologies in partnership with industry and with other space agencies, funding for space science research in Canada, in particular in the areas of atmospheric studies and microgravity, and assignments of Canadian Astronauts for space shuttle missions.

The 2003 Canadian Space Strategy was approved by the Government of Canada in February 2005. It replaced the Long Term Space Plans as the framework that guides the Canadian Space Agency in leading Canada's national Space Program. That strategy is short on concrete plans but it established the following objective with respect to the Canadian space industry:

"The Canadian Space Agency will continue to foster the growth of a viable, vibrant space industry in Canada. The Agency will promote our national space industry as the primary custodian and developer of our space technology base, including our capability to design, build and where and when appropriate, operate space and ground-based assets.

Canada's space industry must be sufficiently large and diverse to meet our needs and goals in space. We must also sustain the high caliber of products and services

our industry has demonstrated to date. However, given that the Canadian market is relatively small, it is critical that industry be able to leverage foreign investments and generate export sales. Capitalizing on export revenue depends on industry's ability to commercialize highly competitive products and services, as well as the Government of Canada's ability to establish open trade regulations with its closest international partners. In order to help industry meet and succeed these challenges, the Canadian Space Agency will align its programs and actions to build synergies that will bolster industry's competitiveness and market development efforts."<sup>12</sup>

The current President of CSA, Steve McLean, was asked to prepare a new space plan when he was appointed in 2008. That plan has not yet been made public.

The 2011 Space Competitiveness Index, compiled by the US consulting firm Futron, said that government delays in presenting a long-term space plan are offsetting Canada's competitive advantages. That analysis of the 10 leading space nations found that Canada lost its sixth-place ranking to India in 2010 and is being challenged hard by Brazil, China, Israel, Japan and South Korea.<sup>13</sup>

The stakeholders consulted for this paper feel that when a new plan is prepared it must represent and engage all stakeholders: government, industry and academia. It may be coordinated by CSA, but it must not be seen as only their document. And, most importantly, it must receive the full and enduring commitment of the federal government.

### 4.3 CSA's Program Activities

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In lieu of a current long-term space plan, Canada's intentions in space are best summarized by the CSA's Program Activity Architecture.<sup>14</sup>

CSA's program activities are to contribute to the following strategic outcome: "Canada's exploration of space, provision of space services and development of its space capacity meet the nation's needs for scientific knowledge, innovation, and information." The Canadian space program is further defined in terms of the three following activities that contribute in various degrees to the strategic outcome:

**1) Space Data, Information and Services:** This program activity includes the provision of space-based solutions (data, information and services) and the expansion of their utilization. It

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<sup>12</sup> Canadian Space Agency (2005) Canadian Space Strategy

<sup>13</sup> Globe and Mail, September 26 2011, "Canada losing ground in space competitiveness, report says". <http://www.theglobeandmail.com/technology/science/canada-losing-ground-in-space-competitiveness-report-says/article595618/>

<sup>14</sup> European Space Agency (201) European Space Technology Master Plan

also serves to install and run ground infrastructure that processes the data and operates satellites. The contributions of this program activity to the strategic outcome are expected to result in an expanded use of space data, applications and information by government departments and agencies so that they can better deliver their policy and programs and perform their operational responsibilities effectively. This calls for a strong partnership between the Canadian Space Agency and other government departments and agencies.

Current operation priorities under this program activity include:

- To further the development of the RADARSAT Constellation in order to provide continuity and enhanced functionalities to the users of RADARSAT-1 and RADARSAT-2 and to help the government address key priorities: the Arctic, defence, sovereignty, safety and security, resources and the environment. Ground stations located in the Canadian Arctic are required to take full advantage of RADARSAT Constellation and to receive data from various Canadian and foreign satellites.
- To further study the development of the Polar Communication and Weather (PCW) mission. This key space asset is intended to provide broadband communications services and weather observations in the Canadian Arctic to support the Canadian Forces' operations, and foster social and economic development.

**2) Space Exploration:** This Program Activity provides valuable Canadian science, signature technologies and qualified astronauts to international space exploration endeavours. The contributions of the Program Activity to the strategic outcome are expected to be advances in knowledge, exploration, technologies and expertise, as well as an increased use of this knowledge and know-how both in space and on Earth.

Current operational priorities under this program activity include:

- Continue as an active partner and participant in the International Space Station, operating robotic elements such as Canadarm2 and Dextre, performing scientific experiments and technology demonstrations and having access to flight opportunities for Canadian astronauts.
- Fostering the development of advanced space robotics and mobility systems capable of contributing to international space exploration missions. These advancements have potential to improve how we live, prosper, and develop on our planet.

**3) Future Canadian Space Capacity:** This program activity attracts, sustains and enhances the nation's critical mass of Canadian space specialists, fosters Canadian space innovation and know-how, and preserves the nation's space-related facilities capability. In doing so, it encourages private-public collaboration that requires a concerted approach to future space missions. The contributions of this Program Activity to the strategic outcome are expected to be the maintenance of the critical mass of academic, industrial and business expertise needed to

address future national needs and priorities in space, as well as an increased pace of discovery and innovation.

Current operational priorities under this program activity include:

- The continuation of Canada’s partnership with the European Space Agency to enhance its technology base and improve access to European markets. Canada is currently involved in the following ESA Programs in Earth Observation (EOEP, GMES Space Component, Earth Watch GMES), Telecommunications (ARTES-1, -3, -4, -5, 8, -21), Navigation (Galileosat, GNSS Evolution), Space Exploration (Aurora, Transportation & Human Exploration), Microgravity (ELIPS), and Generic technology development (GSTP).
- The development and use of sub-orbital platforms (balloons, aircraft and sounding rockets) and small satellites to increase the pace of training and discovery. The use of sub-orbital platforms is a highly cost-effective way to provide space researchers with frequent space missions to hone their skills and produce research results at reasonable cost.

Spending in 2011-2012 across the activities is shown in Figure 9. Of the Canadian Space Budget, \$47.3M was allocated to the Canada-ESA cooperation agreement (0.5% of ESA’s budget).

**Figure 9: CSA Program Activity Spending**

Activities	Spending	%
Space Data, Information and Services	\$136.6M	32%
Space Exploration	\$152.4M	36%
Future Canadian Space Capacity	\$86.1M	20%
Internal Services	\$49.4M	12%
<b>Total</b>	<b>\$424.5M</b>	<b>100%</b>

Canada is continuing to develop a comprehensive space technology plan to define technology thrusts and build roadmaps that guide and prioritize technology research and development both internally and externally, and support the preparation of future missions and programs in earth observation, satellite communications, and space science and exploration.

## 4.4 Future Space Technologies

The program activities of CSA provide a sense of the space technologies on which Canada is currently focusing. But what is the future of space technology? Of course, predicting the future

is an inexact science. However, examining the space research of other countries perhaps provides a window on where the evolution of technology is likely to head.

Europe has spent considerable effort in harmonizing the space research efforts of ESA (including Canada), the European Commission, and the individual European countries. Therefore, ESA’s research plans provide insight into the future of European space technology. This section reviews ESA’s research programs.<sup>15</sup>

Agenda 2015 was published in December 2011 and is the analysis of ESA’s position today by the Director General on how to meet the challenges of the future and the importance of the organization in shaping Europe’s future.<sup>16</sup> With respect to industrial competitiveness, it highlights that ESA, in partnership with industry and in cooperation with other industrial actors, must continue taking actions to:

- Develop the technologies that enable the space services of the future (e.g. payload technologies for broadband access, multispectral systems for the incipient Earth observation markets) in a general context of total improvement (e.g. miniaturization for lower mass, volume and power consuming systems);
- Facilitate in ESA missions the balance between product exploitation and innovation so that industry benefits together with ESA from economies of scale, from reuse and from derisking achieved in ESA missions and demonstrations outside the commercial projects;
- Develop engineering and operations practices and tools that allow delivering and exploiting systems more efficiently, using lessons learnt from innovative concepts such as GIOVE-A, Proba and Private-Public-Partnerships in telecoms.

ESA’s budget for 2011 of approximately €4 billion is split into 10 major lines under either the mandatory Programmes or the optional Programmes, as presented in Figure 10. It should be noted that the Technology activity line budget in Figure 10 covers only GSTP and third party financing.

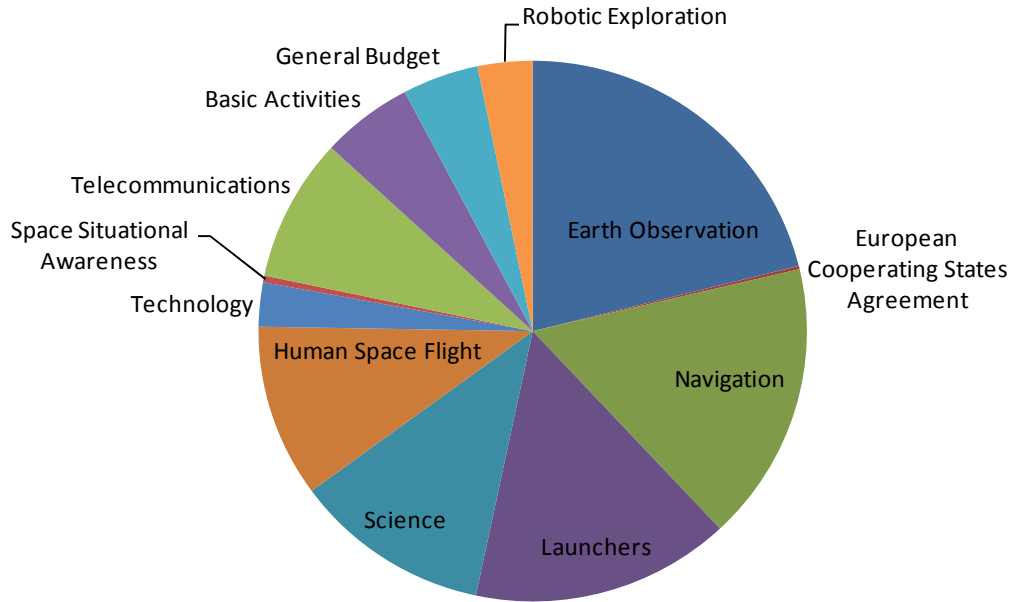
**Figure 10: Major ESA Activity Lines for 2011**

Activity Lines	Spending (M€)	%
Earth Observation	843.9	21.1
Navigation	665.7	16.7
Launchers	612.5	15.3
Science	464.8	11.6
Human Space Flight	410.9	10.3
Telecommunications	341.3	8.5
Basic Activities	216.7	5.4

<sup>15</sup> European Space Agency (2011) European Space Technology Master Plan

<sup>16</sup> European Space Agency (2011) Agenda 2015

General Budget	179.9	4.5
Robotic Exploration	129.4	3.2
Technology	105.1	2.5
Space Situational Awareness	15.7	0.4
European Cooperating States Agreement	7.9	0.2



ESA’s technology activities are implemented through several ESA preparatory Programmes, either of a thematic (Telecommunications, Launchers, Earth Observation, Human Spaceflight, Science, Exploration, etc.) or horizontal nature. The Technology Research Programme (TRP), the General Support Technology Programme (GSTP), the Future Launchers Preparatory Programme (FLPP), and the Telecom/ARTES programmes account for about three quarters of all technology R&D conducted in ESA.

**Basic Technology Research Programme (TRP)** – TRP covers classical technology development, ITI, and Star-Tiger. Classical Technology Development Themes are:

- Earth Observation – Technology developments for the next Earth Explorer Core missions, the post-EPSC missions and candidate missions for which further technology preparations have been recommended.
- Science – Developments for the Cosmic Vision Plan (2015-2025) and particular the so-called Large Missions candidates (IXO, LISA and Laplace), the Medium ones, and the preparation of future mission concepts recommended by the Space Science Advisory Committee (SSAC); developments for the Mars robotic exploration.



- Human Space Flight and Exploration – Technologies related to Robotic Assistance to Human Missions, Life & Physical Sciences, Human Exploration Technologies and (Moon) Autonomous Robotic exploration.
- Telecommunications – Mobile interactive services, fixed services, direct broadcast service, interactive broadband services, data relay and security services.
- Navigation – EGNSS evolution, Galileo evolution and Enabling Technologies and Techniques for GNSS Evolution applications.
- Generic Technologies – complement the application driven Technologies by taking care of technologies common to two or more application domains, e.g. platform, ground segment or payload technologies.

The TRP Innovation Triangle Initiative (ITI) supports the identification, validation and development of disruptive innovations which show the potential to cleverly address space problems. ITI gives preference to innovations coming originally from non-space industrial or research sectors.

The Space Technology Advancements by Resourceful, Targeted & Innovative Groups of Experts & Researchers (StarTiger) selects a multi-disciplinary team of highly motivated scientists and engineers from several institutions and grant them priority access to state of the art equipment, facilities for a fixed period of time.

**General Support Technology Programme (GSTP)** – GSTP addresses new needs and emerging applications. It has been organized into four elements:

- Element 1: General Activities – covers the standard GSTP activities in all Service Domains except telecommunications.
- Element 2: Building Blocks and Components – covers the development of products for ESA and commercial missions, bringing individual components to a high Technology Readiness Level.
- Element 3: Security for Citizens – covers the development of technologies for systems with security applications. It also includes the ESA Preparatory Space Situation Awareness programme.
- Element 4: In-Orbit Demonstration – makes berths available for in-orbit technology qualification aboard small demonstrator satellites, along with the demonstration of novel research and operation techniques.

**Telecommunications Programme (Telecom/ARTES)** – Advanced Research on Telecommunication Satellite Systems (ARTES) programme elements are as follows:



- ARTES 1: dedicated to strategic analysis, market analysis, technology and system feasibility studies, and to the support of satellite communication standards.
- ARTES 3-4: dedicated to the development, qualification, and demonstration of new products, and to the improvement and update of existing ones. Telecommunications applications can also be undertaken under the terms of this element.
- ARTES 5: dedicated to long-term technological development.
- ARTES 7 – EDRS: supports development and implementation of a European Data Relay System.
- ARTES 8 – Alphasat: supports the development and deployment of Alphasat, which incorporates innovative on-board process technology and will promote user services.
- ARTES 10 – Iris: supports development of a satellite-based communication system that will complement the future generation of an air traffic management system.
- ARTES 11 – Small GEO: supports the development and implementation of the Small GEO System. The RedSat satellite will incorporate advanced payload technology.
- ARTES 20 – IAP: supports the development, implementation and pilot operations of Integrated Applications; applications of space systems that combine different types of satellites, such as telecommunications, earth observation and navigation.
- ARTES 21 – SAT-AIS: supports the definition and design of European satellite-based AIS.

**European Component Initiative (ECI)** – reduces in a sustainable manner the dependence of the European Space Programme on non-European single sources Electrical, Electronic and Electromechanical (EEE) components, particularly those that might be subject to export restrictions (such as ITAR).

**Science Core Technology Programme (CTP)** – CTP funded activities generally take the proof of concept demonstrated under TRP to a higher state of technological maturity that is up to full-scale engineering models fully tested in relevant environmental conditions.

**Earth Observation Envelope Programme (EOEP) Development and Exploitation Component** – EOEP is made up of two main components:

- The Earth Explorer component involves the development and launch of new types of Earth observing spacecraft, aimed to respond to the requirements of the scientific community through new sensing technology.

- The Development and Exploitation component includes all preparatory activities for future missions, including Earth Observation Preparatory Activities (EOPA), Earth Watch Definition (EWD), and Instrument Pre-Development (IPD). They cover end-to-end preparation of missions, from new sensor and spacecraft technologies to overall mission architecture and supporting science studies. This component addresses both science-themed Earth Explorer candidates as well as operational Earth Watch missions.

**European GNSS Evolution Programme (EGEP)** – undertakes technology research, development and verification related to GNSS and to accompany the introduction of GNSS operational systems with a view to support the maintenance of the scientific, technical and industrial expertise necessary for Europe and prepare for the evolution of the European GNSS infrastructure.

**European Life and Physical Sciences Programme (ELIPS)** – prepares for and implements research on the International Space Station, and other experiment platforms like ground-based facilities, parabolic flights, sounding rockets and unmanned orbital vehicles, in fundamental, applied and exploration-related life and physical sciences. A part of the budget is aimed at reducing ISS download requirements.

**European Transportation and Human Exploration Preparatory activities (ETHEP)** – prepares for future human exploration missions in low Earth orbit and beyond, including human exploration scenario studies, advanced re-entry vehicle, lunar lander, international berthing and docking mechanism, operations avionics subsystem, and human exploration capabilities.

**Exploration Technology Programme (ETP)** – covers technology development activities for robotic exploration needs, including novel power sources, enhanced propulsion engines, and thermal protection systems.

**Future Launchers Preparatory Programme (FLPP)** – helps determine how Europe maintains and strengthens its independent access in space into the future. Its major fields of activity are: Launch systems and technologies, and Intermediate eXperimental Vehicle (IXV).

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## 4.5 Space Technology Competencies

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Figure 11 was generated through the ESA Industry Capability Mapping (ICM) database, and contains Technology Competencies per country logged in two different ways:

- Accredited competencies – competencies ascertained through Harmonization meetings.
- Declared competencies – competencies declared by Delegations.

The Canada column is highlighted in red.

Figure 11: Country Space Technology Competencies

TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK	
1 - On-Board Data Systems	1-A - Payload Data Processing	■	■	■	□			■	■	■		□	■	■		■	■			□	□		■	■	■	■	
	1-B - On Board Data Management	■	■	■	□	■		■	■	■	■	□	■	■						□		□		■	■	■	■
	1-C - Microelectronics for digital and analogue applications	■	■	■	□	■		■	■	■	■		□	■				■	■	□	■			■	■	■	■
	1 - On-Board Data Systems Total	■	■	■	□	■		■	■	■	■	□	■	■		■	■	■	■	□	■	□		■	■	■	■
2 - Space System Software	2-A - Advanced Software technologies	■		□	■	■		□	■	■	■	□		■			□			□	□		■	■	□	■	
	2-B - Space Segment Software	■	■	□	■	■		■	■	■	■	□	■	■			■	■		■	□		■	■	■	■	
	2-C - Ground Segment Software			□	□	□		□	□	□									□			□	□		□		
	2-D - Ground Data Processing			□	□	□		□	□	□		□	□	□					□		□	□	□	□		□	
	2-E - Earth Observation Payload Data Exploitation			□	□	□		□	□		□	□	□	□			□	□	□		□	□	□	□		□	
	2 - Space System Software Total	■	■	□	■	■		■	■	■	■	□	■	■		□	■	■	■	■	□	□	□	■	■	■	■
3 - Spacecraft Electrical Power	3-A - Power system architecture	■	■	□	□	■		■	■	■		□	■										■	■		■	
	3-B - Power generation technologies		■		□			■	■	■		□	□	■		■	■	□					■		□	■	
	3-C - Energy storage technologies				■		■		■	■	■		■					■		■			□		■	■	
	3-D - Power conditioning and distribution	■	■	□	□	■		■	■	■		□	■						□				■	■	□	■	
3 - Spacecraft Electrical Power Total	■	■	□	■	■	■	■	■	■	■	□	□	■		■	■	■	■	□	■		■	■	■	■	■	

TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
4 - Spacecraft Environment & Effects	4-A - Space Environment:	■	■	□	■	■		■	■	■	■	□	■	■			■	■	□	■	□		■	■	■	■
	4-B - Environment effects	■	■	□	□			■	■	■		□	■				■	■		■	□	□	■	■	■	■
	4-C - Space Weather			□	□	□		□	□	□									□	□		□	□		□	
4 - Spacecraft Environment & Effects Total		■	■	□	■	■		■	■	■	■	□	■	■			■	■	□	■	□	□	■	■	■	■
TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
5 - Space System Control	5-A - Space system architecture and autonomy	■		□	□	■			■	■				■				□		□	□	□	■	■	□	■
	5-B - Space segment Guidance Navigation and Control (GNC)	■	■	■	□	■		■	■	■	■		■			■	■	■		■	□	□	■	■	■	■
5 - Space System Control Total		■	■	■	□	■		■	■	■	■		■			■	■	■		■	□	□	■	■	■	■
TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
6 - RF Payload and Systems	6-A - Telecommunication (sub-)Systems			□	□			■	□	□		□	□				■	□		□	□		■		■	
	6-B - Radio Navigation (sub-)Systems	■	■	■	□				■	■				■				■			□	□	■	■	■	■
	6-C - TT&C (sub-)Systems		■	□	□	■			■	■		□	■					■				□	■		□	■
	6-D - RF Payloads			□	□				■	■		□	■					□	□			□	□	□	□	□
	6-E - Microwave and millimeter wave technologies and equipments	■	■	■	□	■			■	■	■			■	■			■	■			□		■	■	■
6 - RF Payload and Systems Total		■	■	■	□	■		■	■	■		□	■	■			■	■	□	□	□	□	■	■	■	■

TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
7 - Electromagnetic Technologies and Techniques	7-A - Antennas	■	■	■	■	■		■	■	■	■		■	■		■	■	■	■	■	□	□	■	■	■	■
	7-B - Wave Interaction and Propagation			□	□			□	■	■		□							□				□		■	■
	7-C - EMC/RFC/ESD			□	□				□				□	□									□		□	
7 - Electromagnetic Technologies and Techniques Total		■	■	■	■	■		■	■	■	■	□	■	■		■	■	■	■	■	□	□	■	■	■	■
TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
8 - System Design & verification	8-A - Mission and System Specification		■	□	□	■			■	■				■			■	□		■		□	■	■	□	■
	8-B - Collaborative and Concurrent Engineering			□	□				□	□			□	□			□	□			□	□	□		□	
	8-C - System Analysis and Design		■	□	□				■	□							■	□				□	■	■	□	
	8-D - Verification and AIT			□	□	□			■	□													□		□	■
8 - System Design & verification Total			■	□	□	■			■	■			□	■			■	□		■	□	□	■	■	□	■
TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
9 - Mission Operation and Ground Data systems	9-A - Advanced System Concepts			□	□				□														□			
	9-B - Mission Operations			□	□	■			■	■			□	■		■	■	□			□		■		□	■
	9-C - Ground Data Systems (MCS)			□	□			□	□	□				□		□	□	□				□	□		□	
9 - Mission Operation and Ground Data systems Total				□	□	■		□	■	■		□	■		■	■	□			□		□	■		□	■

TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
10 - Flight Dynamics and GNSS	10-A - Flight Dynamics			☐	☐				☐	☐				☐				☐		☐	☐		☐		☐	
	10-B - GNSS systems and ground-related technologies			☐	☐				☐	☐									☐		☐	☐		☐		☐
10 - Flight Dynamics and GNSS Total				☐	☐				☐	☐				☐				☐		☐	☐		☐		☐	
TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
11 - Space Debris	11-A - Measurements			☐	☐				☐	☐	☐												☐		☐	
	11-B - Modelling, Databases and Risk Analysis			☐	☐				☐	☐									☐	☐		☐	☐	☐		☐
	11-C - Hyper-Velocity Impact (HVI) and Protection			☐	☐																		☐			
11 - Space Debris Total				☐	☐				☐	☐	☐								☐	☐		☐	☐	☐		☐
TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
12 - Ground Station System and Networks	12-A - Ground Station System		■	■	☐	■			■	■		☐	☐	■		☐	☐	☐		☐	☐	☐	■	■	■	■
	12-B - Ground Communications Networks			☐	☐				☐	☐		☐	☐			☐	☐			☐	☐		☐			
12 - Ground Station System and Networks Total			■	■	☐	■			■	■		☐	☐	■		☐	☐	☐		☐	☐	☐	■	■	■	■

TECHNOLOGY DOMAIN	TECHNOLOGY SUBDOMAIN	AT	BE	CA	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LT	LU	NL	NO	PL	PT	RO	SI	ES	SE	CH	UK
		13 - Automation, Telepresence & Robotics	13-A - Applications and Concepts			□	□				■	■				■			■			□		□	□	
13-B - Automation & Robotics Systems				□	□			■	■	■				■			■			■		□	□		■	■
13-C - Automation & Robotics components and Technologies	■		■	□	□				■	■		□		■				■		□	□	□	■	□	■	■
13 - Automation, Telepresence & Robotics Total		■	■	□	□			■	■	■		□	■				■	■		■	□	□	■	□	■	■

# 5. The Needs of the Canadian Space Sector

Canada's capability as a space-faring nation is at risk. The problem is multi-faceted, but in the view of the stakeholders consulted for this report, the path to recovery is plain: Canada needs:

1. A **vision**,
2. A **plan**,
3. A **commitment** to follow through.

Although a simple enough recipe, there are a number of barriers to its achievement that are reviewed in the following sections.

## 5.1 Governance

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Crafting a vision and plan for Canada's involvement in space will require the contribution and participation of many players – government departments, industry, and academia.

Space issues are horizontal in that they involve players across departments and sectors. However, responsibility for space has become increasingly vertical, with the bulk of the duty being shouldered by CSA.

This was not always the case. In 1969, the Interdepartmental Committee on Space was created to coordinate the space activities scattered among several federal government departments and agencies. While under this arrangement, Canadian space research and exploration activities remained fragmented, there at least was a formal mechanism to bring together senior representatives across government.

In an effort to reduce this fragmentation, it was concluded that a distinct Canadian space agency was needed to bring focus to Canada's space activities. It was believed that a separate agency that emphasized the contracting out of research and development could ensure the active involvement of the private sector and universities and enhance the social and economic benefits of Canada's civilian space program. As a result, the Canadian Space Agency was established by order-in-council in March 1989.

The situation now is that no federal department has space as their prime priority. While the number of departments with space as high priorities means that, horizontally, space is very



important for the Government of Canada, without a horizontal governance mechanism to add those priorities together, space projects invariably receive less support than they need to go forward. To be sure, the interested departments and agencies do communicate, but it is felt that this occurs at too low a level in the organizations to have the necessary impact.

Further, industry's participation in the governance of the sector has been all but eliminated as the industry consultation and advisory councils that once advised CSA no longer meet. If industry is expected to do their part in make the Canadian space sector a success, they must be consulted and involved in the policy making and planning process.

## 5.2 International Partnerships

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The Space Report 2012 noted the increasing efforts of space faring nations and the private sector to cooperate and pool resources.<sup>17</sup> As a small economy with small space firms, this is especially important for Canada; and it has in fact been Canada's approach from the beginning. Canada has had particularly close relationships with both NASA and ESA, and has also worked with many other nations, including Sweden, Norway, France, and Japan. Canada has had a cooperative agreement with ESA since 1979 as an associate member allowing Canada to participate in ESA programs commensurate with Canada's financial contribution to the program.

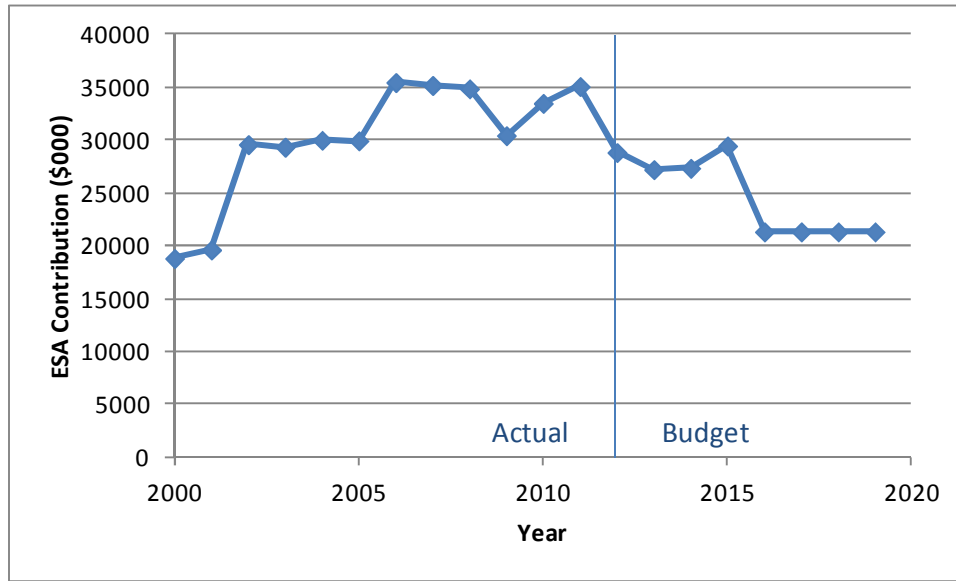
Canada's current lack of spending in international space programs means that there are fewer opportunities for companies to obtain the vital experience and exposure that comes from participation in international missions. For example, most ESA programs work on a subscription and geo-return basis whereby countries buy into a program and a country's industry can participate to the value of that buy-in. Figure 8 shows Canada's historic and future ESA contributions. This year, contributions fell by 18%, and in four years they will be only 60% of the levels they have been over the previous six years.

Given the long-term uncertainty of NASA's plans and funding, Canada would be perhaps better served by decreasing involvement in US missions in order to be able to increase involvement in ESA programs. And given the strides being made by emerging economies, Canada could look to strengthening ties there also.

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<sup>17</sup> Space Foundation (2011) The Space Report 2012

Figure 8: Canadian ESA Contributions



Source: CSA

### 5.3 Domestic Demonstration and Support

It is commonly considered essential that companies demonstrate their capabilities at home before they can hope to obtain foreign work. Canada is somewhat an exception in this regard as Canadian companies have overall succeeded in obtaining substantial foreign work in spite of the lack of domestic support by the federal government.

Domestic support can come in two ways. The first is through direct government involvement and investment in space companies. This is common in all space countries except Canada and the United States. The following table illustrates this with a sample of major international space companies from around the world and the public sector investment in each of them.

Company	Public Sector Investment
Astrium	15% France, 5% Spain
Thales Alenia Space	18% France, 10% Italy
Kongsberg	50% Norway
Telespazio	10 % France, 20% Italy
Swedish Space Corporation	100% Sweden
Alcântara Cyclone Space	50% Brazil, 50% Ukraine
RKK Energia	38% Russia
Hindustan Aeronautics Limited	100% India
China Aerospace Corporation	100% China

In addition to direct investment, foreign countries often become involved in promoting their domestic industries to a much greater degree than does Canada.

The second form of support is through procurement. All of the major spacefaring countries have substantial domestic investments in space. This is particularly true for the United States which supports (subsidizes) its domestic companies with massive investments in defence, aerospace, and space.

In Canada, DND is currently spending about as much on space as CSA. However, DND does not have the industrial development mandate that CSA does, and much of their spending has no direct benefit to Canadian industry.

### 5.4 Government Research

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The origins of Canada's involvement in space are rooted in government research laboratories. Canada's first four satellites, Alouette 1 and 2 and ISIS 1 and 2 from 1962 to 1971, were created by a team from the Defence Research Telecommunications Establishment led by John Chapman. Through the 1970s and 1980s, the National Research Council, the Canada Centre for Remote Sensing, and the Communications Research Centre played important roles in different aspects of Canada's involvement in space.

Two factors have dramatically reduced the involvement of government in space research over the last twenty years. First, with the creation of CSA in 1989 other federal departments and agencies saw their role in space superseded. This was particularly true for NRC which gave up a large part of its capability to the initial staffing of CSA. Second, and later, departmental space capabilities were reduced as part of the government's overall reduction in the conduct of research. For example, CCRS, once a world leader in remote sensing research, has turned its attention to serving the narrow internal needs of NRCan, and CRC has essentially eliminated its work in satellite communications. CSA, while a sponsor and coordinator for research, has no internal research capacity.

Today, Canada relies primarily on the universities and industry for the bulk of its space research. While industry will conduct research under contract, it does little on its own accord; just 2% of industry revenues are spent on R&D (most R&D is conducted under contract for clients). Canadian universities are world leaders in aspects of space research and technology development – particularly the universities of Calgary and Toronto.

Finding the appropriate balance among government, industry, and academia for space research is not straightforward. Government research has, admittedly, not always been effective and efficient. But on the other hand, it is difficult to maintain long-term, stable, and significant, research initiatives within the Canadian university system; effort waxes and wanes with the interests of professors and graduate students.

However, it is clear the loss of an internal capability for space research has had a significant impact on the government's 'absorptive capacity' – the ability of the Canadian government to understand, assess, and decide what to build or buy to meet its needs.

## 5.5 Data Policy

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In the earth observation space sub-sector, the majority of the economic value and the benefits for Canadians come from the application of the data, not the construction or operation of the satellites. Therefore, the goal should be to get as much data to as many users as possible.

The terms under which data is made available is governed by the satellite's data policy. The policy of the United States government has been to make EO data, such as from Landsat, freely available. While ESA has in the past charged for data from Envisat under some conditions, they have determined that that is not the preferred approach for the future and will be making data from the Sentinel missions freely available.

The RADARSAT data policy is constrained by the government's agreement with MDA for their investment in RADARSAT 2 and their role as the distributor of RADARSAT 1 data. The result is that RADARSAT data is considered to be extremely expensive; to the extent that the utilization of the satellites has been severely curtailed. The majority of Canadian users of RADARSAT data have obtained it through the government's allotment of 'free' data. In many cases, other satellite data, such as Landsat, has been used even when it is less applicable because of the cost issue. In short, it is felt that the RADARSAT data policy has prevented Canada, and Canadian taxpayers, from benefiting fully from the government's investment in the satellites.

CSA is just beginning to work out the data policy for RCM. CSA has noted the 'world-wide trend toward full and open data sharing' and initial indications are that they intend to make RCM data available at the 'lowest possible cost'. However, with the increasing costs of the RCM mission, there are concerns within the EO community that the government will revert to the former 'user pays' approach.

## 5.6 Funding Plans

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At the core of any plan must be a budget. Resources are never infinite, but aspirations often are, so decisions must be made on how to allocate what is available. The space sector recognizes that there are limitations on what Canada can accomplish; what they ask for is clarity on the choices that will be made and long-term funding stability so that they can make appropriate plans of their own.

The current funding situation is difficult; partially because of austerity measures that are affecting all of government (CSA has had cuts of 12%), but primarily because of a number of commitments that have left little room for other interests.

The bulk of these commitments are being borne by CSA. One is Canadian participation in ISS which includes a yearly subscription fee (\$20M) and responsibility for maintenance of the Canadarm (\$7M). Another is Canada's membership in ESA (\$30M). A third is the planning and development of RCM (\$200M so far, \$1.1B total), for which costs have escalated because the program is attempting to develop new technologies as part of the satellite design and construction.

To a great extent, such things are the cost of entry to space and do not in and of themselves have significant economic benefits. With these investments, we are in the arena, but we are not yet playing in the game – that will require more money, money that has not been forthcoming. As a result, the activities that would have real industrial and social benefits are not pursued; activities such as participation in ESA programs, development of downstream services, commercialization of space technologies, utilization of data, support of science missions, etc. The current budget of CSA (Figure 9 previously) could be examined to see what reallocations might be made to enable the attainment of these benefits.

CSA once claimed that approximately 80% of their budget was contracted out for projects involving industry, universities, and specialized research institutes. That portion is now considered by stakeholders to be about half of that. Long-term funding stability is a concern for Canada's space community. Uncertainty does not allow industry to make the long-term investments in personnel and infrastructure that are required to be competitive in the space market.

## 6. Conclusions

Both Canada's budget and capabilities are, and will remain, limited. This means that Canada must be careful and strategic in the investment decisions it makes:

- First, we must decide what we will, and importantly will not, do; a vision of where we are going. Considerations in these choices should include Canadian competencies; international competition; social, scientific, and economic opportunities; costs; and barriers to success.
- Second, we must cooperate and collaborate, both externally and internally. Externally with our international partners: continuing our existing relationships with NASA and ESA, and increasing our cooperation with the new rising space powers. Internally among the Canadian stakeholders, industry and academia, and, in particular, among the departments of the federal government.
- Third, we must support and build our industry. The space sector is not a level playing field. If we want our industry to survive, government must become more engaged – as a champion of industry, as well as financially.
- Fourth, we must articulate those decisions in a public plan. The plan must come from the federal government, not just the CSA. The plan must engage all stakeholders, allowing each to make its own decisions with the full knowledge of the context and the roles of others. It must be remembered that plans do not exclude flexibility – plan to be spontaneous and take advantage of opportunities.
- Fifth, we must follow through on our commitments. Space policies and plans will demand significant investments of effort and money by all the parties involved. All stakeholders, nationally and internationally, need confidence that each will do their part.

In consulting with Canadian space sector stakeholders, our study team was struck by the degree of consensus on both Canada's problems and the necessary solutions. What has been reviewed here is not new; it has been repeated by those who have been involved in the Canadian space sector for a number of years now.

# A. Canadian Space Missions

The following are summaries of Canadian satellites or satellites in which Canada has had an involvement.

## A.1 Communications Satellites

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- ANIK – The Anik satellites are a series of 15 geostationary communications satellites launched by Telesat Canada from 1972 through 2007. In Inuktitut, Anik means ‘little brother’. Anik A1, launched in 1972, was the world's first domestic communications satellite operated by a commercial company. Four of the later satellites in the series remain operational providing voice, broadband Internet, broadcast, and direct-to-home services to the United States and most of Canada. Anik F1 was launched in 2000 and at the time was the most powerful communications satellite ever built. Anik F1R was launched in 2005 and also carries a GPS/WAAS payload (see Navigation below).
- Hermes – The *Communications Technology Satellite*, also known as Hermes, was an experimental high-power direct broadcast communications satellite. It was a joint effort of Canada's Department of Communications, who designed and managed it, NASA and ESA. It was launched in 1976 and operated until 1979. Experiments in telemedicine for emergency medical service, teleconferencing, and community TV were conducted. The satellite was also used to televise Stanley Cup hockey playoffs to Canadian diplomats in Peru to demonstrate its international capacity. In 1987 Canada's Department of Communications and NASA received an Emmy award for developing direct broadcast TV satellite technology with the Hermes CTS program.
- NIMIQ – The Nimiq satellites are a series of eight geostationary telecommunications satellites owned by the Telesat and used by satellite television providers. Seven of the satellites are still operational. ‘Nimiq’ is an Inuit word used for an object or a force which binds things together.
- Telstar – Two Telstar satellites owned by Telesat provide Ku-band communications to South America and the Southern USA.
- MSAT – MSAT, short for Mobile Satellite, was a satellite-based mobile telephony service developed by the National Research Council.
- PCW – A proposed Polar Communications and Weather (PCW) mission is being investigated by CSA, DND, and EC to fill gaps in high data rate communications and weather monitoring

in the high Arctic to support Canadian sovereignty and security, to improve quality of life, and to facilitate economic development and world-class scientific research. It will use two satellites in tandem in a highly elliptical polar orbit.

- WDS – The Wideband Global SATCOM system (WGS) is a high capacity satellite communications system planned for use in partnership by the United States Department of Defense (DoD), the Australian Department of Defense, and Canada's Department of National Defence. DND invested approximately \$350 M. The system will consist of six satellites, four of which have already been launched beginning in 2007. Boeing is the prime contractor and there is no Canadian content.
- CASSIOPE (MDA) – Launch planned 2013. "CAScade, Smallsat and IOnospheric Polar Explorer" (CASSIOPE) is a made-in-Canada small satellite. It will use the first multi-purpose small satellite platform from the Canadian Small Satellite Bus Program. It will carry two payloads: e-POP, a scientific payload consisting of eight high-resolution instruments used to probe the characteristics of near-Earth space, and Cascade, a high data rate, high capacity store and forward technology payload. Partners in the mission include the University of Calgary, Communications Research Centre, Bristol Aerospace, and MDA, the prime contractor for the overall mission.

## A.2 Earth Observation Satellites

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- RADARSAT-1 – Launched in 1995 and equipped with synthetic aperture radar (SAR), RADARSAT acquires images of the Earth day or night, in all weather and through cloud cover, smoke and haze. It provides marine surveillance, ice monitoring, disaster management, environmental monitoring, resource management and mapping in Canada and around the world. The system was developed under the management of CSA in cooperation with provincial governments and the private sector. Canadian industrial team members who designed and built RADARSAT-1 include: MDA (formerly Spar Aerospace, prime contractor for construction of the satellite), COM DEV, SED Systems, and Fleet Industries. The ground receiving stations and processing facilities were built by MDA. In total, approximately 100 Canadian and international organizations were involved in the design and construction of the space and ground segments. Now 12 years beyond its design life, RADARSAT-1 continues to operate well.
- ENVISAT (ESA) – ENVISAT was launched in 2002 and was lost in 2012. ENVISAT carried instruments to collect information that will help scientists to understand each part of the Earth system and to predict how changes in one part will affect others. Many of ENVISAT's instruments were a development of those that flew on the ESA's Earth-observing missions of the 1990s (ERS-1 and -2). EMS Technologies (now MDA) manufactured, and tested onboard electronic sub-systems for the Advanced Synthetic Aperture Radar (ASAR) antenna.



ABB Bomem provided support in instrument design and data analysis, and developed optical test equipment for the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). Bomem also developed software to allow selection and generation of Medium Resolution Imaging Spectrometer (MERIS instrument) products. COM DEV of Cambridge, Ontario, supplied the MIPAS signal processing subsystem electronics and onboard flight software, and delivered two space qualified oscillator units for the microwave radiometer (MWR). MPB Technologies built three transponders, part of a system that characterizes the signal from the ASAR instrument. MDA was the main supplier of high-speed data acquisition and processing systems. They developed and provided eight innovative Front End Processors, a direct-to-disk data capture system and created systems capable of processing ERS SAR data into ENVISAT format. Finally, the Canada Centre for Remote Sensing (CCRS) played a key role in the reception and distribution of ENVISAT ASAR data information through ground stations in Gatineau, Quebec and Prince Albert, Saskatchewan.

- RADARSAT-2 – Launched in 2007, RADARSAT-2 is the follow-on mission from RADARSAT-1 providing enhanced SAR capabilities. In this case, MDA owns and operates the satellite and ground segment, while CSA helped fund the construction and launch of the satellite and is recovering this investment in the value of RADARSAT-2 data supplied to the Government of Canada during the lifetime of the mission. The satellite bus was built by Alenia Aerospazio of Italy. The SAR antenna was built by MDA.
- RADARSAT Constellation Mission (RCM) – RCM is proposed as a follow-on mission to RADARSAT 1 and 2 with the objective of ensuring data continuity, improved operational use of Synthetic Aperture Radar (SAR) and improved system reliability. The three-satellite configuration will provide complete coverage of Canada's land and oceans offering an average daily revisit, as well as daily access to 95% of the world to Canadian and International users. The mission development began in 2005, with the launching of the three satellites planned for 2016 to 2017.

### **A.3 Space Weather**

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- CASSIOPE (MDA) – Launch planned 2013. "CAScade, Smallsat and IOnospheric Polar Explorer" (CASSIOPE) is a made-in-Canada small satellite. It will use the first multi-purpose small satellite platform from the Canadian Small Satellite Bus Program. It will carry two payloads: e-POP, a scientific payload consisting of eight high-resolution instruments used to probe the characteristics of near-Earth space, and Cascade, a high data rate, high capacity store and forward technology payload. Partners in the mission include the University of Calgary, Communications Research Centre, Bristol Aerospace, and MDA, the prime contractor for the overall mission.

- THEMIS (NASA) – THEMIS is a mission to investigate what causes auroras in the Earth's atmosphere to change launched in 2007. The University of Calgary works with the University of California, Berkeley on the Ground-Based All-Sky Imager (ASI) Array which observes the optical aurora over Alaska and Canada to determine the timing and location of the auroral substorm onset in relation to the events in the magnetosphere.
- INTERBALL-2 (Russia) – In 1996, Canada placed a highly specialized camera, the auroral ultra-violet imager (UVAI), aboard the Russian satellite Interball-2 to study the aurora borealis. The University of Calgary was in charge of the Canadian team that gathered and analyzed the ultraviolet images acquired by UVAI. The camera was built by CAL Corporation of Ottawa.
- AKEBONO (Japan) – Akebono (known as EXOS-D before launch) is a satellite studying aurora and Earth's magnetosphere environment. Developed by Japan, it was launched in 1989 and is still operational. The science team for the Suprathermal Ion Mass Spectrometer was led by the University of Calgary.
- VIKING (Sweden) – Sweden's Viking was launched in 1986 with a payload designed to make detailed measurements of energy processes in the auroral region. A Canadian instrument, the Ultraviolet Imager (UVI) provided Canadian scientists with their first photographs of the entire aurora region. The UVI instrument, designed and built by CAL Corporation (now MDA), consisted of a pair of small telescopes used to image ultra-violet auroral. Canada's scientific team was led the University of Calgary and included scientists from Canadian universities and various government agencies.

### A.4 Astronomy

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- JWST (NASA) – Launch planned 2018. The James Webb Space Telescope (JWST) is an international collaboration between NASA, the European Space Agency, and the Canadian Space Agency. Canada is designing and building one of JWST's four science instrument packages consisting of two parts: high-sensitivity cameras known as the Fine Guidance Sensor (FGS), and the Tunable Filter Imager (TFI), both built by COM DEV. The science team includes the Herzberg Institute of Astrophysics and the Université de Montréal. Canada is also providing functional support of the science operations for JWST.
- ASTRO-H – Launch planned 2014. ASTRO-H is an X-ray space telescope currently under development by the Japan Aerospace Exploration Agency (JAXA) with contributions from the United States, Europe and Canada. Canada is involved in one of the spacecraft's instruments, the Hard X-ray Telescope. Neptec Design Group is developing the Canadian ASTRO-H Metrology System, or CAMS. CAMS will be used to calibrate the data of the Hard X-ray Telescope and significantly enhance the telescope's performance. Canada is

represented on the Science Working Group by Saint Mary's University, the University of Waterloo, and the University of Manitoba.

- NEOSSat (CSA/MDN) – Launch planned 2012. Canada is currently building NEOSSat (the Near-Earth Object Surveillance Satellite), the world's first space telescope dedicated to detecting and tracking asteroids and space debris. NEOSSat applies key technology already demonstrated in Canada's MOST satellite. NEOSSat is jointly funded by CSA and Defence Research and Development Canada (DRDC). The satellite is built by Microsat Systems Canada Inc., with support from Spectral Applied Research and COM DEV (formerly Routes AstroEngineering). The science team includes DRDC, the University of Calgary, the University of British Columbia, the Planetary Science Institute, the University of Arizona, the University of Western Ontario, the University of Hawaii, NASA, and SAIC.
- BRITE Constellation – Launch planned 2012. The six nanosats of the BRITE (BRight Target Explorer) Constellation will join MOST in orbit to make highly precise measurements of the brightness variations of a large number of bright stars. Canada is a partner in BRITE Constellation with Austria and Poland, and is funding two of the six satellites. BRITE's design originates from the University of Toronto (UTIAS-SFL ) and the science team includes the Université de Montréal and the University of British Columbia.
- HERSCHEL (ESA) – The Herschel Space Observatory was launched in 2009 together with the Planck Space Telescope. Canada contributed to two of the three science instruments: the Heterodyne Instrument for the Far Infrared (HIFI) and the Spectral and Photometric Imaging Receiver (SPIRE). The University of Waterloo led the HIFI science team. COM DEV was the prime contractor for Canada's contribution to HIFI. The University of Lethbridge led the SPIRE science team. Blue Sky Spectroscopy hosts the centre of expertise for the SPIRE imaging spectrometer. The Canadian Herschel team includes scientists from the universities of British Columbia, Calgary, Western Ontario, Toronto, Victoria, McMaster University and the National Research Council Canada.
- PLANCK (ESA) – Planck was launched jointly with the Herschel Space Observatory in 2009. The satellite is the most sensitive telescope ever designed to study the cosmic microwave background. Canada participated in the development of the LFI and HFI, the two instruments on Planck, mainly through development of the rapid interpretation software and the real-time analysis software that made it possible to verify the data in the preliminary stages of the mission. The data analysis software for the LFI and HFI were developed in parallel by two teams, one at the University of British Columbia and one at the University of Toronto.
- MOST – The MOST (Microvariability and Oscillations of Stars) project is a cooperative scientific partnership to create the world's smallest astronomical space telescope to measure the ages of stars in our galaxy. MOST was launched in 2003. Dynacon Enterprises Limited (now Microsat Systems Canada Inc.) was the lead contractor. Other key partners included:

the University of British Columbia, the University of Toronto Institute for Aerospace Studies (UTIAS), the Centre for Research in Earth and Space Technology (CRESTech), and COM DEV (formerly Routes AstroEngineering), and a team of scientists from across Canada and the U.S. led by the University of British Columbia.

- FUSE (NASA) – FUSE (Far Ultraviolet Spectroscopic Explorer) satellite operated from 1999 to 2007. FUSE was jointly built by NASA, CSA, and France's Centre national d'études spatiales. Canada contributed the fine error sensors used to stabilize and point the telescope with extreme precision. In return, Canadian scientists got about 5 percent of the observing time on the telescope and participated in the international science team that directed the mission. It was built by COM DEV with technical advice and design work from the Herzberg Institute of Astrophysics.

### A.5 Environmental Science

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- SMOS (ESA) – SMOS was launched in 2009. It is the first satellite designed to both map sea surface salinity and monitor soil moisture on a global scale, thus contributing to a better understanding of the Earth's water cycle. As a secondary objective, SMOS will also provide observations over snow and ice-covered regions, contributing to the study of the cryosphere. Array Systems Computing developed a soil moisture processor.
- CLOUDSAT (NASA) – Launched in 2006, CloudSat is gathering new data on cloud thickness that would help to determine volume and the quantity of water, snow, or ice clouds contain. CloudSat was developed by NASA in partnership with the Canadian Space Agency. CPI and COM DEV developed a key element of the cloud profiling radar, as well as a central component of an electronic receiver. MSC and the Université du Québec à Montréal are members of the CloudSat mission research team.
- SCISAT (CSA) – Launched in 2003, SCISAT-1 is a Canadian satellite designed to make observations of the Earth's atmosphere to help a team of Canadian and international scientists, led by the University of Waterloo, improve their understanding of the depletion of the ozone layer, with a special emphasis on the changes occurring over Canada and in the Arctic. Its main instruments are an optical Fourier transform infrared spectrometer, the ACE-FTS instrument, and an ultraviolet spectrophotometer, MAESTRO. These devices record spectra of the Sun, as sunlight passes through the Earth's atmosphere, making analyses of the chemical elements of the atmosphere possible. SCISAT is a relatively small satellite. The Canadian Space Agency coordinated its design, launch and use. Contractors included Bristol Aerospace, ABB Bomem, EMS Technologies, Routes AstroEngineering, and COM DEV. The array detectors for the on-board cameras were contributed by Belgium. NASA provided the launch. There were also contributions by the Meteorological Service of Canada, the University of Toronto, and the Natural Sciences and Engineering Research Council.

- **Odin (Sweden)** – Sweden’s Odin satellite, launched in 2001, has a dual-purpose mission to study ozone depletion and to search for water and oxygen in interstellar space. The project is carried out and funded jointly by the space agencies of Sweden, Canada, Finland and France. Its main instrument is a 1.1 m-diameter radio telescope. Canadian participation is led by the University of Calgary and includes the University of Waterloo, St. Mary's University, McMaster University, the University of Saskatchewan, and the Herzberg Institute of Astrophysics. CSA and NSERC provided funding.
- **TERRA (NASA)** – The Canadian instrument MOPITT (measurements of pollution in the troposphere), a Canadian contribution to NASA’s Earth Observing System (EOS), is one of five instruments launched in 1999 aboard the NASA satellite Terra. It was designed by the University of Toronto and manufactured by COM DEV.
- **UARS (NASA)** – WINDII was one of ten instruments aboard the American UARS satellite, which was launched in 1992 and operated until 2004, to study the winds of the upper atmosphere. It was built in cooperation with France with a scientific team was lead by York University.

## A.6 Planetary Exploration

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- **CURIOSITY (NASA)** – Launched in 2011, Curiosity is estimated to arrive on Mars on August 6, 2012. Curiosity is carrying a Canadian-made geology instrument that will enable the rover to determine the chemical composition of the rocks and soil on Mars. The APXS instrument on Curiosity is an updated version of the spectrometers that were successfully used on the Mars Exploration Rover and Mars Pathfinder missions. The science team is led by the University of Guelph and includes: the University of New Brunswick, University of Western Ontario, JPL, University of California, San Diego, Cornell University, and the Rensselaer Polytechnic Institute. MDA is the prime contractor for APXS.
- **PHOENIX (NASA)** – The Phoenix Mars Lander was launched in 2007. It landed near Mars’s northern polar cap in 2008 where it operated successfully for more than five months. Canada’s meteorological station recorded the daily weather at the landing site: temperature and pressure, clouds, fog and dust in Mars’ lower atmosphere. York University led the Canadian science team with the participation of the University of Alberta, Dalhousie University, and Natural Resources Canada, and CSA, and international collaboration from the Finnish Meteorological Institute. MDA was the prime contractor for the meteorological station, in partnership with Optech.
- **NOZOMI (Japan)** – A Canadian instrument called the Thermal Plasma Analyzer, or TPA, was one of 14 instruments onboard the Japanese satellite Nozomi, a mission designed to study Martian atmosphere and its interaction with solar wind. The satellite was launched in 1998

but it was impossible to place Nozomi in orbit around Mars. The science team for TPA was led by the University of Calgary.

## **A.7 Technology Demonstration**

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- PROBA-2 (ESA) – Proba-2 was launched in 2009 as part of ESA’s In-orbit Technology Demonstration Programme, a series of microsatellites that are being used to validate new spacecraft technologies. The satellite hosts 17 technology demonstrations and four significant science experiments that focus on solar observations, plasma measurements and space weather. Three Canadian space companies contributed to the Proba-2 satellite. MPB Communications Inc. provided a Fiber Sensor Demonstrator, which will be the first demonstration of a full fibre-optic sensor network used in a space environment. Microsat Systems Canada Inc. supplied four micro-reaction wheels, which are used to assure the accurate orientation of the spacecraft. NGC Aerospace Ltd provided on-board intelligent software to support the autonomous guidance, navigation, control and failure detection of the spacecraft.

# B. Canadian Space Companies

## B.1 Space Hardware Companies

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### 6.1.1 MacDonald, Dettwiler and Associates

MacDonald, Dettwiler and Associates (MDA) provides information solutions, principally for the Surveillance and Intelligence sector and the Communications sector. In addition, the Company conducts a broad range of customer funded Advanced Technology development for various other market sectors. MDA has capabilities in program management, business engineering, systems engineering, hardware and software development, systems integration, and ongoing support services. Product lines include:

- Surveillance and intelligence systems and services that integrate information from space-based, airborne, maritime, and ground-based sources.
- Communication satellite payloads, a large range of electronic products, antenna subsystems and composite structures, and complete communications satellites.
- Advanced technology solutions for demanding operational environments spanning markets as diverse as manned and unmanned space exploration, robotic surgery, aviation navigation, and nuclear reactor maintenance.
- Geospatial services such as data, data processing, and associated expertise and services.

### 6.1.2 COM DEV

COM DEV International Ltd. is a designer and manufacturer of space hardware, particularly the production of space-qualified passive microwave equipment, specialized electronics and optical subsystems. These products and subsystems are sold to major satellite builders for use in communications, space science, and remote sensing. The company is currently organized into four operating divisions:

- COM DEV International Products (CDIP) is responsible for the design and production of spaceflight hardware for the commercial satcom market.
- COM DEV USA (CDU) serves the US military space market, with a focus on complex microwave filtering and specialized electromechanical switches.
- COM DEV Canada (CDC) is primarily focused on the Canadian civil space market with spaceflight subsystems and instruments used in earth observation, space science and remote sensing.
- COM DEV Europe (CDE) is focused on European Space Agency activities and technology development.



### **6.1.3 SED**

SED Systems is a developer and integrator of systems, products and services used in communications, test and control applications. Their primary market is communications satellite manufacturers, operators and service providers. They also provide satellite operations services to control and monitor satellites for government and commercial clients. They design, install and test the system, assist in developing operating scenarios and procedures, and provide expert support to system commissioning and service rollout. They also provide a range of off-the-shelf, customizable products for satellite communications applications.

### **6.1.4 Telesat**

Telesat is a global fixed satellite services operator providing satellite-delivered communications solutions worldwide to broadcast, telecom, corporate and government customers. The company has a fleet of 13 satellites, with more under construction, and manages the operations of additional satellites for third parties. Telesat also provides full-service satellite consulting to customers who require independent guidance and support on a full range of technical and commercial matters related to satellite communications and earth observation.

### **6.1.5 Magellan Aerospace**

Magellan Aerospace Corporation designs, engineers, and manufactures aeroengine and aerostructure components for aerospace markets, advanced products for military and space markets, and complementary specialty products. This includes sounding rockets and payloads, space shuttle payloads, International Space Station payloads, and spacecraft buses and integration services. Magellan has developed a variety of satellite busses to meet science, technology demonstrations and operational LEO mission requirements.

### **6.1.6 ABB**

ABB operates five divisions: Power Products, Power Systems, Automation Products, Process Automation and Robotics Division. Each of ABB's divisions also offers a complete Service portfolio for power and automation customers. ABB Analytical Measurements has expertise and capabilities in Fourier spectrometers and optical instrumentation, providing airborne and spaceborne optical instruments, infrared calibration systems, hyperspectral imagers, and software for ground segments and simulation.

### **6.1.7 Microsat**

Microsat Systems Canada Inc. (MSCI) applies dynamics and control technology in the space market for reaction wheels, rate measurement units and complete microsatellites. MSCI provides the design, development and delivery of cost-effective, adaptable Multi Mission Microsatellite Buses capable of hosting a wide variety of remote sensing, communications,



scientific and military payloads. MSCI also has proven capabilities in systems engineering analysis, the development of sophisticated, cost-effective attitude control system solutions and their implementation into flight hardware and software.

### **6.1.8 Blue Sky Spectroscopy**

Blue Sky Spectroscopy specializes in custom spectroscopic solutions with emphasis on infrared Fourier transform spectrometers. Their capabilities cover complete system development from the optical, mechanical and electronic design through to manufacture, assembly, integration and verification of state-of-the-art instrumentation.

### **6.1.9 MPB**

MPB Technologies Inc. specializes in high technology products and systems, research and development, and measurement services. The company activities encompass: Telecommunications, electromagnetics, fusion, lasers, natural resources instrumentation, space technology, and telerobotics.

### **6.1.10 NGC Aerospace**

NGC Aerospace offers analysis, simulation and design services for the guidance, navigation and control (GNC) of planetary exploration vehicles and terrestrial satellites. NGC aims to increase the autonomy, performance, reliability and safety of intelligent vehicles while, at the same time, reducing their operational costs. NGC's main activities include mathematical modelling, dynamics & control analyses, simulator development and real-time software development associated with the navigation, guidance, control, intelligent management and failure detection/identification of autonomous and complex systems.

### **6.1.11 Array Systems Computing**

Array Systems Computing offers services in sonar, radar, satellite remote sensing, 3-D modelling and simulation, and Intelligent Transportation Systems (ITS). Array specializes in developing digital signal processing and image analysis software. Array's main markets include the domestic and international defence, simulation and aerospace industries.

### **6.1.12 Optech**

Optech develops, manufactures, and supports advanced laser-based survey instruments. They offer lidar solutions in airborne terrestrial mapping, airborne laser bathymetry, laser imaging, mine cavity monitoring and industrial process control, as well as space-qualified sensors for orbital operations and planetary exploration in applications such as rendezvous and docking, hazard avoidance and precision landing, planetary and small body mapping, and surface operations and science.

### **6.1.13 Sinclair Interplanetary**

Sinclair Interplanetary is a supplier of hardware, software, training and expertise to the spacecraft community. The primary focus is on low-cost, rapid-schedule programs to produce micro- or nano-satellites. Standard products are: digital sun sensors, reaction wheels, magnetic torque rods, and star trackers.

### **6.1.14 CPI**

Communications & Power Industries (CPI) provides microwave, radio frequency, power and control solutions for critical defense, communications, medical, scientific and other applications. CPI's Satcom Division (CPI Satcom) provides uplink amplifier products and systems for satellite communications.

### **6.1.15 BlackBridge Aerospace**

BlackBridge Aerospace provides satellite ground segment support services from facilities in Lethbridge and Inuvik. BlackBridge facilities are strategically located to provide advantages for polar orbiting missions, and missions with a Canadian focus. Services include technical consulting and implementation support for construction of new antenna systems, operational support for ongoing hosting and maintenance of antenna systems, and uplink/downlink capacity on existing antennas. BlackBridge Aerospace also supplies high and medium resolution satellite imagery, including satellite reception, image processing, custom application development and on-line data access.

### **6.1.16 NovaTel**

NovAtel designs, markets and supports a broad range of products that determine precise geographic locations using the Global Positioning System (GPS). NovAtel focuses on precise positioning GPS applications such as surveying, geographic information systems (GIS), aviation, marine, mining and machine control and precision agriculture. NovAtel manufactures:

- Receivers
- Firmware Options
- Antennas
- Inertial augmented systems
- Post-Processing Software

### **6.1.17 Exact Earth**

exactEarth Ltd., a company jointly owned by COM DEV International Ltd and HISDESAT Servicios Estratégicos S.A. exactEarth's service, exactAIS®, is a global vessel tracking and maritime domain monitoring system based on space-based AIS (Automatic Identification System) detection technology.

### **6.1.18 Neptec**

Neptec Design Group Ltd. is an experienced spaceflight engineering company specializing in the development, production, integration, operation and support of intelligent spaceflight sensors, payloads, instruments and equipment. An affiliated company, Neptec Technologies Corp., focuses on the migration of Neptec's technology to terrestrial markets. Neptec vision systems:

- Provide real-time, precise visual and numerical alignment and positioning cues.
- Perform on-orbit inspection of spacecraft.
- Allow "targetless" Autonomous Rendezvous & Docking (AR&D).
- Provide ranging and situational awareness information on surrounding objects including space vehicles, satellites, and debris.

Neptec combines space and defence technologies to offer solutions for subsea, oil & gas, power & energy, mining, and transportation industries.

### **6.1.19 Spectral Applied Research**

Spectral Applied Research develops optical instruments for a wide variety of applications, primarily optical instruments for the medical research community. They have expertise in many aspects of optics including lasers, hyperspectral, interferometry, remote sensing, calibration, spectroscopy, etc.

### **6.1.20 UTIAS – SFL**

The UTIAS Space Flight Laboratory (UTIAS/SFL) collaborates with business, government and academic institutions on spacecraft projects and the development of new space technologies. As a laboratory at the University of Toronto, its aim is to promote the use of novel technologies in space, and to train graduate students to strengthen the Canadian skill base in space systems engineering. In addition to micro and nano spacecraft projects, the Space Flight Laboratory engages in technology research to facilitate the microspace revolution. Active research programs include deep space communications, electric propulsion, and a component radiation effects and mitigation program to enable far-reaching missions with low-cost spacecraft exploiting mass-produced commercial components.

### **6.1.21 U of Calgary**

The Institute for Space Imaging Science (ISIS) is a partnership among the University of Calgary, the University of Lethbridge and Athabasca University, with links to the National Research Council of Canada's Herzberg Institute of Astrophysics and Canadian Space Agency.

Space Imaging Science within ISIS encompasses fundamental and applied research in planetary science, astrophysics, space physics and geomatics. Within these broad areas, specific current research thrusts include asteroid and meteoroid studies, radio astrophysics of galactic structure,

star formation and cosmic magnetism, auroral physics, solar-terrestrial interaction, magnetospheric and geospace plasma processes, and global navigation systems. Space Imaging also includes research and development of enabling technologies in imaging required to advance the research goals.

### **6.1.22 Institut National Optical**

INO offers integrated services in the fields of optics/photonics. They collaborate with the main space agencies and astronomy research centers to study and develop components that are critical to the observation of the earth, atmosphere, and universe, as well as to the future of spatial exploration, including fiber optic communications systems and uncooled infrared microbolometric detectors.

## **B.2 Earth Observation Value Added Companies**

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### **B.2.1 C-Core**

C-CORE is an independent not-for-profit R&D corporation with capabilities in remote sensing, ice engineering and geotechnical engineering. C-CORE is also home to LOOKNorth, a Canadian Centre of Excellence for remote sensing innovation to support northern resource development, and the Centre for Arctic Resource Development (CARD). C-CORE's Remote Sensing group provides climate change adaptation services, public and environmental safety, intrusion/integrity monitoring of critical infrastructure such as oil and gas production facilities, pipelines and dams, reliable environmental characterization for new field exploration and development, and real-time monitoring of environmental conditions such as ice and icebergs.

### **B.2.2 Hatfield Consultants**

Hatfield Consultants provides high-quality environmental services for private and public sector clients throughout the world, including North and South America, Asia, Europe and Africa. Hatfield provides services in the areas of aquatic ecology, environmental assessment and monitoring, contaminant monitoring, GIS and remote sensing, environmental information systems, biodiversity assessments and international development. Hatfield Consultants' remote sensing and Geographic Information System (GIS) products and services complement and extend Hatfield's environmental assessment, management and monitoring services.

### **B.2.3 Noetix**

Noetix Research Inc. specializes in remote sensing and geographic information systems for land and marine applications including project management, software and engineering solutions.

Noetix is comprised of three groups: GeoInformation Systems, Land and Marine Applications and Interactive Learning.

#### **B.2.4 Effigis Geo Solutions**

Effigis (formerly VIASAT GeoTechnologies) provides earth observation services, infrastructure inventory, telecommunications network monitoring, GNSS software, and geological studies.

#### **B.2.5 IES**

Info-Electronics Systems Inc. (IES) is an engineering, integration and project management services company. IES has expertise in the area of meteorological applications and the required communications systems for collection, processing and distribution of meteorological information.

#### **B.2.6 Enfotec**

Enfotec Technical Services is a subsidiary of the Fednav Group that specializes in providing ice analysis and vessel-routing services for ships operating in ice-covered waters. The core of the business is IceNav™, a computerized shipboard ice navigation system providing clients with near-real-time satellite images, charts, and forecasts of ice conditions. Enfotec's expertise concentrates on environmental impact assessments and marine accessibility studies for marine operations through ice-covered waters.

#### **B.2.7 ASL Borstad**

ASL Borstad Remote Sensing, a wholly-owned subsidiary of ASL Environmental Sciences Inc, provides remote sensing services to the environment, mining and military sectors using airborne and satellite sensors. They provide data gathering, mapping, monitoring, consulting and training services worldwide with a variety of satellite and aircraft sensors including thermal, short wave infra-red, visible and radar systems. They have particular expertise in hyperspectral airborne and satellite systems.



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