# The Future of Canada's Space Sector

## An Engine of Innovation For Over Fifty Years

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AIAC
Aerospace Industries Association of Canada
L'Association des industries aérospatiales du Canada

# “Space is at the cutting edge of innovation.”

*Hon. Navdeep Bains, Minister of Innovation, Science and Economic Development*
*Launch of Canada’s fourth recruitment campaign for Canadian Astronauts*
*Canadian Aviation Museum – Ottawa – June 17, 2016*

# EXECUTIVE SUMMARY

Canada has a 50-year history as a spacefaring nation. That history is part of what defines Canada as a globally important, advanced economy. That 50-year investment has also left a legacy of infrastructure, institutions and industry that generates significant socio-economic benefits and directly supports or enables government priorities across several departments, including National Defence, Environment & Climate Change, Fisheries & Oceans, Indigenous & Northern Affairs, Natural Resources, Transport, Public Safety and Innovation, Science & Economic Development. Canada's space sector is also a modern ecosystem of innovation that involves and inspires Canadians in government, academic institutions and private sector companies. The sector supports world-leading Canadian science, generates technological innovation and exports on a daily basis, and has been justifiably identified as an example of the kind of "innovation ecosystem" which the Innovation Agenda seeks to build and expand.

It is, however, a sector that faces both significant opportunities and major challenges. Internationally, the industry is in the throes of a generational transformation that is seeing the rise of new players and whole new business models. This provides a host of new opportunities. Unfortunately, domestically, the combined forces of reduced funding and lack of investment certainty are depriving the space innovation engine of the fuel that it needs to respond to this dynamic environment and live up to its full potential.

Two things are needed. They are needed soon. It is crucial that a new long term vision for Canada's space program be developed. It is also critical that the government make a new, modest, investment in the sector while plans for the long term are being laid. If these actions are taken, the space sector in Canada will continue to be a source of innovation, jobs, economic prosperity and pride to all Canadians and a sought-after partner on the world stage. If these actions are not taken, it is inevitable that erosion of Canada's leadership in space will continue and the ability of our space sector to retain its position "at the forefront of innovation" will eventually be compromised by the eventual loss in the ability to design, build and operate spacecraft.

In this paper, we present the broad outline of a long-term vision for space that we hope the government can use to inform a wider consultation on the future of space in Canada. We also present a detailed summary of what new funding is needed now, in order to stabilize the sector while a durable plan is being developed within the next year.

This plan is based on aggressive targets for growth and performance. By 2026, we believe that Canada's space sector should aspire to:

- Increase Canadian space sector revenues by over $8 Billion over 10 years
- Increase its contribution to Canada's GDP by over $3.6 Billion over 10 years
- Increase employment by over 30,000 person-years over 10 years - over half of which will be HQP

Achieving these targets will demand a bold "whole of government" plan that addresses both Canada's civil and defence space requirements. This plan will need to be centred on three essential pillars of the civil space program:

1. Support for a robust program of space technology development
2. Support for a balanced program of affordable space missions
3. Support for flagship space programs that continue Canada's leadership in space.

It will also need to proceed with long-planned and budgeted military space investments using Canadian industry's world-leading capabilities.

With the appropriate level of investment Canada's space industry has the capacity to meet these requirements, and to continue to be an export driven engine of economic prosperity, innovation, and inspiration.

# INTRODUCTION

In the following discussion, we will provide an industry perspective on Canada's Space Program. We will discuss Canada's history of investment in space that has made Canada a leading space-faring nation. We will touch on the, partnerships, benefits and achievements that have accrued to Canada and Canadians as a legacy of this investment. We will consider the current socio-economic benefits that accrue to Canada from its activities in space and we will analyse the industry through the lens of the Innovation Agenda. Finally, we will consider the transitional state of the global space sector, discuss both the opportunities and threats that this situation poses, and present a vision for Canada's future in space.

# THE HISTORY OF CANADA'S INVESTMENT IN SPACE

To understand where we are as a nation, we must understand how we got here. Space is inherently government business. Until quite recently, national governments were the only buyers of space systems – be they communications or remote sensing satellites, or scientific or exploration instruments. Certainly, the International Space Station (ISS) is the ultimate government-led space program, bringing together many nations sharing the common goal of space exploration and science.

Canada originally invested in space because national decision-makers determined that in a country as vast and dispersed as Canada, space is essential to the operations of a national government and a modern economy. In 1962, Canada became the third nation in space with the launch of Alouette 1 for ionospheric research into the properties and behavior of the earth's upper atmosphere. This led to the launch of the first domestic communications satellite (two years before the US), and the first direct broadcast satellite, Hermes.

Since those early bold investments in Canada's national needs, Canadian industry has remained at the forefront of global satellite communications technologies. Our initial focus on linking Canadians together through satellite communications was soon eclipsed by the realization that space-based Earth observation (EO) could further enhance our economic growth by contributing to a multitude of national needs, most notably: ice monitoring, resource management, environmental monitoring and stewardship, coastal and maritime situation awareness, surveillance and security and forestry and agricultural management, among many others. With Canada's RADARSAT family of satellites, we remain global EO leaders and continue to contribute to Canada's economy and economic growth and global scientific knowledge.

Over the past three decades, as Canada grew more prosperous, the utility and wonder of space led to other investments in world-leading science, astronomy and, of course, space robotics. Canada's iconic contributions of Canadarm to the Space Shuttle and Canadarm2 and Dextre to the International Space Station (ISS) established Canada as a valued partner in international space exploration.

Canada has traditionally managed its space interests through a government-wide planning framework called the Long Term Space Plan (LTSP). In 1986, LTSP I invested in RADARSAT-1 Mobile Communications Satellite (MSAT) and, of course, the ISS. In 1991, the Canadian Space Agency (CSA) was formally established to lead Canada's space interests. In 1994, LTSP II invested in RADARSAT-2, an Advanced Satellite Communications platform (Advanced SatCom) and confirmed the ISS partnership.

In 1999, an A-Base of $300M was established for the CSA. At the time, it was noted that this level of funding would maintain Canada's core program requirements, but would not accommodate any incremental investment in major projects. As will be noted below, this has been proven to be the case.

In 2001, as the CSA and Canadian industry worked to develop LTSP III - which was to include a follow-on radar program, a hyper-spectral mission and a mix of technology, science and astronomy investments, the events of 911 changed the focus of all national governments, including Canada. The 2001 November Economic Update concentrated new government investment on national security and intelligence.

Budget 2002 was cancelled, and it was not until 2005, that the Government approved a reduced LTSP III, which comprised the first tranche of funding ($210M) for the RADARSAT Constellation Mission (RCM), the next generation space radar capability for Canada. In addition to RCM, the government gave policy approval for a hyper-spectral mission, but allocated no funding.

Since 2005, new investment and the future of Canada's Space Program has not been considered at the Cabinet level. Space has been on the agenda, but mainly for the purposes of the on-going requirements of existing major crown programs, RCM and ISS. Over the life of the last government, in order to meet the demands of these two programs while coping with a steadily decreasing A-base that is not tied to inflation, the CSA was forced to reduce spending in many areas of activity, including space science, space technology development and demonstration, astronomy, education and outreach, and international cooperation. The only significant new program to move forward during this period was RCM. In satellite communications, the CSA retreated from any involvement in the sector, deeming it a mature commercial sector that no longer required technology development funding. This has turned out to be an inaccurate assessment of the fiercely competitive global sector where technology and products are in constant evolution. Apart from receiving $110M in the 2009 'stimulus' budget to advance space robotics capabilities, Canada's space sector has seen virtually no government investment in new space initiatives over the last decade and no renewal of the vision for the government's long-term needs and spending in space.

In 2015, the government announced the extension of Canada's participation in the ISS from 2020 to 2024, albeit without the allocation of additional funds to the CSA. Industry applauded when Budget 2016 allocated $379M over eight years for Canada's participation in the ISS to 2024. This is an excellent first step.

Over the past decade there has been frequent and substantive dialogue between senior government officials and Canada's space industry. The Emerson Report on Space (Reaching Higher: Canada's interests in Space) required significant industry effort involving months of direct interaction and considerable investment in personnel and resources. Throughout this period the overriding concern of industry has continued to be the lack of a long term vision for Canada's space program. As the last long term plan has gradually expired, industry concern has grown over the lack of any new program funding. This concern has now reached the stage of alarm. The combined effect of lack of long term certainty combined with the lack of near term opportunities is casting an active chill on the

amount of investment in the space sector in Canada. Canadian subsidiaries of larger multinational corporations find it increasingly difficult to attract corporate resources to Canada. Firms that have the option to invest in other jurisdictions are pursuing those opportunities.

There is a widespread feeling that the Canadian legacy of excellence and achievement is in danger of being taken for granted and that the industry / government partnership that was instrumental to the development of Canada's space industry has been allowed to atrophy, and must now be reinvigorated with diligence and purpose if Canada's space sector is to survive and prosper. Attention needs be directed at core aspects of Canadian space capability, including robotics, optics, radar, satellite communications, space science and technology development and applications.

# THE PROVEN SOCIO-ECONOMIC IMPACT OF SPACE INVESTMENT

This history of investment in space has allowed Canada to develop a world-leading space manufacturing, operations and services industry that provides significant socio-economic benefits to all Canadians.

## GLOBAL SOCIO-ECONOMIC BENEFITS[1]

In 2013 (the last year that comprehensive global data is available), the revenue of the global space industry was $250 (US) Billion, and comprised 58 nations with active space programs. The majority of these revenues were created in the commercial market ($204 Billion), with $46 Billion coming from the government sector. The drivers of global commercial space revenues have been satellite communications (66%) and SatNav (32% - primarily GPS). On the government side, the program mix has been more balanced and has been driven by new partnership models between public and private investment. Looking forward, the commercial market will continue to dominate and is forecast to grow to $284 Billion by 2023 – an increase of nearly 40%. The government market, on the other hand, is forecast to grow by only $3 Billion to $49 Billion.

## CANADIAN SOCIO-ECONOMIC BENEFITS

In Canada, national space investments over the past decade have focused largely on security and sovereignty, notably RCM, although the government baseline for space investments has declined. Today, Canada's annual space budget is well below the global average for space-faring nations. Canada's space sector is comprised of 226 organizations, with private sector firms making up the largest segment (75%) and research institutions (25%) making up the rest. Annual revenues are $5.37 Billion, including broadcasting enabled by satellite technologies.

1 This section is based on the results of the "Socio Economic Impact Assessment of the Canadian Space Sector" prepared by Euroconsult for the Canadian Space Agency in March 2015.

When broadcasting is excluded, the annual revenues of the space sector are $3.7 Billion. This represents annual revenue growth of 3.7% per year for over the past five years – well ahead of the average growth in the national economy of only 1.8%.

The economic impact of the space sector is significant, both in relation to its contribution to Canada's GDP and its contribution of tax revenues. The space sector has an economic multiplier of 1.85, which is the ratio of direct GDP contribution to indirect and induced GDP contribution. Space contributes $2.9 Billion to GDP, comprised of direct (54%), indirect (25%) and induced (21%) benefits. Interestingly, the SME community makes a major contribution at 45% of direct GDP.

As a source of tax revenues, the space sector contributes upwards of $750 Million, comprised of direct (65%), indirect (19%) and induced (16%) contributions. Services and manufacturing lead the way with 55% and 30% respectively.

High quality employment is perhaps one of the most positive contributions of Canada's space sector. Canada's space sector is growing six times faster than Canada's job market generally. In 2013, the sector's contribution to job creation was 24,354 jobs, comprised of direct jobs (9,784 – 40%), indirect jobs (7,895 – 32%) and induced jobs (6,675 – 30%).

For every job created in Canada's space sector, another 1.5 jobs are created indirectly through the supply chain and in the broader economy. And, perhaps of most significance, 53% or the jobs created are for highly qualified STEM (science, technology, engineering, mathematics) workers. A visit to one of Canada's leading space manufacturing or service companies will also show the depth of our collective commitment to inclusion, diversity and gender equality in their respective work forces. Women and men work together to maintain and expand Canada's technology excellence.

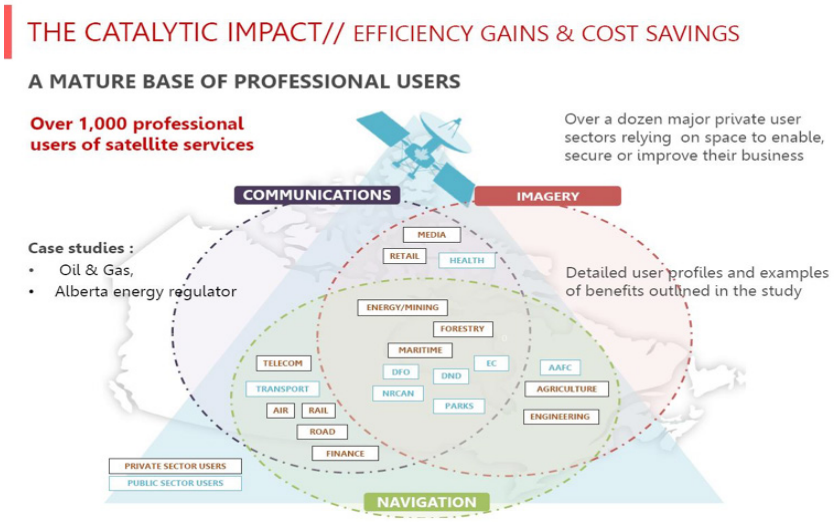
Canada has a mature base of over 1,000 professional users of satellite services, with dozens of private user sectors relying on space to enable, secure or improve their business. Analysis of the catalytic impact of space technologies suggests that the economic impact of space continues to evolve and grow. According to a study by HEC Montreal, each dollar invested in space results in a spill-over effect of $1.2 created in the economy, e.g. for $387 Million invested by the CSA, the Canadian space industry generated an additional $408 Million for the Canadian economy. The impact of space spending is found in virtually every sector of the Canadian economy, from aerospace and defence, to structures, composites, life sciences, health care, propulsion, biotech, energy and many others.

Space also contributes significantly to the growth of knowledge and innovation. Annual space private sector R&D expenditures are $180 Million, split between upstream and downstream investments: 68% and 32% respectively. This means that space is more R&D intensive than the national average for other economic sectors. Canada's rate of business R&D investment in the sector is higher than in Europe or other industry sectors. Canadian space researchers also make a strong contribution to scientific knowledge, accounting for 6.9% of the world's total research publications; ranking 6$^{th}$ or 3$^{rd}$ respectively depending on the discipline. Suffice to say, Canada punches above its weight.

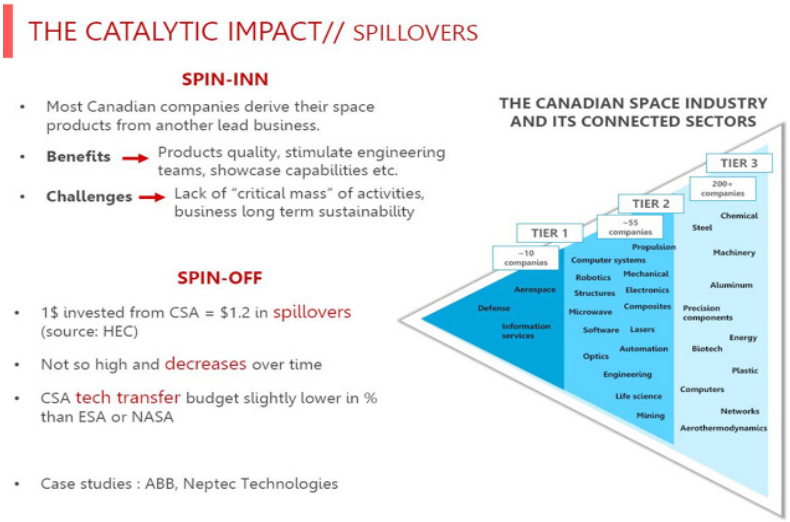
Despite these facts, Canadian government investment in space lags behind that of other OECD nations, being currently less than half the OECD average.

The Euroconsult Report also provides a number of examples where Canada's space industry has a social and strategic impact on Canada and its people:

- **Quality of Life** – several measures provide the scope of space's contributions to Canadians, including the value of weather forecasts ($5.4 Billion per year), GPS usage by Canadians (one million kilometers of roadways).
- **Public Safety** – the COSPAS/SARSAT system has saved 1,500 Canadian lives since 1982. Over 122 million passengers move through Canadian airports each year with the benefit from space-based systems. Disaster relief and recovery efforts are aided by space-based systems.
- **National Security and Sovereignty** – DND has played an increasing role in the national space program, developing capabilities in satellite communications as well as intelligence, surveillance and reconnaissance (ISR), with emphasis on the Arctic and maritime domain awareness.
- **Connectivity** – All of Canada's northern communities have relied on advanced satellite telecommunications capabilities for connectivity for their homes, businesses and government services since the late 1970's. Canadians benefit from 1,200 TV channels broadcast by satellites to 2.7 million homes. Canada has over 200,000 satellite broadband subscribers (second largest market in the world), including half of Arctic households.
- **Inspiration** – Canadarm is a treasured national icon. The CSA has 226,000 registered viewers of CSA YouTubeTV and 180,000 Twitter followers. Former astronaut Chris Hadfield continues to be followed by over 1.7 million people worldwide.
- **Climate Change** – With 10 million square kilometers of landmass, 244,000 km of ocean borders, extensive forests and ecologically sensitive areas, Canada leverages its space-based assets to monitor global and national climate change.
- **Resource Monitoring** – Canada is resource rich: Energy and mining contribute $170 billion to Canada's GDP; agriculture and agrifood contribute $100 billion; and forestry contributes $55 billion. Also, Canada has the 3rd largest reserve of fresh drinkable water. Space-based data is essential for the management and monitoring of all of these national assets.
- **International cooperation** – The CSA has signed 197 cooperation agreements with other space-faring nations. Canada is the only non-European member of the European Space Agency (ESA), and is recognized globally as a reliable partner in scientific and technological research.




*Source: Comprehensive Socio-economic impact assessment of the Canadian Space Sector" prepared for the Canadian Space Agency*




*Source: Comprehensive Socio-economic impact assessment of the Canadian Space Sector" prepared for the Canadian Space Agency*

These graphic depictions of the impact of Canada's space sector on the Canadian economy illustrate the importance of space investments.

According to our own analysis of the impact of investment in Canada's space sector, additional investment in a renewed Space Program will have important long-term benefits for the Canadian economy.

# CANADA'S SPACE ECOSYSTEM AS AN ENGINE OF INNOVATION

In addition to the examining socio-economic benefits that flow from the Canadian space sector, it is also possible to view the sector through the lens of the Innovation Agenda. The nature of the problem of getting to, and operating in, space demands a wide variety of specialised expertise. This need has generated a whole space community or ecosystem in Canada. This ecosystem takes the raw material of innovation: talent, inspiration, investment, and expertise and turns it into scientific discovery, technological breakthroughs and economic prosperity, which it then recycles to begin the process again. This "innovation engine" is based on, and continues to promulgate, many of the values upon which the Innovation Agenda is based.

As the space sector has grown, Canadian space firms, such as SPAR Aerospace, MacDonald Dettwiler and Associates (MDA), COM DEV, and Canadian Astronautics Ltd., have laid the foundations of Canada's space entrepreneurial and innovation culture. The achievements in communications, EO and space robotics were created by the entire ecosystem of government, academia and private industry sharing in the risks required to develop the technologies of tomorrow.

Today, while some of these names have changed, the core STEM clusters created in the 1970s, '80s and '90s continue to provide leadership to Canada's space industry. These firms are located across Canada, in Halifax, Quebec City, Montreal, Ottawa, Toronto, Cambridge, Winnipeg, Saskatoon, Vancouver, and in many smaller centres.

It is worth examining how this innovation ecosystem operates through the six areas of action defined in the Innovation agenda.

## ENTREPRENEURIAL AND CREATIVE SOCIETY

Canada's space sector combines the entrepreneurship of the inventor, the foresight of the risk-taking investor and the expertise of program management and execution, with the targeted achievement of national objectives that satisfy the social and economic needs of Canadians. Space has always inspired the best and the brightest. From the early days of the "space race" to the current generation of young engineers and scientists working on projects to explore our solar system and the universe and solve new problems using the International Space Station as a unique laboratory for materials science, robotics and human physiology research – space has an almost unparalleled ability to inspire young people to take up careers in science, technology, engineering and mathematics.

In the past few years, new business models are emerging in the space sector. These models are more entrepreneurial, drawing inspiration from Silicon Valley in their market-based and investor-focused approach. The level of venture funding in the sector has exploded in the past two years. Canadians and Canadian firms are well placed to take advantage of this trend.

The space industry is often the post-graduate "training school" for Canadian engineers and technologists. Personnel with experience in the space sector are highly sought internationally. Canada, as a leading space-faring nation enjoys a significant advantage over other countries that do not possess our heritage of

achievement, our advanced space infrastructure and our access and ability to participate in international space programs. We can use all of these strengths not only to inspire Canadians but also to attract talent to Canada to continue to build on more than 50 years of success in space.

## GLOBAL SCIENTIFIC EXCELLENCE

Canada's space sector is globally renowned for its scientific and technological excellence. From our earliest experiments into the properties and behaviour of the upper atmosphere, to the first geostationary domestic satellite, and the first direct broadcast satellite, Canada has been a world leader. Given our modest national investments in space, Canada has always punched above its weight. We are recognized for our scientific excellence in space robotics, optics, satellite communications and Earth Observation, as well as countless contributions to international collaborative science missions over the past five decades. A strong and vibrant space sector in Canada provides employment for thousands of graduates in engineering, science and technology fields. Canadian engineering capability combined with Canada's reputation and access to international partnerships provide opportunities for Canadian researchers and institutions to participate in cutting-edge research that would be inaccessible otherwise.

John MacDonald, one of the founders of MDA, referred to space as "the visible tip of the knowledge economy". There is perhaps no other industry sector that calls upon the skills and expertise of such a myriad of different intellectual disciplines, from engineering to ergonomics, from chemistry to astrophysics. Space workers are the workers of the future, highly skilled, highly mobile, highly motivated and in demand globally.

## WORLD-LEADING CLUSTERS AND PARTNERSHIPS

In the discussion about the Innovation Agenda there have been many views on what constitutes a "world leading cluster." While the characteristics of clusters are open to debate, there is a general agreement that the net outcome of effective clusters is that the whole of the cluster is greater than the sum of the individual parts. Essentially, a "cluster" is defined by the fact that the relationships within a cluster reinforce each other and accelerate the growth of ideas, innovations, products, services and ultimately economic growth. Because the space business is, by its nature a small community, because the barriers to entry are high and because both the risks and rewards inherent in working in space are substantial, clusters tend to naturally form. Since no one gets to space alone, and because niche expertise is so critical to being successful in space, clustering is essential.

Canada is one of a handful of countries that boasts an "end-to-end" space cluster, which has the capabilities to take an idea from the university classroom all the way to space. From our lead partner and core technology leadership role on the NASA Space Shuttle and International Space Stations programs, to our unique non-EU member status in the European Space Agency, Canada is a sought-after partner in international space ventures. This experience has allowed Canadian industry to develop relationships with the world's leading space companies that have created high quality job opportunities at home and consistent export success abroad.

Canada boasts a number of global players in the space economy, such as Telesat – the world's fourth largest fixed satellite services (FSS) operator – and MDA – the world leader in space robotics and wide-area radar satellites, and the world's leading manufacturer of commercial communications satellites via its US operations. These high-impact firms anchor Canada's space innovation ecosystem. There are core clusters of space expertise in a number of regions across Canada: Halifax (IMP, MDA, Airbus), The Quebec City, Sherbrooke, Montreal area (ABB, INO, MDA, MBB, NGC, GHGsat, Xiphos), Ottawa (Honeywell/COMDEV–EMS, Magellan, Neptec, Telesat, MDA, iDirect Canada, Mission Control Space Services), the Toronto-Waterloo corridor (MDA, aflare, Canadensys, Honeywell/COMDEV, exactEarth), Winnipeg (Magellan), Saskatoon (SED Systems), and Vancouver (MDA, Urthecast). In all of these space clusters, industry works together and with academic institutions such as: the University of Toronto Institute of Aerospace Studies (UTIAS), the University of Waterloo's Institute of Quantum Computing (IQC), York University's Centre for Research in Environment and Space Science (CRESS), Western University's Centre for Planetary Science and Exploration (CPSX), and the Canadian Astronomical Society (CASCA), among many others, to advance shared technology and science objectives.

In addition to established players, new networks are emerging to take advantage of the new Silicon Valley model of space investment and exploitation. Accelerators and incubators such as Waterloo-based MaxQ and Ottawa-based Carleton LED Accelerator that actively promote development of space applications are in operation or planned for the near future. These facilities will draw on the pool of existing talent and expertise in Canada to create a new generation of space entrepreneurs and companies.

## GROW COMPANIES AND ACCELERATE CLEAN GROWTH

Space missions are core to the advancement of science and our understanding of the natural dynamics of our planet and the universe. Climate and weather modelling rely on the multitude of environmental factors (such as sea ice) that are most effectively monitored, measured and analyzed from a space-based instrument or platform. With extensive experience in Earth Observation applications and data modelling, Canada's space industry is well positioned to provide information on climate change, global warming and environmental management and stewardship to the global research community.

Further, because of the nature of the space business, it is a sector the demands long-term commitment to developing and deploying technology. Canada's space industry has traditionally had very high levels of reinvestment in research and development. As an R&D performer, Canada's space sector is a key source of breakthrough innovations for other industry sectors. In many instances, the development of new space technologies involves innovations in science, engineering, applications, manufacturing or process engineering, new discovery and state-of-the-art outcomes. As a result of Canada being an early space-faring nation, Canadian prime contractors and supply chain partners alike have developed crucial flight heritage, science and technology capacity, market profile and international partnerships that were subsequently translated into commercial business both in space & adjacent terrestrial markets around the world.

## COMPETE IN A DIGITAL WORLD

Canada's space sector has, by necessity, led the way in the digital revolution in Canadian industry from innovations in early satellite telecommunications advancements, through to novel techniques for the exploitation of data captured via space assets for many 'downstream' applications. Space was an early adopter of digital technologies and capabilities, developing much of the technology to enable the transfer of huge volumes of data related to Earth Observation, Satellite Communications, and Inter-Satellite Communications. Innovations in the capture and analysis of digital models serve a multitude of national needs, from scientific and environmental research, to defence and security applications, fisheries protection, agricultural efficiencies and connecting Canadians in remote and rural communities, to name but a few.

Canada's expertise in digital technologies and applications has contributed to the cross-sector fertilization of ideas and innovation. Further developments in big data using innovative Low Earth Orbit (LEO), Highly Elliptical Orbit (HEO) and other small satellite constellations for EO and ubiquitous global telecommunications (including in the polar Arctic) will transform the Canadian economy and be a catalyst for inclusion and full participation in economic opportunities.

> *"In the second century of Confederation, the fabric of Canadian society will be held together by strands in space just as strongly as railway and telegraphy held together the scattered provinces in the last century."*
>
> *John H. Chapman (founder of Canada's Space Program)*

Canada has always been a welcoming environment to the world. The space sector is a microcosm of Canada's ethnic, cultural and religious diversity; with engineers, technicians and scientists from all walks of life and communities working together to meet shared objectives. One only needs to look at the faces in the graduating classes of Canada's leading universities and community colleges to see this diversity reflected as the new Canadian mosaic. In the space sector, advancement is based on ability and innovation, not on one's religious, cultural or ethnic background. The luck of birth is replaced by the performance of individual minds seeking answers to the unknown and extending the horizons of our collective knowledge and understanding.

Canada has world-leading niche technology expertise that is the envy of the world. We are sought after partners for space collaboration and technology cooperation. Our status as a space faring nation brands us as an innovative and progressive society. In the space business, Canadians innovate every day – to stay even with our global competition and to be able to operate successfully in the challenging environment of space. However, the job of competing and sustaining the space "innovation engine" is getting harder every day as well.

# THE SPACE INDUSTRY AT A CROSSROADS

Space technologies and applications are moving to smaller and smaller platforms; and private funding, renewed government investment and industry/government partnerships are driving innovation, expansion and growth.

The revolution in design and manufacturing of space hardware is nothing short of transformative. It is referred to as Space 2.0. Constellations of small satellites and High Throughput satellites will transform the economics of telecommunications and expand opportunities for economic growth. Privately financed global networks will create massive opportunities for economic development in under-served global markets. New space ventures will reach remote, rural and isolated locations everywhere. Technology transformation will reach deep into most strategic industrial sectors: Space, aerospace, defence, security, cyber-security, finance - and many more.

At the same time, governments around the world are increasing investments in space. For example, the United Kingdom has recently reinvigorated its domestic space program after many years of relative neglect. The result has been nothing short of spectacular, as the UK is now among the fastest growing space sectors, with investment flowing into the UK from around the world, including from Canada. By creating incentives for private sector partnerships, the UK is well on the way to achieving its target of growing its space industry from six percent to ten percent of the world market by 2030, thereby creating 100,000 new high quality technology jobs.

Private investors, such as Greg Wyler (OneWeb), Elon Musk (SpaceX), Jeff Bezos (Blue Origin), Richard Branson (Virgin Galactic), and companies like Sierra Nevada Corporation, Google, Facebook and Canada's own Telesat are leading a transformation in space. Canadian firms such as GHGSat, Urthecast, and exactEarth are responding to the new entrepreneurial environment with market-based solutions delivered from space.

Those space sector players nimble enough to meet the aggressive schedules of these new explorers will reap substantial rewards. Companies and countries that do not will find themselves increasingly pushed to the margins. Survival requires innovation, focus and a long term vision. At the federal government level, Canada's long term vision has long since expired.

## A BALANCED WHOLE OF GOVERNMENT APPROACH

Given the ubiquity of space-based services and information sources required by federal Departments and Agencies, future space sector requirements are best managed as a "whole of government" undertaking. Since space-based infrastructure impacts "whole of government" operations, and in select circumstances requires support across a broad portfolio of government interests, costs too should be apportioned appropriately. While the CSA is the appropriate entity to coordinate the space agenda across government, the determination of national space needs must be on a whole of government basis.

New investment is needed now to retain Canada's space capacity and position for future expansion and growth in both the civilian and defence sectors. An integrated and innovative plan for the space sector is essential for industry to focus its own resources, fulfil national needs and create high quality leading-edge sustainable jobs. Multiple stakeholders have an interest in Canada's future investments in space: federal, provincial and territorial govern-

ments, academia and, of course, the private sector. Over the past few decades, clusters – both real (Toronto/Waterloo Region corridor and Quebec City/Montreal/Ottawa nexus) and virtual (in many areas of scientific research) – have contributed to the performance and success of Canada's space sector.

Going forward, a balanced approach that supports both flagship programs and a range of emerging innovative space initiatives in remote sensing, telecommunications, optics, science and exploration is essential. Incremental investment should be focused to support and extend new missions with adequate funding to re-establish a balanced Canadian Space Program. Over time, Canada needs a long-term vision for Canada's future in space that sets realistic and compelling objectives to guide the priorities of Canada's space program.

Canada's space industry aspires to grow in Canada and beyond in terms of its contribution to GDP, its share of global space sector markets and, of course, high quality leading-edge innovative jobs. Success in space will contribute to Canada's global competitiveness, economic growth and export performance. The next Space Plan should set aggressive targets for growth and performance. By 2026, with adequate focus and funding Canada's space sector will:

- Increase Canadian space sector revenues by over $8 billion over 10 years
- Increase its contribution to Canada's GDP by over $3.6 billion over 10 years
- Increase employment by over 30,000 person years over 10 years - over half of which will be HQP

To achieve these targets, Canada's space industry is recommending that the government implement a bold whole of government Space Plan that meets Canada's civil and defence space requirements for the next decade. This combined civil / defence Space Plan will reinvigorate private sector investment and facilitate growth, foster innovation and create new export opportunities for Canadian industry.

## CANADA'S CIVIL SPACE SECTOR AND URGENT PROGRAM PRIORITIES

The space business is cyclical in nature, with programs entailing large investments, complex technologies, long lead times and extended intervals between contract awards. As such, it is often difficult to maintain the critical mass – in knowledge and capability – that is required to remain internationally competitive without consistent government investment and planning certainty.

Canada's space industry is a dynamic element of Canada's economy with global focus and world-leading technology and expertise to capitalize on emerging opportunities in global markets. In most nations, preference is given to domestic space companies either by designating space as a strategic sector or by providing direct support through research and development investment on major domestic programs to remain competitive. In many countries, particularly in the US and Europe, expenditures for defence space requirements exceed those in the civilian sector and the resulting enhancements to the technology base contribute to the competitive advantage in the civil sector.

In Canada's case, the lack of sufficient economies of scale from Canada's civil requirements works against the competitiveness of Canadian space companies in international markets. Canada's defence space spending has been modest. For the most part, Canada's space sector has survived by developing best-in-class technologies in key niche markets, and by then dominating those markets globally.

Going forward, Canada will need to be even more nimble, and future investments in both civil and military space will need to be coordinated to reinforce the strengths of Canada's space technology sector. Today, Canada's space industry still has niche technology leadership in important segments of the space sector. But, growing investment by competitor nations is calling into question our ability to retain this leadership position. It is time for Canada to protect, position and propel its space interests to meet its future needs.

Canada's space industry also has an outstanding record of developing export sales from its modest domestic base. Canadian firms successfully compete against some of the largest corporations in the world – and win consistently. Examples abound of Canada's niche technology dominance of international markets. Space is an important sector in a national economy, and this is particularly so in an advanced G7 nation. Innovation is at the very core of space sector development and leading-edge research and development. A renewed Canadian focus on innovation must, by definition, include a forward-looking Civil Space Plan that will position Canada and the Canadian economy for continued growth and prosperity well into the 21st Century.

**In line with our pre-Budget submission to the Finance Committee of the House of Commons, it is recommended that the government move quickly to approve and implement the following requirements of the Civil Space Program:**

## SUPPORT FOR FLAGSHIP PROGRAMS AND CAPABILITIES

Canada is the world leader in satellite communications, space radar, and robotics because of decades-long investments at the cutting edge of satellite communications technology, the RADARSAT Earth Observation program and our partnership with NASA for space exploration programs. These unique capabilities brand Canada on the world stage as an advanced technology leader and an instrumental partner for global security cooperation and international space science and exploration missions.

Flagship programs also provide the mass and scale necessary to build the anchors around which a successful space cluster can be built. The long term nature of the work allows companies and research institutions to develop the depth of expertise and experience that spawn a robust ecosystem of supporting players and which also generate the entrepreneurial spin-offs which are the hallmark of leading high-innovation clusters.

Commitment to flagship programs needs to be robust and long term. Over the history of the Canada's space program, flagship programs have typically run for more than ten years and have required budgets in excess of $1Billion to complete. The needs of such programs vary from year to year as they progress from preparatory activities through design, build, launch and operations. In order to ensure at reasonably continuity of expertise in these very complex endeavours, both inside government and in Canadian Industry we should assume that Canada will usually have three flagship programs in progress at a time – with one in definition, one in the design and build – and one in a transition to sustained operations. We note that has been the rule rather than

the exception until the last few years. We believe that a long term vision for space in Canada will need to return to account for this historical level of spending on flagship missions on an on-going basis in order to retain the critical mass that allows the space sector to operate as an engine of innovation and to grow this capacity.

There are a variety of flagship missions which are currently under consideration, including: Canadian participation in the next multinational space collaboration to develop a lunar-orbiting outpost, possible Canadian contribution to the next major space astronomy mission, the next steps in Canada's RADARSAT space based radar program and missions to bring advanced communications and surveillance to the polar arctic. It is beyond the scope of this paper to examine these options in detail. But it is certain that, in order for Canada to maintain a healthy space innovation ecosystem, provision must be made for continuing our practice of supporting such marquee missions.

As such, it is also critical to note that important decisions need to be made in the short term to maintain and grow Canada's leadership in both of these strategically important areas. To support these decisions, $17.5M is required over the next two years as an interim step. This will position Canada for the work to design next generation options for review and approval by government. Studies and analyses are required so that Canada is in position to make the right investment decisions in the longer term. Such investments are incremental to the current A-Base of the Canadian Space Agency.

## CANADIAN SPACE MISSIONS PROGRAM

Space missions are the heart of innovation and renewal for Canada's space industry. Global space technology markets are exploding and Canadian industry needs to consolidate their niche leadership in key technology areas to grow in future. New innovative technologies developed for space can only be validated if they are actually launched into orbit on a space mission. Therefore, new space missions are essential. The AIAC and Canada's space industry recommends that Canada immediately initiate a program for the definition, design, development and execution of multiple new Canadian space missions over the next five years, with a budget that will ramp up to $200M per year. As with flagship programs, this level of commitment is necessary to ensure that there is a sufficient cadence of missions to ensure that the program can achieve a balance across all of the priorities that it needs to serve. While there are many ways in which to achieve this balance and a variety of mission options available our analysis indicates that this level of commitment will be essential regardless of the particular set of missions that is eventually chosen. Annex A provides more detail on this analysis and a survey of representative missions that could be encompassed by the program.

By allocating a budget of $27.5M over the next two years, selection can begin immediately. These missions will address government priorities in the areas of climate change, advanced technology approaches to communications and connectivity, monitoring weather, water management, security, cyber security, resource management, international collaboration, space science and exploration. These missions will be competitively selected and will provide flight opportunities for a range of Canadian space technologies that are the essential prerequisite for commercialization. The scope of these missions would include stand-alone missions, Canadian-led contributions to larger international space missions, or the utilization of Canada's access to the International Space Station for research experiments or demonstration of new technologies for commercial or exploration technologies.

Clearly one of the critical features of this program will be a robust selection process which not only selects the best missions but which also maintains a balance across the portfolio. This will almost certainly require a multi-stakeholder committee to identify urgent government mission priorities for assessment and implementation. This committee will need to establish a program framework with clear mission selection criteria. Suggestions relating to the definition of mission categories and selection criteria are offered in Annex B.

## INCREASED FUNDING FOR SPACE TECHNOLOGY DEVELOPMENT AND INNOVATION

The 2012 Emerson Report on Space recognized the vital importance of technology development to the success of Canada's space sector and the need for immediate action in this regard. An additional $55M should be allocated over the next two years for research and development of innovative Canadian space technologies including satellite communications, space based radar, and optical systems and robotics through competitive, broad based programs such as CSA's Space Technologies Development Program (STDP); or participation in other ESA technology development programs. Investment in preparatory activities such as STDP would be $45M, with an additional $10M to spur the development of "downstream applications" that exploit space data as a growing component of the "big data" revolution. Once established, this level of support for technology development activities should be continued. Industry recommends that technology development funding be focused in Canadian government priority areas and in areas that will provide a strong economic benefit to Canada. Annex C describes a categorization of Technology Development Activities.

## NATIONAL DEFENCE SPACE OPERATIONS AND URGENT PROGRAM PRIORITIES[2]

In 2011, DND first appointed a Director General (DG) Space. Prior to that date, Canada's defence space interests were pursued in partnership with our US ally under the NORAD Agreement, primarily in support of the aerospace warning mission, which included space surveillance and missile warning. On any given day, Canada has upwards of 40 personnel dispersed across various US facilities tasked to support the US Joint Force Component Commander Space at Vandenberg AFB.

In Canada, the daily operational activities of "space watch," known as the Canadian Space Operations Centre (CANSpOC), provides a wide range of services to the Commander Canadian Joint Operations Command (CJOC), including missile warning, notification of space launches, satellite conjunction analysis (through its partnership with the US Joint Space Operations Center), re-entry predictions, reporting of satellite electronic interference, reporting of GPS accuracy, status reporting of Canadian and allied space systems that support CAF operations (Sapphire, SATCOM systems, missile warning sensors, space weather events, etc.) reporting of space events, warnings and threat assessments and both deliberate and contingency planning. In addition, the CANSpOC can deploy up to two teams anywhere in the world to provide space-related operational support and advice to a deployed Canadian Task Force Commander.

2 This section benefits greatly from "An Overview of Canadian Military Space in 2014 – Part 1 and Part 2" by Andre Dupuis.

Most space agreements with the United States Department of Defense fall under or are managed through a bilateral umbrella agreement called the Space Cooperation Forum. The Space Cooperation Forum was established in 2010 to harmonize, coordinate and collaborate national security space policy, strategy and operations. Canada has another important international agreement with our Five-eyes partners (Canada, US, UK, Australia, New Zealand) – the Combined Space Operations Memorandum of Understanding. Together, these arrangements set the stage for broader information sharing with our defence alliance partners going forward.

Canada has a robust military space operations capability: the 24/7 CANSpOC watch, Canadian personnel at US space units, the Canadian Space Surveillance System (the Sapphire satellite and its associated ground systems which are now part of the US Space Surveillance Network), the contributions that Polar Epsilon is making to space-based maritime domain awareness and North American security, an active AIS data service (monitoring global maritime traffic), the RADARSAT Constellation Mission (planned for launch in 2018), and significant investments in military satellite communications (via the US Advanced EHF Satellite system, the Wideband Global SATCOM project / Mercury Global).

The 2016 DND Defence Acquisition Guide offers a strong indication of the growing importance of space operations and capabilities, and outlines an intention for DND to invest in a range of space requirements.

Included in DND's space priorities are the Enhanced Satellite Communications Program (Global UHF narrowband SATCOM and wideband capacity for the North); Mercury Global (new Ground Terminals); Surveillance of Space 2 (to track space objects), Medium Earth Orbit Search and Rescue (MEOSAR), Five-Eyes Collaborative Environment, and several smaller programs.

It is also noteworthy that the Defence Policy Review Public Consultation Document (April 2016) asks an important question with respect to Canada's future requirements in the space sector, notably:

> *"What types of investments should Canada make in space … and to what extent should Canada strive to keep pace and be interoperable with key allies in the space domain?"*

In the recent Defence Policy Review Roundtable with space and aerospace representatives, DND's space priorities were articulated as follows: Secure Communications for Canada's North; Enhanced Maritime Situational Awareness; and Enhanced Space Situational Awareness. In all of these areas of space capability, Canadian industry has the requisite knowledge, expertise and industrial capacity to fully implement these programs in Canada, by Canadians. Canada has proven world-class expertise in all of these specialized areas of space technology; and in cooperation with our government partners at the CSA and DND (and Defence Research and Development Canada), and our specialist academic partners in the university sector, Canadian industry can cost effectively deliver on all of these commitments.

These priority defence program requirements are not one-off requirements for Canada. The need for secure communications and broad situational awareness across all areas of national interest are part of the Government's core obligations to the Canadian public. By investing in such national space infrastructure, Canada will not only be more secure, but Canada's space industry will be further strengthened in international export markets.

**It is recommended that the government move quickly to consider, approve and implement the following space requirements of the Department of National Defence, currently defined in DND's Defence Acquisition Guide.** These items have been widely studied and, on an accelerated basis, will meet the urgent needs of the Canadian Forces using Canadian industrial capabilities.

## ENHANCED SATELLITE COMMUNICATIONS PROGRAM (ESCP)

This will provide much needed secure communications to tactical and mobile platforms around the world. It will provide secure communications in Canada's North, and contribute strongly to Canadian sovereignty and security in the region. It will meet the needs of deployed CF operations globally, including in the Middle East and Central and Eastern Europe, as well as make a Canadian contribution to the communications infrastructure of our Allies.

## SPACE SITUATIONAL AWARENESS PROJECT

Sapphire, Canada's contribution to the US Space Surveillance Network has been recognized as an essential element of the broad space situation awareness picture. Knowing where objects in space are is important to the operations of satellites and to the understanding of space debris dynamics. Canada should advance the follow-on Sapphire program to the earliest possible date to allow Canada to sustain its commitment to the Space Surveillance Network beyond 2021. This will maintain an important and leading Canadian contribution to NORAD, and sustain core capabilities within Canadian industry.

## MEDIUM EARTH ORBIT SEARCH AND RESCUE (MEOSAR) PROJECT

As part of Canada's longstanding commitment (since 1979) to the International Cospas Sarsat Program, the Medium Earth Orbit Search and Rescue (MEOSAR) project will deliver the next generation space segment, comprising up to 24 Search and Rescue (SAR) repeaters that will be hosted on United States Air Force's next-generation GPS III satellite constellation. This builds upon previous Canadian contributions to the system that detects and locates emergency beacons activated by aircraft, ships and backcountry hikers in distress, and which is credited with saving tens of thousands of lives. The project will also deliver a ground segment comprised of up to three satellite ground stations in Canada with specialized satellite tracking software and information processing systems. The MEOSAR system is expected to deliver improved response times for SAR activities in Canada's three ocean approaches and the entire land mass.

## FIVE-EYES COLLABORATIVE ENVIRONMENT- SPACE BASED INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE PROJECT

The need for accurate information, intelligence, surveillance and reconnaissance of vessels, cargo and people on Canada's maritime approaches are imperative to Canada's national security and sovereignty. Similarly, the need to understand these variables with an informed global picture is equally important to our NORAD and NATO obligations, and is a key collaborative aspect of the Five-Eyes environment.

Canadian industry has world-leading capability in the provision of global maritime vessel data for ship tracking and maritime situational awareness. Through the flagship RADARSAT Program, Canada's world-leading radar capability provides critical data sources for maritime situation awareness. Space-based Automated Information System (AIS) data from Canadian industry is in use today in Canada's defence operations centres and has been supplied to support international obligations.

Building upon this domestic capability and our core strengths in space based radar, optics and data analysis, Canada has an opportunity to meet our national needs and provide this strategically important data output to our Five-Eyes partners as a contribution to our collective security. Such an initiative will meet Canada's domestic defence requirements, and provide a strategically significant data set to our Alliance partners. This will enhance Canada's reputation as a sound and viable defence partner and reduce criticism of Canada not pulling its weight in the defence sector.

These projects have been discussed with industry or are part of the Defence Acquisition Guide (DAG) and Canadian industry is well-positioned to address these operational requirements in a whole of government approach to space. This is not an exhaustive list of space-related items in the Defence Acquisition Guide, as there are other strategic investments and international collaborations that have been identified and are being studied. As new operational requirements are identified and analyzed over time, Canadian industry is prepared to take a partnership role with the Canadian Forces and Canadian government to address these in a timely and cost-effective manner. Underlying all this should be a stated intent that Canada provide niche leadership in space-based resources and capabilities to our allies, using competitive Canadian domestic industrial capabilities. Coupled with a Whole of Government approach to civil space requirements, addressing space-based requirements for our Forces can be a catalyst for industry success in international commercial markets.

# CONCLUSION

Canada's space program is at the cutting edge of innovation. Over the course of more than 50 years Canada has developed a powerful space ecosystem that is driven by the talent, creativity and hard work of Canadians and which has branded Canada as an trusted international partner and as a nation of innovators. This success has been built on a partnership between industry, government and research institutions. Underlying this past success has been a clear vision for the Canadian space program and sufficient government funding for programs to make it a reality. Both of these ingredients are missing in the current environment. The long term plan for Canada's space program has expired and has not been renewed. There is currently no guidance available to companies and institutions attempting to make long range plans for their Canadian operations. Exacerbating matters, the annual budget of the Canadian Space Agency has declined to the point where there is little funding for new initiatives.

This situation is occurring against the backdrop of a dynamic global space industry in which new technologies and new business models are emerging and in which other countries are renewing or expanding their investments in space. The net result is that Canada can seize the opportunity to consolidate its clear advantage in this strategically important industry sector by initiating the process of outlining a bold national long term vision for our participation in space while also moving now to stabilise the sector to prevent further erosion of our national capability and capacity.

With the right plan incorporating a whole of government approach to space we believe that over the next ten years, Canada should aspire to meet aggressive growth targets for space sector growth to:

- Increase Canadian space sector revenues by over $8 Billion over 10 years
- Increase its contribution to Canada's GDP by over $3.6 Billion over 10 years
- Increase employment by over 30,000 person-years over 10 years - over half of which will be HQP

To be effective government investment must be sufficient to achieve a balanced portfolio across programs and must be of a magnitude sufficient to maintain a world leadership position in niche areas, facilitate access to affordable and more frequent opportunities to validate and flight-test promising new technologies, as well as modest funding for R&D into novel and innovative technologies. The investments proposed are aimed at consolidating Canada's position in the expanding global space market, and provide opportunities to develop innovative funding mechanisms that will allow the government to invest in new business models where government uses its purchasing power as a means of encouraging the private financing and development of new space infrastructure that will then generate increased commercial activity in space.

Canada's leading space industry firms are looking forward to working with the government to define, confirm and execute Canada's next generation of space technologies and programs.

We are convinced that timely investment in space innovation and technology development will have a positive multi-sector impact on Canada's prospects for industry led innovation and commercialization; and on our national infrastructure for science, security, resource management, environmental responsibility, HQP job creation, exports and economic growth.

# ANNEX A: A SURVEY OF PROSPECTIVE MISSIONS

The heart of any balanced long-term plan for space in Canada will be a balanced portfolio of missions. The key to designing this portfolio will be to define a mechanism for selecting missions in such a way to ensure both affordability and balance while maintaining a cadence of missions that ensures that Canadian technology and science capacity stays current and globally competitive. There are several ways in which balance can and should be achieved. It will be necessary to find a balance between missions that result in world-class science and discovery and those that demonstrate innovative and commercially competitive new capabilities. Within the science missions category, it will be necessary to find a balance between furthering academic and research interests and addressing government policy and operational priorities. Within the capability demonstration missions category, it will be necessary to find a balance across current key technology areas while retaining the flexibility to support disruptive ideas based on new and emerging technology areas. Finding this balance is necessary in order to maintain and further develop Canadian capabilities and capacities needed to achieve a global competitive advantage. Failure to do so will lead to atrophy as effort is applied in a too-limited set of capabilities any of which run the risk of becoming irrelevant.

Of critical importance will be to implement missions using the implementation approach that best serves the mission need. For many missions, solutions will be able to be developed that leverage the significant recent advancements in the area of small-satellites and nano-satellites. These mission implementations may involve the use of a single satellite or a constellation of a number of satellites to achieve the mission objectives. For other types of missions, it will be necessary to use larger satellites that are able to achieve the required measurement accuracy and data throughput. Flying hosted payload missions on larger satellites or on the International Space Station can provide relatively affordable access to space but are only useful for particular kinds of missions. Likewise, providing small parts of large international missions may prove to be an affordable way to access the wider international effort, but will be constrained to the larger projects limitations and timelines. In short, it's complicated. One thing that needs to be ensured is that the government avoid un-necessarily dictating a specific mission implementation approach and leave it to innovators in Canadian industry and academia to propose the details.

The central question that must be answered is, of course, how much should such a program of Canadian missions realistically cost, and how much effort needs to be expended to achieve a balance between competing priorities over reasonable time scales. The budget provided for any program should be limited enough to encourage innovative and efficient use of the funding; but it must be sufficient to ensure that competition occurs often enough so that high quality teams will be formed and motivated to expend the effort needed to make high quality proposals.

There are many possible approaches to analyzing this problem. The approach we have used is to first categorize the missions by the different domains for scientific missions and by types of applications for capability demonstration missions. We then further sub-categorized the missions int 6 science categories and 5 capability demonstration categories. Of course, the system solutions needed are not the same in each sub-category but we estimated that on average typical mission costs would be between $20M and $100M and that it would be possible to define some low cost missions in the range below $20M. Over a 5-year period, we felt that doing and average of 1 or 2 medium cost missions and 2 or 3 low-cost missions in each sub-category would represent a reasonable

cadence and balance of sizes. Working with approximate average values, we estimated the yearly budgets that would be required in each category. This is shown in Table 1. In order to give a flavor of the types of missions that would be accessible through such a program Table 2 shows a survey of representative missions that might be considered. The majority of the missions identified in Table 2 fall into the science category. Specific missions in the capability demonstration category should for the most part be based on proposals from industry and academia and selected on the basis of their relevance to address national needs and potential to provide tangible economic benefits and commercial opportunity.

## TABLE 1: REPRESENTATIVE BALANCE MISSION SCENARIO – ANNUAL BUDGET

| Yearly Budget (after ramp up): | Budget ($M) | % |
|---|---|---|
| | $200 | |
| Science Mission Budget | $100 | 50% |
| Capability Demo Mission Budget | $100 | 50% |

| Science Mission Budget | Budget ($M) | % |
|---|---|---|
| Atmospheric Science | $20 | 20% |
| Earth Science | $10 | 10% |
| Space Weather | $10 | 10% |
| Planetary Exploration | $25 | 25% |
| Space Astronomy | $25 | 25% |
| Life Science | $10 | 10% |

| Capability Demo Mission Budget | Budget ($M) | % |
|---|---|---|
| Land (incl. fire) / Water Resource Monitoring | $30 | 30% |
| Climate / Air Quality / GHG Monitoring | $20 | 20% |
| Maritime Domain Awareness | $10 | 10% |
| Satellite Communications, incl. cyber security | $30 | 30% |
| Spacecraft Technologies | $10 | 10% |

# TABLE 2: SURVEY OF REPRESENTATIVE MISSIONS

| Mission | Description | Rationale | Category | Partners | Earliest Launch |
|---|---|---|---|---|---|
| Advanced Crew Medical System (ACMS) Space Medicine Decision Support System (SMDSS) | Demonstration mission of a clinical decision support system capable of detecting pre-selected medical conditions and infer possible and likely outcomes for given health state and symptoms | Leverage Canadian strengths in autonomous medicine and experience in operational space medicine in preparation for a BLEO contribution | Life Science | | 2020 |
| Advanced Telescope for High-ENergy Astrphysics (ATHENA) | ATHENA - (formerly known as IXO) and selected as 2nd Large mission in ESA Cosmic Vision. | | Space Astronomy | ESA | 2028 |
| ARRM | Robotic asteroid redirect mission | Robotic mission to visit a large near-Earth asteroid, collect a multi-ton boulder from its surface, and redirect it into a stable orbit around the moon | Planetary Science | NASA | 2022 |
| Canadian micro-sat/rover mission (secondary payload) | Small exploration science mission as secondary payload | | Planetary Science | | various |
| Chinook | Smallsat environmental mission to study stratospheric winds, ozone transport and other atmospheric phenomena. | Lead to advances in weather and climate prediction models to provide answers on the health of the ozone layer and climate change. | Atmospheric Science | | 2022 |
| Cosmological Advanced Survey Telescope for Optical and UV Research (CASTOR) | Smallsat Canadian space telescope astronomy mission that would provide unique panoramic, high-resolution imaging of the Universe in the UV/optical spectral region. | Provide ultra-deep imaging to complement data from planned international astronomy satellite missions like Euclid and WFIRST. | Space Astronomy | | 2024 |

| Mission | Description | Rationale | Category | Partners | Earliest Launch |
|---|---|---|---|---|---|
| Canadian Wildland Fire Monitoring Satellite (CWFMS) | Wildfire monitoring and management | Improved infrastructure to monitor and manage wildfires and forecast environmental effects | Resource Monitoring | | 2020 |
| eDeorbit | Develop and fly robotic capture capabilities to effect successful capture of a tumbling Envisat spacecraft | Remove one of the current most signficant space debris hazards and demonstrate the technologies (robotic capture devices, camera and lidar based visions systems) required for on-going remediation of physically larger space debris | Technology Demonstration | ESA | 2023 |
| ESA Exploration mission (Moon, Phobos-Deimos, or, MSR) | | | Planetary Science | ESA | 2023 |
| GEO Satellite Servicing Flight Demonstration | Demonstration of satellite robotic refueling technology in geosynchrononous orbit on an existing satellite. | Demonstrate in-space refueling of existing communication satellites with a first "customer", enabling commercial business to provide this service. | Technology Demonstration | DARPA (RSGS) and/or Commercial PPP | 2020 |
| Israel Canada Advanced Radio & Thermal- location µ-Satellite (ICARUS) | RF geo-location and thermal detection nanosat constellation | Enhancements in maritime domain awareness and other surveillance applications | Domain Awareness | Israel Canada Advanced Radio & Thermal-location µ-Satellite (ICARUS) | RF geo-location and thermal detection nanosat constellation |

| Mission | Description | Rationale | Category | Partners | Earliest Launch |
|---|---|---|---|---|---|
| JAXA mid-class mission (Moon, Phobos-Deimos, or, MSR) | | | Planetary Science | NASA | 2023 |
| JUICE | JUICE - JUpiter ICy moons Explorer - is the first large-class mission in ESA's Cosmic Vision 2015-2025 programme | | | ESA, NASA, JAXA | 2022 |
| KARI Lunar Pathfinder Lunar Rover | Lunar lander and rover mission with NASA support | Planned follow-up mission to KPLO with lander and rover to demonstrate ISRU technology. KARI seeking international expertise to contribute to mission success/training, in exchange for payload opportunities, well aligned with Canadian developed technology. | Planetary Science | KARI | 2020 |
| KARI Pathfinder Lunar Orbiter (KPLO) | Lunar orbiter mission with NASA support and hosted payloads | First mission in a series of Korean lunar missions including orbiter and landers to demonstrate ISRU technology. KARI seeking international expertise to contribute to mission success/training, in exchange for payload opportunities. | Planetary Science | KARI | 2018 |
| LEO Satellite Servicing Flight Demonstration | Demonstration of robotic servicing in Low-Earth orbit on an existing satellite. | Demonstrate LEO servicing with a first "customer", enabling commercial business to provide this service. | Technology Demonstration | NASA (RESTORE/ ARM) and/ or Commercial PPP | 2020 |

| Mission | Description | Rationale | Category | Partners | Earliest Launch |
|---|---|---|---|---|---|
| LiteBird | Cdn instrument contribution to cosmic microwave radiation astronomy mission | Leverages Cdn capabilities in advanced microwave detector readout electronics, aligns with astronomy community priorities | Space Astronomy | JAXA / NASA | 2022 |
| LSRS Bio-Analytics | Diagnostic system on ISS for quantifying soluable biomarkers in a liquid sample and analyzing the presence of biomarkers on cellular surfaces | Leveraging Canadian strengths in terrestrial bio-analytics and experience in operational space medicine | Life Science | | 2019 |
| Lunar science rover (human precursor) | Human Lunar Exploration Precursor mission with focus on Lunar Sample Return and future Human Surface operations | | Planetary Science | | 2030 |
| Measurements of Climate and Air Pollution (MCAP) | Smallsat environmental mission to measure carbon monoxide, nitrogen oxides, ozone, methane and other species as well as clouds and aerosols. | Provide air quality measurements and insight into climate change processes. | Atmospheric Science | NASA/JPL, Germany | TBD |
| Miniature Earth Observer Satellite (MEOS) | Microsatellite environmental mission to measure greenhouse gases and other pollutants. | Data would be assimilated into atmospheric and ecosystem models used by climate change researchers at Environment Canada and other organizations. | Atmospheric Science | China | TBD |
| MSR-Mars 2024 rover | robotic sample return from Mars | The mission would use robotic systems and a Mars ascent rocket to collect and send samples of Martian rocks, soils and atmosphere to Earth for detailed chemical and physical analysis | Planetary Science | NASA | |
| NASA Discovery 2020 | competition | | | NASA | 2026 |

| Mission | Description | Rationale | Category | Partners | Earliest Launch |
|---|---|---|---|---|---|
| NASA New Frontier 5 | competition | | | NASA | 2027 |
| NeMO (Mars 2022) | Mars communication orbiter with potential international contributions (system, science) | Timely Renewal and Enhancement of Mars communication infrastructure to Support Future Missions; | Planetary Science | NASA | 2022 |
| Outer Radiation Belt Injection, Transport, Acceleration and Loss Satellite (ORBITALS) | Smallsat space weather mission to study the previously unexplored inner magnetosphere. | Canadian contribution to International Living with a Star (ILWS) program and complements Canadian Geospace Monitoring (CGM) instrumentation. | Space Weather | NASA | 2023 |
| PACE Coastal Water Imager | Environmental monitoring of coastal inland in-land water | Improved management of water quality, wetland habitats, forestry and agriculture, and event response | Resource Monitoring | NASA | 2022 |
| Quantum Encryption and Science Satellite (QEYSSAT) | Quantum Key distribution and optical comms demo either from ISS or on a dedicated microsat | Position Canada to provide a central element in the rapidly changing secure comms market | Satellite Comms | | 2020 |
| Raven | Cdn instrument contribution to EE9 upper atmospheric mission | Improved understanding and ability to monitor effects of climate change | Space Weather | Sweden / ESA | 2024 |
| Resource Prospector | Lunar south pole ISRU technology demonstration mission with lander and rover | Leverages significant Exploration Surface Mobility investment by CSA (rovers, mobility systems, autonomy, drills and dust mitigation) for mission. NASA still has interest in canadian contributions, discussions ongoing. | Technology demonstration/Space Science | NASA | early 2020s |

| Mission | Description | Rationale | Category | Partners | Earliest Launch |
|---|---|---|---|---|---|
| Resource Prospector Mission | robotic subsurface exploration prospecting mission to Cabeus crate lunar south pole. Potential Canadian contribution of rover and sample drill | Leverages existing Canadian capabilities in robotics and mining. RPM is the first mission focussed on subsurface prospecting for lunar volatiles | Planetary Science | NASA\others | 2023 |
| SMILE | Cdn instrument contribution to international space weather mission | Builds on Cdn strengths in UV imaging to study interaction between earth's magnetosphere and solar wind | Space Weather | ESA / China | 2021 |
| Solar Occultation for Atmospheric Research (SOAR) | Smallsat environmental mission to investigate chemical processes and transport of pollutants in the troposphere. | Monitoring atmospheric trends by continuing long time series observations to provide comprehensive data sets for climate change model validation. | Atmospheric Science | | TBD |
| SPICA | Cdn contribution to future IR space telescope | Future astronomy program of high interest to the Canadian astronomy community | Space Astronomy | ESA / JAXA | TBD |
| Technology Demonstrations on the International Space Station (ISS) | Development and testing of new robotics and optics technologies on the ISS | Enable more effective and efficient future human and unmanned beyond-low-earth-orbit exploration missions involving assembly, resupply and maintenance operations on spacecraft and outposts. | Technology Demonstration | | 2019 |
| Terrestrial Snow Mass Mission | Mission for high-resolution measurements of terrestrial snow water equivalent. | Snow water equivalent is a required observational input to land surface data assimilation systems under development at Environment Canada. | Earth Science | | TBD |

| Mission | Description | Rationale | Category | Partners | Earliest Launch |
|---|---|---|---|---|---|
| TicFIRE | Demonstrate capability to monitor Thin Ice Clouds | Improved weather forecasting and climate prediction models | Atmospheric Science | | 2022 |
| WFIRST | Cdn instrument contribution to Wide Field IR space telescope | Highest priority Canadian astronomy program, leverages JWST heritage | Space Astronomy | NASA / others | 2024 |

# ANNEX B: MISSION CATEGORIES AND POSSIBLE SELECTION CRITERIA

| Mission Category | Attributes | Selection Criteria |
|---|---|---|
| Technology Demonstration Missions | Missions that demonstrate significant technology advancements<br><br>Mission cost of $5M – $20M and implementation over 2 to 3 years<br><br>Funded substantially by government | Level of innovation and potential long term benefits to Canada<br><br>Significance of the mission in allowing industry to "close the business case" and justify commercial investment |
| Scientific Missions | Dedicated Canadian science mission or instrument contributions to international science missions<br><br>Mission cost of $20M - $100M and implementation over 3 to 5 years<br><br>Fully government funded | Alignment with Canadian scientific strengths<br><br>Global impact of the science<br><br>Development of HQP in academia<br><br>Magnitude of science benefit relative to overall cost<br><br>Industrial benefits of resultant technology |
| Capability Demonstration Missions | Missions that demonstrate a new Canadian capability and provide a proto-operational data service<br><br>Mission cost of $20M – $100M and implementation over 3 to 4 years<br><br>Development cost shared between government and industry<br><br>Government to obtain rights commensurate with level of investment | Relevance to Canadian national needs and priorities<br><br>Commercial business potential<br><br>Technology readiness level<br><br>Industrial benefits |

# ANNEX C: CATEGORIZATION OF TECHNOLOGY DEVELOPMENT ACTIVITIES

| Technology Development Category | Attributes | Selection Criteria |
|---|---|---|
| Mission Enabling Technology Development | Technology development needed to demonstrate feasibility and retire risk on Canadian government led missions<br><br>Advancement of TRL to support government funding approval process and to facilitate fixed price contracting<br><br>Project cost > $2M<br><br>100% government funded | Relevance of the proposed technology development to Canadian government priority programs<br><br>Magnitude of cost and schedule risk reduction achieved through the investment |
| Industrial Competitiveness Technology Development | Industry initiated projects to advance technologies that improve industrial competitiveness and/or address emerging market opportunities<br><br>Project cost > $2M<br><br>Partially funded by industry, typically at 50% | Strength of industrial business case<br><br>Net benefit to Canada of the proposed project |
| ESA Technology Development | Technology development needed to position Canadian industry to participate in ESA programs<br><br>Applicable to ESA communications, Earth Observation and Science programs<br><br>100% government funded | Strategic alignment with Canadian priorities<br><br>Opportunity to create long term economic benefits to Canada |