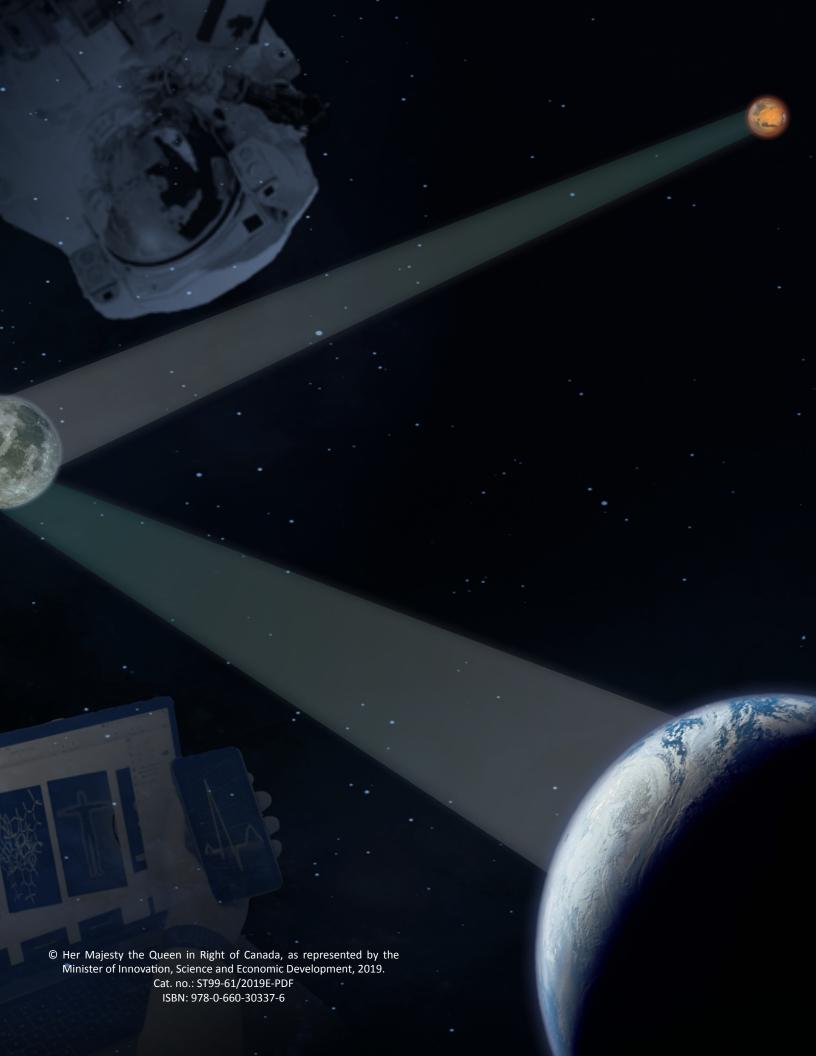# Canadian Healthcare in Deep Space:

Advancing our country's leadership in autonomous care in space and on Earth

Report of the Expert Group on the Potential Canadian Healthcare and Biomedical Roles for Deep-Space Human Spaceflight

March 2019

9 February 2018

Mr. Sylvain Laporte
President of the Canadian Space Agency
St-Hubert, QC

Dear President Laporte,

Please find attached the report of the *Expert Group on the Potential Canadian Healthcare and Biomedical Roles for Deep-Space Human Spaceflight*. This is the outcome of our consultations with several prominent stakeholders engaged in spaceflight and Canadian healthcare, as well as of our own discussions and deliberations.

We were pleased to be asked by the Canadian Space Agency to investigate a potential new role and orientation for Canada in deep-space exploration – a strategic re-orientation that could inject vibrancy and relevancy into society for decades to come. Our intent with this report is to present the "what" and "why" of deep-space astronaut healthcare – not the "how", which should be addressed later.

Throughout our mandate, we have appreciated your support of our activities. Your vision for Canada's space program is evident to us all. We similarly hope that a spirit of exploration will galvanize Canadian society; and that new partnerships, investments and yes, challenges, will take our national space program to the next level.
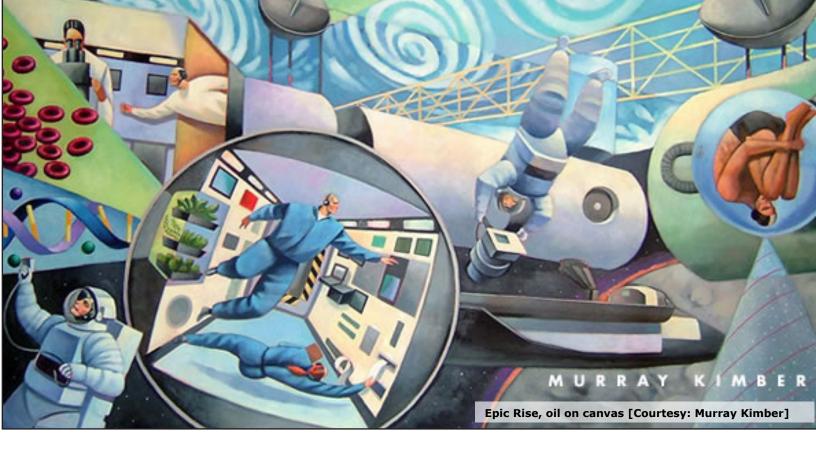
We hope this report will provide insight and clarity to you and your colleagues as you engage in further discussions and decisions about deep-space roles and partnerships.

Robert Thirsk (Chair)	David Hart	Alex Mihailidis
Evan Adams	Yves Joanette	Anne Snowdon
Mark Casselman	Brian Lewis	Teodor Veres
Jacques Corbeil	Linda Maxwell	Dave Williams
Diane Côté	Ivar Mendez	

CONTENTS

Epic Rise, oil on canvas [Courtesy: Murray Kimber]

EXECUTIVE SUMMARY

Canada is globally recognized as a major space-faring nation, with expertise and capacity supporting a breadth of space sciences, technologies and human space exploration. In addition to the more than $5 billion economic stimulus provided by the Canadian space sector, the Canadarm and human participation in the International Space Station (ISS) have achieved iconic recognition with Canadians.

After a half-century of human exploration in Earth orbit, there is a shared recognition among the international partners of the need to reach beyond. The technologies required to support long-duration human exploration missions to the surface of the Moon or Mars will be critical to the next 50 years of space exploration.

The Canadian Space Agency is perfectly positioned to build on the national robotic capability developed for the space shuttle and ISS programs by incorporating the results of long-duration microgravity research and clinical expertise into the development of a new contribution to human spaceflight – an advanced autonomous crew healthcare system. Through participation in ISS and associated research, Canadian scientists, clinicians and specialists in space medicine have demonstrated elements of virtual clinical care including remote minimally invasive surgery. This expertise and these technologies are the platform upon which a robust capacity for virtual care can be built. It will support human space exploration, enhance Canadian military operations and transform the delivery of remote healthcare and care for the elderly. While the benefits to Canadians are numerous, the expansion of Canadian leadership in space medicine is the next step in ensuring a continuous role as a major space-faring nation.

Our overarching recommendation is that the Canadian Space Agency pursue a leadership role in deep-space astronaut healthcare, with a consortium of partners, prior to the Mars exploration missions, through a strategic vision with a bold objective and ambitious timeline. This would be a significant opportunity for Canada. We could lead the planet.

LIST OF RECOMMENDATIONS

1.

Canada should invest significantly in deep-space autonomous healthcare, as a bold contribution to space exploration and a means to develop national capacity in virtual healthcare for the benefit of all Canadians.

2.

Canada should pursue a role as the lead integrator and operator for astronaut healthcare in deep-space missions.

3.

In addition to operational oversight, Canada should contribute healthcare technologies to deep-space healthcare facilities, according to our national expertise.

4.

To assist the Canadian Space Agency with development and implementation of this potential opportunity, an external and diverse collaborative body should be established, representing Canada's space operational, health-service delivery, commercial, research and government expertise.

Hubble Ultra Deep Field
[Courtesy: NASA, ESA, S. Beckwith (STScI), the HUDF Team, 2014]

Moon as seen from the International Space Station [Courtesy: NASA/A. Gerst, 2018]

PART 1

THE SPACE EXPLORATION ROADMAP

We are entering a new era in space exploration, with the ambitious goal to go beyond low-Earth orbit and the International Space Station (ISS), to return to the Moon and to explore Mars. These bold leaps need collaboration and new technologies that could have transformative impacts on our society and economy.

The international space exploration community came together in 2007 around a vision for globally coordinated space exploration, focused on destinations in the solar system where people may someday live and work. In this vision, robotic missions precede human explorers to the Moon, near-Earth asteroids and Mars, unveiling many of their secrets, characterizing their environments and identifying potential risks and resources there. The International Space Exploration Coordination Group, made up of 15 national space agencies, was established to develop a strategy, called the Global Exploration Roadmap (GER), to help turn this vision into reality. While not committing individual agencies to specific steps and activities, the GER serves to generate innovative ideas and solutions that address challenges ahead.

The third edition of the Global Exploration Roadmap "reaffirms the interest of 14 space agencies to expand human presence in the Solar System, with the surface of Mars as a common driving goal." This begins with the construction and development of a deep-space gateway in the lunar vicinity. The Roadmap is designed to inform individual nations, commercial and academic enterprises as they make investment decisions that contribute to this effort.

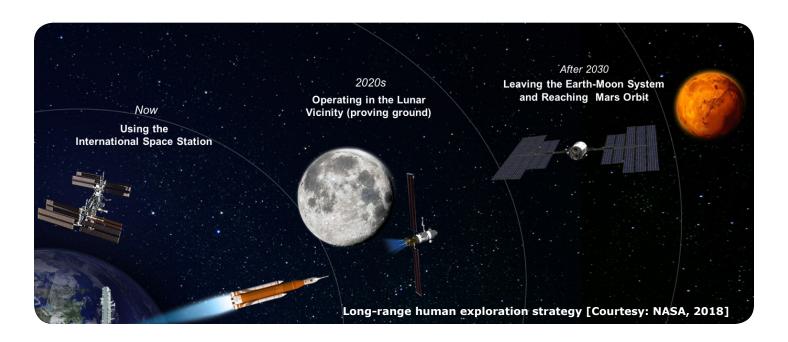**International Space Station [Courtesy: NASA, 2018]**
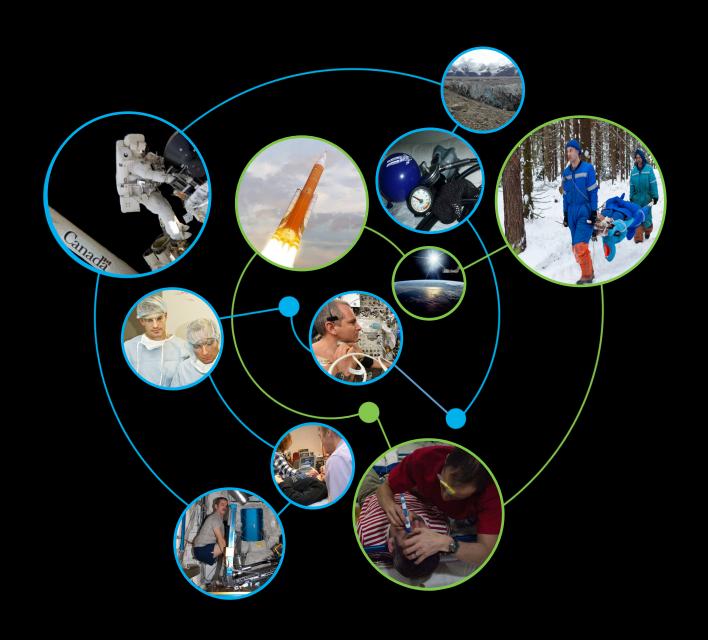
Exploring space in partnership

Canada, as a partner in the ISS, has undertaken important discussions with this global partnership to determine the next steps for human exploration. Using the GER as a guide, the partners are working toward the goal of human exploration of Mars in the 2030s. Even with a decade to prepare, the challenges of such a mission are daunting. A round-trip journey to Mars takes almost three years. During that time, the expedition crew and spacecraft must operate with little or no resupply of air, water, food, medical supplies or spare parts. Astronauts will endure the harmful effects of weightlessness and space radiation for longer periods than ever before. Limited communication and speed-of-light delays will greatly reduce the role of mission control in helping the expedition succeed. Aborting a mission to return early, for example in the case of system failure or crew illness, will be impossible.

With an eye toward what is needed for missions to the Moon and Mars, the international partners have been studying concepts for testing and demonstrating deep-space exploration technologies in Cislunar Orbit, the area of deep space under the gravitational influence of the Earth and Moon. The first step is development and deployment of the Lunar Gateway, a spaceport orbiting the Moon, that will include work-space, propulsive capability and life-support, eventually supporting a four-person flight crew for up to 30 days. It will carry out engineering and operational tests as well as scientific research that enable missions to the surface of the Moon and eventually to Mars.

The follow-on steps will see the establishment of sustained human presence on the surface of the Moon and deployment of the Deep-Space Transport to reach the surface of Mars. During these trips, the Lunar Gateway will remain in Cislunar Orbit, serving as a research and staging platform to travel to these destinations.

Now
Using the International Space Station

2020s
Operating in the Lunar Vicinity (proving ground)

After 2030
Leaving the Earth-Moon System and Reaching Mars Orbit

Long-range human exploration strategy [Courtesy: NASA, 2018]

PART 2

CREW HEALTH AND PERFORMANCE ISSUES OF DEEP-SPACE MISSIONS

CSA astronaut Robert Thirsk exercises aboard the ISS with the Advanced Resistive Exercise Device [Courtesy: NASA, 2009]

Since the dawn of spaceflight, some 600 people have had the opportunity to live and work in this new frontier. Exploring space, however, comes at a cost. It exposes astronauts to harsh living and environmental conditions including:

- High speeds and accelerations
- A hard vacuum outside of the spacecraft
- Extremes of spacecraft surface temperatures
- High fluxes of ultraviolet and ionizing radiation
- Disrupted circadian rhythms
- Weightlessness

These and other factors can alter how the body functions and harm astronaut health. All organs are affected in some way by the spaceflight environment, which can cause cardiovascular deconditioning, musculoskeletal atrophy, decompression sickness and radiation-related illnesses, for example. Psychological and social well-being, as well as crew performance, can also be an issue. In the worst cases, the success of missions can be jeopardized.

Over the past decades, specialists in space medicine have addressed the health consequences of spaceflight. Their objectives are threefold: To optimize the health and fitness of astronauts prior to flight; to provide healthcare during flight, in order to maintain crew well-being and performance; and to provide post-flight rehabilitation to life back on Earth. The field has made great strides. In the first half-century of spaceflight, clinicians and biomedical engineers have successfully developed countermeasures to deal with most related medical problems.

Medical processes during past flights have been Earth-centric, as the overall health of astronauts and cosmonauts has been supervised by a medical team on the ground. Expected and routine disorders could be diagnosed and treated by onboard crew medical officers. For more complicated issues or medical contingencies that could not be readily resolved in space, a flight surgeon has managed the medical situation from the ground until the ill crewmember could be returned to Earth for further treatment. This "stabilization and transportation" was possible with abundant real-time voice communication between the medical team on Earth and the onboard crew, as well as with the electronic transmission of health data.

CSA astronaut David Saint-Jacques collecting blood samples [Courtesy: NASA, 2018]
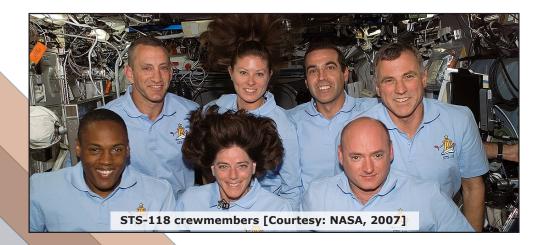
This concept has worked well but will not be realistic once astronauts venture beyond Earth's orbit. In the not-too-distant-future, human exploration missions will feature flights to an asteroid, a Lagrangian point (a position in an orbital configuration between two large bodies, where a small object maintains its position relative to the larger bodies), the Moon, Mars and beyond. These deep-space missions will be unlike those in low-Earth orbit, with greatly increased distances from home as well as lengthy durations. A round-trip mission to Mars would take two-and-a-half years, while typical expeditions aboard the International Space Station today last just six months. Future astronauts will acclimatize to partial gravitational environments upon landing on a planetary or lunar surface. Other operational features of this new class of missions will include:

- Limited crew size
- Limited volume, mass and power allowances of onboard equipment and systems
- Communication delays, with a latency of up to 20 minutes for voice and data transmission between Earth and deep space
- Exposure to high levels of ionizing radiation beyond Earth's Van Allen Belts
- Consumption of long shelf-life, processed food instead of fresh fruits and vegetables
- Continuous loud ambient noise from onboard machinery

Deep-space missions will further expose astronauts to various psychological stressors:

- Heterogeneous crews (different nationalities, cultures, ethnicities, races, skill sets)
- Extreme isolation and confinement
- Privacy and habitability issues
- Strained relationships with distant family and friends
- Complex interactions with ground-support teams

Spaceflight engineers are re-examining the operational concepts of logistics, life support, healthcare and crew performance in these deep-space missions. For instance, crews must be less reliant on cargo replenishment. Given the great distance from Earth, resupply of the spacecraft or habitat with consumables such as water, air, food and clothes, as well as replacement mechanical parts, will be limited or impossible.

STS-118 crewmembers [Courtesy: NASA, 2007]

All spacecraft systems will need to function autonomously, with limited monitoring and management by flight controllers on the ground. Life-support systems – for example for the revitalization of cabin air, recovery of waste water and collection and processing of human waste – will need to be near-closed-loop and more robust and reliable than those aboard current spacecraft. Future habitats may be outfitted with horticultural modules to supplement these life-support systems and provide a fresh-food pantry.

Environmental monitoring of the spacecraft habitat, for instance the cabin atmosphere, water quality and sound levels, will no longer rely on the return of air and water samples to the ground for analysis. Instead, such monitoring will require onboard analysis by crewmembers, who will be trained to identify contaminating microbial organisms, for example.

Medical operations in space will become more autonomous, as real-time consultation with and intervention by ground-based flight surgeons will be impossible. At least one member of the crew should be a broadly experienced physician, with qualifications in space and emergency medicine. There are likely to be cases during a lengthy mission in which surgical intervention is required. Medical situations that have emerged among crews in analogous situations, such as in Antarctic research stations and aboard submarines, include strokes, appendicitis, bone fractures, cancer, intracerebral hemorrhage, psychiatric illness and kidney stones. Accordingly, this physician-astronaut should be trained to conduct minimally invasive surgery and, if needed, use advanced robotic systems for medical support. Refresher crew training will be needed during these long flights, to retain such contingency medical skills.

Onboard systems will be more intelligent than healthcare delivery equipment in any previous spacecraft. Digital information networks will incorporate crew-worn sensors, clinical decision-support systems and artificial intelligence to assist these crew medical officers with the diagnosis and treatment of illnesses.

The size of the onboard medical-care facility will be limited. Physician-astronauts use compact medical kits with a range of ambulatory, resuscitation and surgical equipment. These kits must include antibiotics, allergy treatments, analgesics, stimulants, cardiovascular drugs and medications for motion sickness, anxiety, depression, bone loss and radiation protection. This onboard medical inventory will be augmented by 3-D printing of instruments and pharmaceuticals, as needed. The emergency return to Earth of a seriously ill crewmember will not

CSA astronaut Chris Hadfield with the Radi-N2 experiment for radiation monitoring [Courtesy: NASA, 2013]

The Future Exploration Greenhouse is located at an Antarctic research base. The University of Guelph and other international partners are using this test facility to develop plant cultivation technologies for space [Courtesy: DLR, 2017]

International Space Station Medical Kit [Courtesy: NASA, 2011]

be an option. This onboard medical facility will therefore need to provide complete and definitive care for all eventualities.
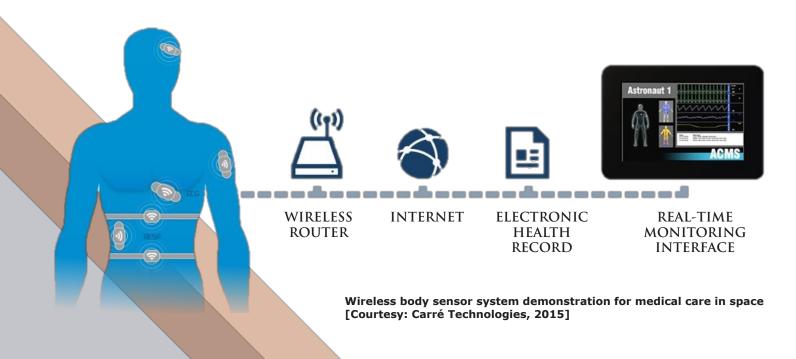
Exercise devices to minimize cardiovascular and musculoskeletal deconditioning will, by necessity, be smaller than the exercise systems currently used aboard the International Space Station. Low-atomic weight materials such as polyethylene will be integrated into the structure of the spacecraft to shield the crew from galactic cosmic radiation. Deep-space vehicles will also include a safe haven to shelter the crew from high doses of radiation in a major solar flare or solar-particle event.
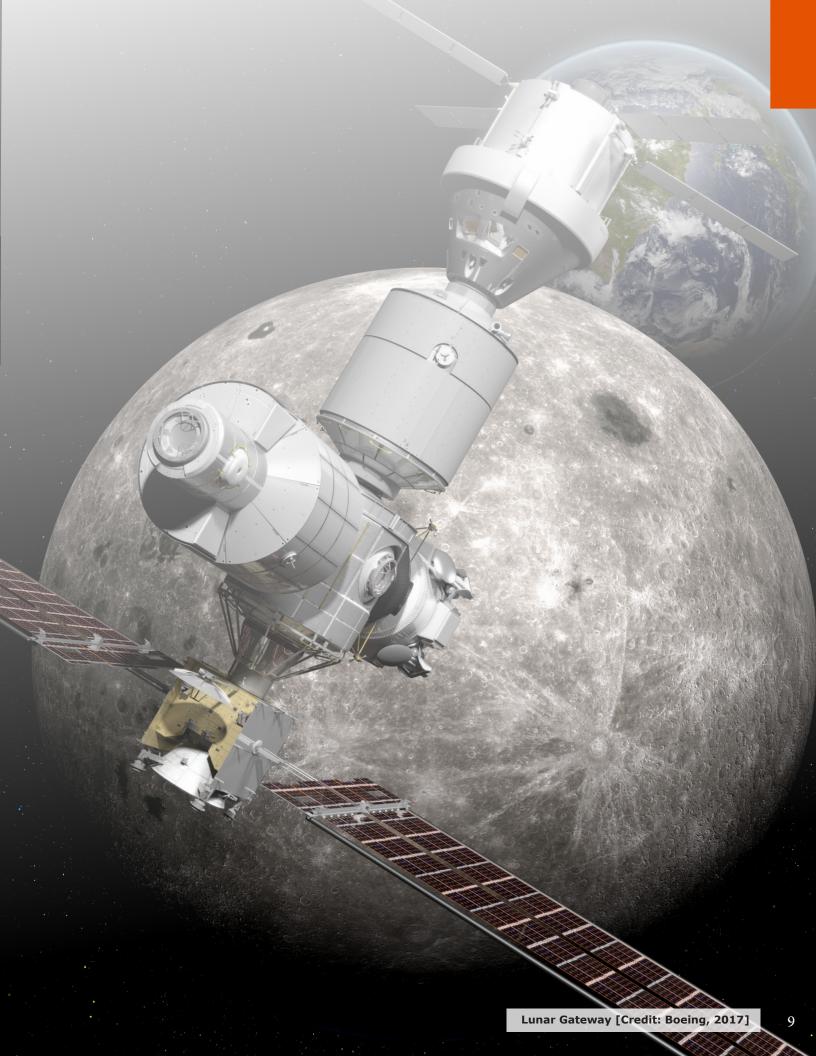
These radically different approaches to complex medical operations in space and the functionality of spacecraft themselves must be validated prior to the first Mars exploration mission. The practice of clinical medicine on Earth also happens to be evolving to become a more patient-centric and point-of-care model, similar to what is envisaged for the care of deep-space astronauts. Thus, this new autonomous model could potentially be evaluated by health-practitioners working in northern communities on Earth and by geriatric patients being remotely monitored at home.

CSA astronaut David Saint-Jacques tries the Bio-Monitor - an innovative smart-shirt system designed to measure and record vital signs [Courtesy: CSA/NASA, 2019]

The proximity of the Moon (a mere three days away) represents a relatively safe setting to evaluate long-duration human health and habitation impacts. In the next 10 years, the Lunar Gateway outpost will be constructed. This test-bed will be used to evaluate and refine novel medical protocols, technologies and systems developed for deep space. This will also provide an opportunity for crewmembers to acquire the knowledge, skills and confidence to become medically independent from Earth.

WIRELESS ROUTER   INTERNET   ELECTRONIC HEALTH RECORD   REAL-TIME MONITORING INTERFACE

Wireless body sensor system demonstration for medical care in space [Courtesy: Carré Technologies, 2015]

Lunar Gateway [Credit: Boeing, 2017]

PART 3

CANADIAN STRENGTHS IN HEALTHCARE AND PERFORMANCE

Healthcare research and innovation is rapidly evolving around the world. An understanding of Canadian capabilities within this dynamic global environment will help to clarify a potential clinical role for Canada in deep-space exploration.

Research skills and talent

Canada is home to some of the world's top universities, and it benefits from deep pools of research skills and talent. Canada ranks first among the Organisation for Economic Co-operation and Development (OECD) countries in the proportion of the population with a post-secondary education.

The 2017 National Taiwan University (NTU) rankings, which focus on research-intensive universities world-wide, put the University of Toronto in fourth place based on research productivity, research impact and research excellence. It followed Harvard, Johns Hopkins and Stanford universities, and was ahead of Oxford University. The University of Toronto is the world's top public university. Two other Canadian universities were ranked by NTU in the top 50: UBC (27th) and McGill (36th).

The University of Toronto is ranked third in the world in the category of clinical medicine. This success rests in the depth and breadth of the research enterprise of its Faculty of Medicine, which accounts for more than half of the university's total research funding. Three other Canadian faculties of medicine were ranked in the NTU's top 50: University of British Columbia (33rd), McGill (39th) and McMaster (46th).

Health research and clinical leadership

The Council of Canadian Academies (CCA) periodically assesses the state of science and technology and industrial (for example business-led) research and development in Canada. According to the CCA's 2018 report, titled Competing in a Global Innovation Economy, Canada ranks:

- 9th in total output of research publications, with 3.8% of the world's output
- 6th in research impact
- 6th in the top-cited 1% of publications in all fields

Canada's research contributions are well regarded internationally:

- 36% of surveyed top-cited researchers around the world identify Canada among the top five countries in their research fields
- Canada ranks fourth overall, behind the United States, United Kingdom and Germany, in international reputation and stature
- Canadian researchers are ranked seventh out of the top 20 countries for the number of publications co-authored with international collaborators
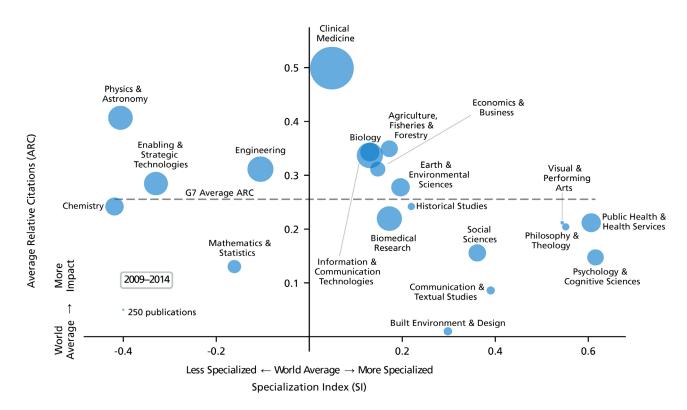

University of Alberta students involved with the development of the Ex-Alta 1 CubeSat [Courtesy: Collin Cupido, University of Alberta, 2016]

The CCA report identifies five strong research fields in Canada, based on:

- Magnitude (the share of world publications in the field)
- Impact (a measure of the number of its citations)
- Growth (reflecting Canada's increase in research output relative to the rest of the world)

The identified research strengths include psychology and cognitive sciences, clinical medicine, and public health and health services.

The performance of Canadian medical researchers is extraordinary. Canada's research publication output is particularly high in clinical medicine (4.1% of the world share). Of all fields, clinical medicine publications have the highest impact in Canada and the highest level of performance in the top-cited 1% of world publications. The impact of Canadian publications in the field of general & internal medicine is particularly noteworthy.

Positional analysis of Canada in 20 fields of research, 2009-2014: The Average Relative Citations are plotted along the y-axis. The x-axis represents citation levels at the world average. The horizontal dashed line represents the average citation level for G7 countries. SI scores (a measure of publication output for a specific field, based on the world average) are plotted along the x-axis. The overall size of the research output (number of publications) is indicated by the area of the blue circles.

The relative positioning and size of clinical medicine research in the country is remarkable. Clinical medicine in Canada has both a high level of publication output and a high impact (above the G7 average). The elevated degree of specialization and impact of clinical medicine have continued to increase over the last decades.

Healthcare innovations

The medical technology industry

The Canadian medical technology industry comprises an estimated 2000 companies spanning many areas of therapeutic focus and technological platforms. However, there are some specific areas of focus that involve multiple companies and a community of expertise, leading to substantive commercialization. These areas of focus and some examples of companies include:

Diagnostic products
- In vitro diagnostics (more than 125 companies)
- Medical imaging/surgical planning (more than 80 companies including *Synaptive Medical, IntelliJoint, Profound, Conavi*)
- Diagnostics monitoring electrical activity and body sounds (*Auscul Sciences*, diagnosis & learning/AI)
- Point-of-care testing (*GenePOC*)/Lab-on-Chip Diagnostics (*CALM Technology, Ananda*)

Artificial Intelligence (AI)
- Clinical decision support, prognostics, radiomics, logisitics (*Imagia, Alayacare*)

Digital health technologies
- Remote monitoring for pulmonary assistance (*Thorasy*) and eye care (*iBionics*)
- Wearables (*Carré/Hexoskin, OM Signal*)

Robotics
- Physical assistance, rehabilitation/ human performance (*Kinova Robotics, Synaptive Medical*)

Virtual training, virtual reality, serious gaming
- Simulation and training (*CAE Healthcare*)
- Virtual reality entertainment, therapy, learning, autonomy (*Ubisoft*)

European Space Agency astronaut Frank De Winne testing an Augmented Reality system [Courtesy: NASA, 2009]

A unique feature of Canada's medical technology community is that it is largely organized into clusters. In addition to sharing a common therapeutic or technological focus, these clusters are characterized by:

- A base of essential talent
- A critical mass of required academic and research infrastructure
- Local knowledge and experience in product development
- Successful commercialization (mostly export)

Training and simulation

[Courtesy: CAE, 2019]

CAE Healthcare offers cutting-edge learning tools to healthcare students and professionals. This allows them to develop practical experience through risk-free simulation training, before treating real patients. The company's simulation products include surgical and imaging simulation, curriculum, center management and highly realistic adult, pediatric and baby patient simulators. Some 8,000 CAE simulators are in use worldwide by medical schools, nursing schools, hospitals, defence forces and others.

Examples of clusters include Greater Montreal's InVivo Life Sciences and Health Technologies cluster, which is home to more than 56,000 positions in leading areas of expertise, and Innovation Boulevard in Surrey, B.C., which contributes significantly to the dynamics of the sector in the province. A recently created Digital Technology Supercluster based in B.C. will use bigger, better datasets and cutting-edge applications of augmented reality, cloud computing and machine learning to improve the delivery of healthcare.

New medical technology research and innovation models are also appearing. Polytechnique Montreal's TransMedTech Institute, funded through the Canada First Research Excellence Fund, is developing next-generation medical technologies for the diagnosis, prognosis, treatment and rehabilitation of three major groups of diseases: cancer, cardiovascular illnesses and musculoskeletal disorders. Researchers, clinicians, engineers, patients, students, equipment vendors and public health system stakeholders work together to build innovative solutions in living-lab environments.

Bio-devices for space and terrestrial applications

MicroPREP is Canadian lab-on-a-chip technology [Courtesy: CSA, 2017]

Monitoring astronauts' vital signs and performing medical tests like blood analysis in space is important to identify and mitigate space-related health risks. Bio-devices such as so-called lab-on-a-chip technologies could automate and integrate multiple complex analytical protocols, generating abundant data that allows for molecular-based medicine and care in space. Through these new technologies, bio-analysis could be conducted in a rapid and inexpensive manner by minimally trained personnel.

The microsurgical robot neuroArm merges machine technology derived from the International Space Station's Canadarm2 with intraoperative imaging [Courtesy: Project neuroArm, University of Calgary]

Incubators, accelerators and startups

The innovation ecosystem in Canada is strong and active. Toronto alone is home to more than 60 incubators and accelerators, and anywhere between 2500 and 4100 startups. Some well-known hubs in the Toronto-Waterloo region include *MaRS Discovery District, The DMZ OneEleven, the Creative Destruction Lab*, and *Communitech*. They support tech startup companies from ideation to early-stage to scale-up. *The Biomedical Zone*, a collaboration between Ryerson University and St. Michael's Hospital, is an example of a healthcare-focused incubator. Montreal is also home to a variety of organizations supporting small and medium enterprises and startups such as *Tandem Launch, District 3* and *CTS.*

Canadian startups have access to funding at the federal, provincial and municipal levels. Favorable tax regimes and a supportive regulatory environment, in which a medical device can get to market in as little as four to six months, make Canada's business landscape startup-friendly.

Canada is home to several specialized research institutes, as well as 23 healthcare-related Networks of Centres of Excellence (NCE), specializing in fields such as technology and aging, kids' brain health and biotherapeutics for cancer treatment. The rich pool of skilled labor, with two-thirds of Canadians holding a post-secondary degree, is also attractive to startups that wish to grow in Canada.

Nevertheless, there are challenges that hinder technology firms from further scaling up domestically. Later-stage companies that rely on venture capital (VC) funding often look to more lucrative U.S. sources. Tax incentives for foreign investment in the U.S. have increased the funding there for Canadian

CSA President Sylvain Laporte speaking at InvestmentSpace 2019, an event to create new opportunities for Canadian firms in the space sector [Courtesy: CSA, 2019]

startups. VC funding in Canada, meanwhile, is limited. Canadian firms typically raise funds less often, later in their development and in smaller rounds than comparable companies in the U.S.

In addition to these access-to-capital challenges, Canada's business ecosystem also suffers from a lack of executive and managerial talent, which can be exacerbated by the country's low risk tolerance.

CSA astronauts Jeremy Hansen (left) and David Saint-Jacques (right) [Courtesy: CSA, 2017]

Technology trends

One of the most rapidly advancing technology fields of our decade is Artificial Intelligence (AI). Machine learning and adaptable systems are becoming ubiquitous in our economy and society, and have the potential to improve our daily lives.

AI is a national core competence for Canada; the country has been at the forefront of the field for years. AI research centres in Edmonton, Toronto and Montreal have become global hubs and are drawing attention from international investors. They lead the world in cognitive computing, deep learning and bioinformatics, and are graduating some of the most promising young talent. High-performance computing platforms such as Compute Canada and the Southern Ontario Smart Computing Innovation Platform (SOSCIP) provide valuable support to Canada's AI community and activities. The Canadian government has made a substantial investment ($572M) in advanced research computing through Compute Canada and Canarie that will benefit all Canadians and the field of AI research and development.

On the global stage, IBM (Watson/Bluemix), Apple and Google (Brain Team) and other key industrial players are investing hundreds of millions of dollars in AI research-and-development labs. Healthcare has been a favorite focus. Medical technologies accounted for 30% of Google's annual venture-capital expenditure in 2017, with the company anticipating a future in which computers and machines power our healthcare system.

Linking academic expertise and business needs

AI is now part of the research portfolio of many Canadian universities which are tasked with training the next generation of AI researchers. For example, the Institute for Data Valorization (IVADO) in Montreal, financed in part by the Canada First Research Excellence Fund, brings together industry professionals and academic researchers to develop expertise in data science, operational research and artificial intelligence.

PART 4

SOCIOECONOMIC YARDSTICKS THAT SHOULD BE MOVED

Needs of the Canadian healthcare system

Canada's publicly funded healthcare system provides universal coverage for medically necessary healthcare services on the basis of need, rather than the ability to pay. While highly regarded and seen as a point of Canadian pride, the system comes with challenges.

There are societal needs that could be addressed by engaging national partners, including the Canadian Space Agency, its astronauts and stakeholders. The expertise, technologies, protocols and systems that will provide healthcare for deep-space astronauts might also benefit citizens in remote regions of the country and chronic-care patients living in their homes.

Healthcare costs in Canada exceed $228 billion annually. However, this level of spending is not keeping pace with inflation and population growth, according to the Canadian Institute for Health Information.

In its 2017 study, the Commonwealth Fund, a private U.S. foundation, compared healthcare systems in 11 high-income nations: Australia, Canada, France, Germany, the Netherlands, New Zealand, Norway, Sweden, Switzerland, the United Kingdom and the United States. Performance was measured using 72 indicators across five domains: care process, access, administrative efficiency, equity and healthcare outcomes.

This international study shows that the top-ranked countries are the United Kingdom,

	AUS	CAN	FRA	GER	NETH	NZ	NOR	SWE	SWIZ	UK	US
OVERALL RANKING	2	9	10	8	3	4	4	6	6	1	11
Care Process	2	6	9	8	4	3	10	11	7	1	5
Access	4	10	9	2	1	7	5	6	8	3	11
Administrative Efficiency	1	6	11	6	9	2	4	5	8	3	10
Equity	7	9	10	6	2	8	5	3	4	1	11
Health Care Outcomes	1	9	5	8	6	7	3	2	4	10	11

Healthcare system performance ratings [Courtesy: Commonwealth Fund, 2017]

Australia and the Netherlands, with Canada relatively underperforming in a number of categories. Overall, it ranks 9th of the 11 nations. Ongoing challenges for Canada include access (for example there are barriers to care for some citizens), equity (disparities in performance between sectors of society) and healthcare outcomes (higher rates of mortality). Countries that join Canada near the bottom of the performance ranking include France and the U.S.

Needs of Canadian healthcare innovation

Like the Commonwealth Fund study, the *Advisory Panel on Healthcare Innovation* noted a slow decline in the performance of Canada's healthcare systems relative to international peers. In its *2015 report Unleashing Innovation: Excellent Healthcare for Canada*, the panel observed that healthcare reform has proven extraordinarily difficult for every provincial and territorial jurisdiction. It found that sustainable improvements in healthcare were unlikely to occur without system re-design and capacity building.

To unleash innovation in Canada's healthcare systems, the panel recommended a stronger culture of inter-jurisdictional collaboration. To scale up existing innovations, it said the provinces need a shared commitment to make fundamental changes in their incentives, culture, accountabilities and information systems.

The panel also recommended reorganizing healthcare systems to emphasize keeping Canadians as healthy as possible (such as better integration of healthcare and social services), and said that patients should be empowered with their own health information.

The aging Canadian population

The pace at which Canada's population is aging is accelerating. In the 2016 census, for the first time the number of Canadians aged 60 and over surpassed the number of those aged 15 and under. In addition, the number of the "oldest old" (those 85 and over) particularly centenarians, is booming, with an increase of 10% in this category between 2011 and 2016.

In 2035, Canada will join the ranks of the super-aged countries, with more than 30% of the population over the age of 60. The overall life expectancy has now reached 83 years for women and 79 years for men. A third of babies born this year in Canada are expected to reach 100. These amazing numbers, made possible through improvements in education, healthcare and wealth, will create unique opportunities in our country and produce a society in which older individuals remain active and take on more familial, societal and even economic roles.

[Courtesy: Health Canada, 2015]

This amazing new demographic landscape comes with major costs, however, as healthy life expectancy has not increased at the same pace as absolute life expectancy. Indeed, 30-40% of Canadians aged 85 and over have three or more chronic diseases that limit their mobility, their capacity to enjoy life and especially their cognitive abilities.

This new reality puts immense pressure on our healthcare systems, particularly as Canadians are working later in life and wish to age at home. Furthermore, as the "family unit" continues to evolve, with more and more family members living apart and children moving away from aging parents, the role of family caregivers in providing support to older adults becomes more complex.
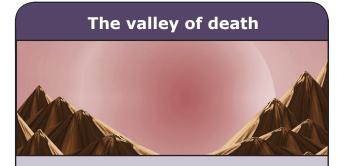
Surveys of Canadians reveal a fervent desire to age at home – whatever "home" is. Access to health services in this context requires a community-based approach where sophisticated, specialized health institutions and hospitals will be limited to treating specific acute-health conditions. This leaves community-based health services with the challenge of monitoring the health of large populations and delivering more specific health interventions.

While research and development to support the aging population through technology has been ongoing in Canada for the last 30 years, this has not resulted in many commercially viable and available products. Few potential solutions that have been developed within our academic and research institutions have been able to cross the "valley of death" and hit the market.

Connected independence

Technology will play a key role in monitoring and managing the health and wellness of older Canadians, enhancing their independence. There are already mobile devices that help older adults follow medication, diet and exercise plans, and that connect them with medical professionals who monitor their state of health. Advances in sensor systems that incorporate Artificial Intelligence and Virtual Reality technologies have the potential to add predictive capabilities to these telemonitoring and telehealth technologies, allowing interventions to be put in place before the onset of disease.

The valley of death

In the health research world, there is a place between the research lab and the marketplace where many good biomedical ideas wither away and die. Known commonly as the "valley of death", it exists in part due to a gap in financing. Grants from the largest funders of biomedical research generally focus on basic research. However, the most basic science discoveries require expensive animal and/or clinical trials before industry investors will commit.

Healthcare in remote locations

Equitable access to healthcare is a fundamental pillar of health service delivery in the Canada Health Act. It is also a universal human right. In truth, there are significant barriers for Canadians who live in rural and remote communities. Representing 20% of our country's population, these citizens experience significant challenges in gaining access to primary and specialized healthcare.

Hardest hit are Indigenous peoples living in underserviced communities. This gap in access affects the most vulnerable segments of this population – children, pregnant women and the elderly. Rates of tuberculosis, addiction, HIV-hepatitis C co-infection, chronic diseases such as diabetes, suicide among youth and traumatic injuries are the highest in Canada. Infant mortality in the Indigenous population is two times higher than in the rest of the country.

In addition to our nation's Indigenous population, Indigenous populations elsewhere in the world number in the hundreds of millions. Like Canada, many governments are struggling to ensure equitable healthcare access and accountability for their founding citizens. The World Health Organization's 2007 Commission on Social Determinants of Health cites the need to take account of colonization, health disadvantages and unique indigenous approaches to health.

Remote presence robotic technologies

Healthcare in remote communities is typically delivered through community-health clinics staffed by nurses, who practice with the support of off-site family physicians. Although there are periodic visits from doctors to these remote clinics, the healthcare delivery system relies heavily on transport by air, posing a significant economic burden to the system. Remote presence robotic technologies provide the sense that physicians are "present", enabling them to provide real-time clinical services at a distance.

Remote presence robot used in patient care
[Courtesy: Ivar Mendez, University of Saskatchewan, 2018]

Raven-in-Moon detail from CSA ISS Expedition 20/21 patch [Courtesy: Bill Helin, 2009]

Expert Group meeting with CSA President Sylvain Laporte [Courtesy: CSA, 2018]

PART 5

RECOMMENDATIONS TO THE PRESIDENT

Canada is a leader in advanced healthcare delivery as well as related research and technologies. Our expertise in minimally invasive surgery, remote medical robotics, medical training and simulation are highly regarded internationally, as are our world-class clusters of medical technology and artificial intelligence (AI).

The Expert Group makes four recommendations based on these strengths in national healthcare innovation. They are founded on three principles, that the Canadian Space Agency:
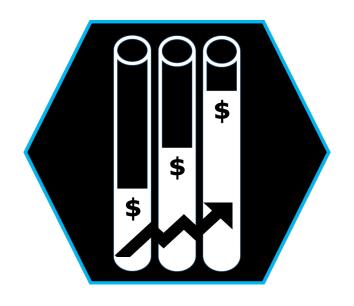
i. Embark on a new initiative that is critical, visible, affordable and socially beneficial, which will build on Canada's role as a respected leader among space-faring nations

ii. Provide an audacious challenge to Canadians that will stretch our national capabilities and rally our strengths

iii. Nurture cross-disciplinary partnerships with non-traditional stakeholders, diversifying the Agency's professional network and scope of capabilities

The Expert Group recommends that:

1. Canada should invest significantly in deep-space autonomous healthcare, as a bold contribution to space exploration and a means to develop national capacity in virtual healthcare for the benefit of all Canadians.

2. Canada should pursue a role as the lead integrator and operator for astronaut healthcare in deep-space missions.

3. In addition to operational oversight, Canada should contribute healthcare technologies to deep-space healthcare facilities, according to our national expertise.

4. To assist the Canadian Space Agency with development and implementation of this potential opportunity, an external and diverse collaborative body should be established, representing Canada's space operational, health-service delivery, commercial, research and government expertise.

CSA Astronaut Chris Hadfield on a spacewalk [Courtesy: NASA, 2005]

Conventional modes of managing, operating and supporting space missions in low-Earth orbit will be unsuitable in deep space. Future exploratory missions – characterized by great distances from Earth and communication and data lags with mission control – will present novel challenges that require new modes of operation. In increasingly harsh and remote destinations, methods that worked well in the past will become obsolete.

Healthcare for deep-space astronauts, for instance, will require the incorporation of new virtual-care capabilities. The term virtual healthcare refers to emerging digital and communications technologies that facilitate the delivery of healthcare to remote locations, including:

- Virtual consultations and patient visits
- Remote ICUs
- AI-based diagnostic decision-support technologies
- Transitional (post-discharge) care and home/mobile health monitoring
- e-Health (internet-enabled remote medical care)
- Remote monitoring of home-based chronic-care patients
- Secure electronic messaging
- Personal Health Records (PHRs) linked to Electronic Health Record (EHR) systems

1. Canada should invest significantly in deep-space autonomous healthcare, as a bold contribution to space exploration and a means to develop national capacity in virtual healthcare for the benefit of all Canadians.

This evolution in technology will include semi-autonomous technologies that rely on local healthcare providers for a level of clinical care delivery, in addition to autonomous technologies where care does not rely on local practitioners. Autonomous diagnostics with evidence-based therapeutic algorithms supported by e-consultation will likely be the first step in this direction.

Incorporating such virtual-care capabilities into deep-space missions could optimize interactions between astronauts and ground-based flight surgeons, and facilitate the transmission of medical information. Furthermore, the development of autonomous healthcare technologies (for example machine-learning decision systems to aid with prevention, diagnosis and treatment) will allow crews to play a greater role in the self-management of their health and well-being. Medicine in space, as on Earth, will evolve to more patient-centric and point-of-care models.

Advances in autonomous and virtual-care systems could also benefit healthcare delivery here on Earth. Much like space, Canada's remote regions are expansive, rugged and isolated.

Harsh northern conditions present challenges to practitioners, who strive to provide optimal and equitable healthcare to patients. Operational approaches and lessons learned from deep space could potentially be adapted to serve communities in those regions.

Primary-care practitioners could also benefit. Specialized skills training and medical support developed for deep space could be translated to empower physicians and nurses working in northern regions where access to clinical specialists, biomedical engineers and advanced technologies is limited. These resources could better equip practitioners to provide primary care in challenging clinical settings and bolster their confidence.

Potential benefits to remote healthcare

Innovations in deep-space healthcare could augment medical operations of Canadian Forces at home and abroad. Our nation's reputation as a reliable first responder to natural disaster missions and international humanitarian relief efforts could be enhanced.

Innovative technologies developed for space travel could be adapted to aid regions where healthcare delivery is deficient. This is especially pertinent in the developing world where five billion people lack access to surgical care. The Lancet medical journal reported in 2015 that 143,000 surgical procedures are not performed every year, resulting in the loss of lives and trillions of dollars in global productivity.

Enhancements in safe surgical procedures for spaceflight could benefit the developing world by making healthcare delivery more feasible and affordable. 3D printing, augmented clinical training and autonomous robotic surgical systems are technological solutions that could be translated from deep space to remote operating rooms.

Additionally, autonomous systems could provide chronic-care patients living in urban homes with tools to self-manage some aspects of their health. Sensor technologies developed to monitor astronaut health status could allow these patients to be monitored centrally, keeping them out of emergency rooms and hospitals.

Thus, the capabilities gained from developing virtual deep-space healthcare methodologies could be transformative for healthcare in Canada and elsewhere in the world. Lessons learned could lead to lower costs and better health outcomes.

Extraterrestrial physiology

Astronauts are extraterrestrials in a sense that normal physiology in space is different than that on Earth. In other words, the baseline for health in space will differ from the health and wellness baseline considered normal on Earth. This means that the development of autonomous systems used to manage astronaut health will need to be custom designed to reflect the adaptations to the space environment of vehicles, and those of habitats on the moon, Mars or elsewhere to respond to unique risks and potential therapies.

2. Canada should pursue a role as the lead integrator and operator for astronaut healthcare in deep-space missions.

Canada's long-term goal should be leadership in deep-space astronaut healthcare. Working in collaboration with international partners, this would give Canada a significant role in the development of autonomous crew healthcare systems to:

1. Maintain astronaut wellness
2. Enable the early detection of disease
3. Enhance crew autonomy in providing treatment for illness and rehabilitation from injury

Canada should be the overall integrator and operator of (not simply a contributor to) the healthcare system for deep-space vehicles and habitats. Canada would function as the system-level provider of astronaut healthcare, under programmatic direction from NASA and the international operational medicine community.

For example, the healthcare system aboard the International Space Station is known as the Crew Healthcare System. This suite of hardware and protocols provides the medical and environmental capabilities to ensure the health and safety of ISS crewmembers. It consists of three inflight sub-systems:

- The **Health Maintenance System** monitors the health of astronauts and provides medical-care capabilities. It also includes equipment for emergency life-support and resuscitation

- The **Countermeasures System** includes equipment and protocols for the monitoring and performance of daily exercise, to minimize the physiological deconditioning effects of spaceflight

- The **Environmental Health System** monitors the spacecraft for gaseous and microbial contaminants, water quality, acoustics and radiation levels

As lead integrator and operator, Canada would oversee the equivalent healthcare system for deep-space vehicles and habitats. This role would encompass both ground and space segments.

Responsibilities associated with the **ground segment** would focus on integration, training and operations. This would include:

- Testing, qualifying and integrating Canadian and international partners' flight hardware, software and virtual-care protocols in the onboard deep-space healthcare system
- Basic and advanced training of all crew, mission-support personnel, instructors and flight surgeons
- Oversight of all medical-flight operations
- Operating laboratories in support of research and technology development

Elements of this ground segment would be developed and networked within Canada. The testbed could include flight-like primary care centres (clinical settings, training simulators, living labs) distributed across remote or northern regions, networked to a major hospital in southern Canada. Patient-centric and point-of-care protocols intended for deep-space astronauts would thus be evaluated in a realistic clinical setting.

CSA astronaut Robert Thirsk telementored from the ground through a proceure to image his eye [Courtesy: NASA, 2009]

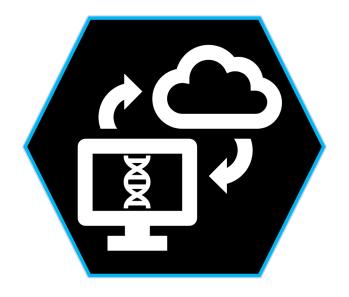**Payload Telecience Operations Centre [Courtesy: CSA, 2018]**

Space segment responsibilities would require Canada's oversight of deep-space healthcare facilities on behalf of its international partners, including:

- Operational oversight of all sub-systems (international and Canadian) of the crew healthcare system, encompassing daily operations (for example clinical data monitoring/uplinks/downloads and inflight maintenance, facilitation of communication with the crew)
- Onboard crew-refresher training (for example medical contingency simulations)
- Managerial oversight of healthcare provisions, such as scheduling, evaluations, debriefs, inventory/resupply, data distribution and archiving, human resources
- Technical facilitation of crew and family support by international flight surgeons and psychologists

This oversight would be limited to onboard facilities. Each participating nation would exercise autonomy over medical monitoring and assessment of their own crewmembers and over the confidentiality of astronaut/cosmonaut medical data.

Canada could leverage its world reputation and capabilities in machine- and deep-learning by establishing the architectural design reference for the onboard health informatics network. This would include decision-support tools with real-time integration and analysis of medical data. It would be aligned with current directions in connected healthcare and innovation.
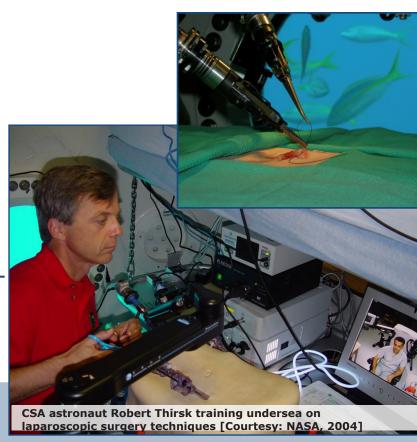
An operator and integrator role for Canada would not preclude sub-system contributions from national partners to the deep-space healthcare facility. Indeed, many international partners would participate in astronaut healthcare by contributing diagnostic and therapeutic elements to the spacecraft, according to each country's expertise and interests.

Canadian industry possesses the capabilities and critical mass to develop solutions for deep-space healthcare. Companies in Canada both small and large have sufficient scope and innovative strength to contribute sub-systems such as:

- In vitro diagnostics and point-of-care diagnostics
- Simulation-based training for healthcare providers
- 3D printing
- Advanced diagnostic imaging
- Advanced surgical navigation/planning/robotics

3. In addition to operational oversight, Canada should contribute healthcare technologies to deep-space healthcare facilities, according to our national expertise.

CSA astronaut Robert Thirsk training undersea on laparoscopic surgery techniques [Courtesy: NASA, 2004]

4. To assist the Canadian Space Agency with the development and implementation of this opportunity, a diverse collaborative body should be established, representing Canada's space operational, health service delivery, commercial, research and governmental expertise.

A deep-space astronaut healthcare initiative would be an audacious challenge for the Canadian Space Agency. It has never undertaken anything like this before. While the CSA does not have the expertise and resources of lead space-faring nations, our national health innovation ecosystem has the capabilities to carry out such an initiative. We recommend that external groups of top-level subject-matter experts be established to work with the CSA to conceptualize and implement this initiative.

In the near-term, such an advisory group would assist the Agency to evaluate the nature of this opportunity, the potential stakeholders involved, its timeline and the effort required (answering the "how" and "who" questions). There are myriad strengths, weaknesses, opportunities and threats to consider.

Members of this near-term group would be well-networked. Collectively, they would both be diverse (in gender, region, ethnicity and age, for example) and have a range of expertise in clinical, public health, research, technology, government, commercial and space operational matters. They would be familiar with clinical standards, policies, regulations and service-delivery models.

This advisory group would help the CSA define the scope and required resources of a potential astronaut healthcare initiative. It would facilitate the Agency's engagement with potential stakeholders. It would also assist in communicating this opportunity to the public, media and government.

The group's perspectives would be collaborative, integrative and holistic. Membership would exclude individuals or organizations with conflicting or vested interests in an ultimate program.

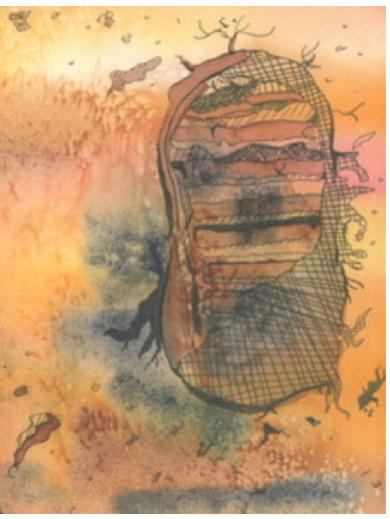If the initiative ultimately becomes an Agency

[Courtesy: CSA/NASA, 2019]

program, we envision it proceeding as a multi-partner national consortium. Each partnering organization would bring unique strengths and contribute necessary expertise, leveraged funding and in-kind services. Collectively, the consortium would become a formidable, distributed and collaborative network.

The CSA at that time could establish and lead a national steering group representing the partners of the consortium. This would be made up of high-level stakeholders who provide oversight on key issues (such as objectives, policy, resource allocation, communications and decisions involving large expenditures) as well as governance.

As with the near-term advisory group, this later-term steering group would embody multi-sector expertise and diversity to implement this ambitious undertaking. It would rely on the services of a central secretariat.

Strong leadership of these two external bodies by the CSA would be critical to bring together a novel and diverse network in a collaborative fashion. This will be new and exciting for the Agency – a broker role among diverse, broad-minded partners. While the CSA has limited medical resources, it has extensive spaceflight

experience and operational capabilities. Leading the consortium, it would retain full oversight, responsibility and accountability.

A deep-space astronaut healthcare initiative would represent a major commitment of time, effort and resources by all partners. However, our national healthcare innovation ecosystem, led by the Canadian Space Agency, has the depth, breadth and credibility to take this on.

These are our recommendations. Deep-space healthcare represents a once-in-a-generation opportunity for the Canadian Space Agency. Canada is well positioned to develop and diversify health innovation as a niche area of its space competence. This would be aligned with the expertise, resources and ambitions of the Canadian healthcare community. It could also transform the delivery of healthcare to patients with chronic diseases and to those living in remote and northern regions.

The Expert Group suggests that the Canadian Space Agency and its national partners pursue leadership in deep-space astronaut healthcare prior to the Mars exploration missions. This is a strategic vision with a bold objective and ambitious timeline.

Be aware that our "Journey to Mars" international partners will likely solicit a sub-system contribution from Canada – as opposed to envisioning a leadership role for the country – in deep-space healthcare. We do not recommend such a contributory participation, which would be inconsistent with the three foundational principles established by the Expert Group. Although affordable, a simple offering of a payload or an instrument would not capitalize on the depth and breadth of healthcare innovation in Canada. It would also not address this country's own remote health-delivery issues, attract young Canadian professionals to careers in space or present an opportunity to lead the planet in this discipline.

Student artwork from children's book *From Blue to Red* [Courtesy: Lord Beaverbrook High School, Calgary, 2012]

PART 6

CONCLUDING REMARKS

The stars are aligning

Deep-space healthcare – characterized by a patient-centered mindset, technology that is digital/AI-enabled and a point-of-care mode of operation – is something with which no space-faring nation has extensive experience.

This is, therefore, an opportune time for the Canadian Space Agency to pursue leadership in this emerging niche field. A deep-space healthcare initiative has the potential to engage many partners, and support a number of national priorities such as fundamental science, innovation and economic growth:

In its 2017 Budget, the federal government introduced the **Innovation and Skills Plan** aimed at building a world-leading innovation economy, and equipping Canadians with knowledge and skills necessary to compete on the global stage.

In response to the **Canada's Fundamental Science Review** that proposed a multiple-year agenda to transform Canadian research capacity and reinvigorate the science enterprise in Canada, Budget 2018 made significant investments in Canadian researchers, research infrastructure, and in big data. Furthermore, government's existing research programming was modernized and consolidated to help fully leverage the potential of business-academia collaborations.

Grass-roots efforts to develop the **Canadian Robotics Strategy** are looking to enhance the national robotics ecosystem and ensure Canada maintains its global reputation in this cutting edge field. Similarly, the Canadian Institute for Advanced Research is leading the federal government's **AI Strategy** aimed at increasing the number of researchers and graduates in the field, and helping build the national AI ecosystem.

A number of **Senate and House Committee Reports point to the changing healthcare landscape driven by disruptive technologies** and the role of automation in direct/indirect patient healthcare and home care. An **Arctic Policy Framework** being co-developed by the federal, territorial and provincial governments, Indigenous peoples and other northern partners represents a fundamental shift in policy making towards a shared leadership model that is built on partnership and collaboration. The Framework aims at addressing a broad range of issues including health, education, infrastructure, employment, environment, emergency preparedness, and culture.

A deep-space astronaut healthcare initiative would leverage Canada's health and medical research base and expertise in human medical systems applications, and our leading edge space capabilities and expertise in emerging technologies such as artificial intelligence, to tackle challenges that are common to health and wellbeing of both Canadians and astronauts. Furthermore, in line with the Government's priority to **promote healthy aging and improve access to health care for seniors**, it would ensure that approaches and technologies developed for space help facilitate independence, keeping the elderly and chronically ill out of emergency rooms and hospitals and improving their overall quality of life.

CSA astronauts [Courtesy: CSA/Adam Scotti, 2019]

Education and outreach

The Space Advisory Board consulted with national stakeholders in 2017 on an ambitious new space strategy. Among six key findings, it urged the government to re-establish the CSA's outreach and educational program to better involve the public in the space program and encourage youth to pursue careers in science and technology. A deep-space healthcare initiative involving a large network of partners and 21st-Century technologies could help accomplish this.

A healthcare initiative could offer a broad range of skills development and career opportunities for young professionals to stimulate the near-term economy. For example, personnel who would support the proposed ground and space segments of the program (managers, instructors, healthcare practitioners and engineers) would be assets to a national space medicine education capability. These personnel, as well as several of the ground segment elements (testbeds, simulators), could be critical in the delivery of certificate/diploma/degree courses and programs in clinical medicine for young professionals.

A deep-space healthcare initiative could include a public education program to enhance the interests and abilities of youth in STEM disciplines, stimulating the future economy. Canada's education system is known worldwide for its high-quality students in these fields. In the OECD's 2016 report *Programme for International Student Assessment*, adolescents around the world were rated for their academic proficiency. Among 72 countries, Canada ranked 7th for science, reading and mathematics, and it was in the top 10 in the world in all other categories.

The educational record for the country's Indigenous peoples, meanwhile, is less positive. High-school graduation rates for Indigenous youth here are half those for non-Indigenous youth. They are also less likely to pursue and complete post-secondary education than their non-Indigenous peers, and Indigenous unemployment is double the rate in non-Indigenous households.

There is much that could be done among these vulnerable populations in both remote and urban regions. An astronaut healthcare initiative, with a culturally informed experiential curriculum, has the potential to boost STEM competencies, community spirit and confidence in such communities. The CSA and its healthcare partners could collaborate within other demographic populations (young women, immigrant youth, low-income households and impoverished regions) to foster cross-disciplinary, hands-on educational opportunities. This would be an opportunity for astronauts, physicians and biomedical engineers to share the joy of learning and the fulfillment of STEM careers.

Student artwork from children's book *From Blue to Red* [Courtesy: Lord Beaverbrook High School, Calgary, 2012]

A spirit of exploration

Shooting the Rapids 1879 by Frances Anne Hopkins

A deep-space healthcare initiative could include a public-outreach element that inspires Canadians and re-kindles a sense of discovery and innovation across the country. While it would bring tangible socioeconomic benefits (improving skills development, the economy and healthcare), this initiative could also bolster the national spirit of exploration.

Canada was founded on the discovery, creativity and innovation of Indigenous explorers and early visitors such as David Thompson, Sir Alexander Mackenzie and La Vérendrye. They, as well as the pioneers, settlers and homesteaders who followed, established our exploratory mindset and founded our early economy. Centuries later, Canadians continue to benefit.

These critical traits, however, are eroding in today's information-based economy and sedentary society. We must guard against this. The exciting accounts of explorers, the human drama of discovery and the pursuit of impossible dreams capture the public's attention and imagination.

We need to inspire today's generation in the same way that baby-boomers were stirred by the audacious dreams of the Apollo era. A challenging Canadian role in deep-space healthcare could be socially transformative and motivational.

A final word

Deep-space healthcare is a huge topic. Many issues that our Expert Group regard as relevant remained unexplored. However, in the short time that we deliberated, we became convinced that one of Canada's largest scientific contributions to the world is clinical research. This expertise could be scaled up to advance the exploration of space, while furthering Canada's agenda on other fronts.

The Expert Group has addressed the "what" and "why" of a deep-space astronaut healthcare initiative. This opportunity should now be defined in more detail (the "how"). Investors and participants (the "who") should be identified and engaged as a collaborative network.

We envision a national, multiple-partner undertaking. No organization in Canada has the experience and resources to proceed alone. A consortium representing relevant jurisdictions, healthcare providers and patients, research institutions, governments, for-profit, youth, social and innovation organizations could develop options for the government's consideration and design the ground- and space-based concepts for this initiative.

Bill Helin's painting *Birth of Life* depicts the Tsimshian legend of human creation

41

Acknowledgements

Expert Group on the Potential Canadian Healthcare and Biomedical Roles for Deep-Space Human Spaceflight

Our Expert Group was composed of 14 members from various regions, sectors and disciplines within the Canadian healthcare, technology and spaceflight communities:

- Healthcare institutions
- Industry associations
- Remote medicine and Indigenous healthcare organizations
- Academic and research institutions
- Former physician-astronauts

Members were selected based on our technical expertise, broad perspectives and professional networks. Collectively, our skills, knowledge and experiences contributed to the overall mandate of the Group.

Robert Thirsk, OC, OBC, MDCM, MBA, LLD (Hon), SM (Chair), Chancellor Emeritus, University of Calgary; former Astronaut, Canadian Space Agency (Ottawa, ON)

Evan Adams, MD, MPH, Chief Medical Officer, First Nations Health Authority (West Vancouver, BC)

Mark Casselman, MSc, Chief Executive Officer, Digital Health Canada (Toronto, ON)

Jacques Corbeil, PhD, Professor and Canada Research Chair in Medical Genomics, Université Laval (Québec, QC)

Diane Côté, BA, President and Chief Executive Officer, MEDTEQ - Quebec Consortium for Industrial Research and Innovation in Medical Technology (Montréal, QC)

David Hart, PhD, Professor at the Cumming School of Medicine, the McCaig Institute for Bone & Joint Health, the Human Performance Laboratory and the Biomedical Engineering Graduate Program, University of Calgary (Calgary, AB)

Yves Joanette, PhD, Professor of Cognitive Neurosciences and Aging in the Faculty of Medicine, Université de Montréal; Scientific Director of the CIHR Institute of Aging (Montréal, QC)

Brian Lewis, BSc, BBA, President & CEO, MEDEC - Canada's Medical Technology Companies (Toronto, ON)

Linda Maxwell, MD, MBA, FRCSC, FACS, ICD.C, Founding and Executive Director, Biomedical Zone; Adjunct Professor, University of Toronto; Distinguished Visiting Professor, Ryerson University (Toronto, ON)

Ivar Mendez, MD, PhD, FRCSC, FACS, FCAHS, Fred H. Wigmore Professor and Unified Head of Surgery, University of Saskatchewan (Saskatoon, SK)

Alex Mihailidis, PhD, PEng, Scientific Director of the AGE-WELL Network of Centres of Excellence; Professor at the University of Toronto and holder of the Barbara G. Stymiest Chair in Rehabilitation Technology Research at the Toronto Rehabilitation Institute-University Health Network (Toronto, ON)

Anne Snowdon, BScN, MSc, PhD, FAAN, Professor and Academic Chair of the World Health Innovation Network; Scientific Director and CEO of SCAN Health - a Networks of Centres of Excellence International Knowledge Translation Platform, University of Windsor (Windsor, ON)

Teodor Veres, PhD, Principal Research Officer and Bio-Analytical Micro-Nano Devices Section Head, National Research Council of Canada; Adjunct Professor, McGill and Laval Universities, INRS-EMT (Montréal, QC).

David Williams, OC, OOnt, MSc, MD, CM, FCFP, FRCP, LLD (Hon), DSc (Hon), President and CEO, Exploration Incorporated; former Astronaut, Canadian Space Agency; former President and CEO, Southlake Regional Health Centre (Oakville, ON)

Project Staff of the Canadian Space Agency

Policy Secretariat:	Mary Preville, Director General of CSA Policy
	Maja Djukic, Executive Director of Major Programs
	Frédéric Pilote, Senior Policy Coordinator
	Nada Fadol, Analyst
With assistance from:	Annie Martin, Project Officer – Operational Space Medicine
	Isabelle Tremblay, Director – Astronauts, Life Science and Space Medicine
	Nicole Buckley – Chief Scientist, Life Sciences and ISS Utilization
	Linda Dao – Research Analyst, Policy

Expert Group Mandate & Process

Government space agencies from around the world have been meeting to consider the next phase of human space exploration for the coming decades. Although not yet formally approved as an internationally coordinated effort, operational concepts are nevertheless emerging.

The partner agencies of the International Space Station (ISS) are particularly keen to work together again to take the next steps in human space exploration beyond the ISS. Canada has been consulted for its technical and programmatic ideas and will soon be approached for specific contributions of hardware, services and resources as a partner.

It is in this context that the Government of Canada has directed the Canadian Space Agency (CSA) to engage industry and the research community and investigate Canadian roles in the human exploration initiative. Five strategic areas for potential contribution are being considered:

- Robotics
- Relative-navigation and vision systems
- Mobility for planetary exploration
- Telecommunications
- Health and bio-medical technologies

Accordingly, the CSA has initiated a series of studies and technology development activities in each of these five areas. The goal is to develop options that would represent an area of clear need to an international partnership and create socio-economic benefits for Canada and Canadians.

The CSA appointed a 14-member external task force with a unique membership – diverse, multidisciplinary, networked and broadly-experienced with Canadian healthcare systems - to investigate a potential Canadian role in astronaut healthcare and biomedical technologies. Known as the Expert Group on the Potential Canadian Healthcare and Biomedical Roles for Deep-Space Human Spaceflight, the Expert Group was mandated by the CSA to provide advice regarding "identifying, scoping and assessing possible bio-medical contributions and healthcare leadership roles for Canada in human-rated deep-space missions". Appendix C of this document contains the Terms of Reference of the Expert Group. Appendix B outlines the various members.

Our Expert Group met seven times from September 2017 to January 2018 for consultations and conversations with health, space and innovation leaders, as well as a few international experts. It has been a rewarding experience.

Expert Group learning and discussions encompassed:

- The Canadian space program
- Issues associated with performance and operations of crew on deep-space missions
- Issues related to delivery of healthcare in Canada

- The state of the Canadian healthcare industry and innovation
- The aspirations of and career opportunities of our youth

Appendix D provides a complete listing of the speakers and topics that were presented to the Expert Group.

In addition to the directions formally stated in the Terms of Reference, the CSA President advised the Expert Group that a Canadian contribution to deep-space exploration should be visible, critical, scalable and affordable. Furthermore, any new initiative undertaken by the CSA should:

- Build upon and showcase existing Canadian strengths
- Provide tangible socio-economic benefits to Canadians
- Provide commercial spin-offs to industry
- Provide high-quality jobs that strengthen the middle class
- Include an education element that enhances youth interest and abilities in science, technology, engineering and math (STEM) disciplines
- Include a public outreach element that inspires Canadians

Following its consultations and deliberations, the Expert Group was to provide its findings and recommendations to the CSA president about a potential role for Canada in deep-space healthcare in a formal report (this report).

We emphasize that our Expert Group was not associated with the Space Advisory Board.

Expert Group Consultations with Stakeholders

The Expert Group met seven times from September 2017 to January 2018. During most of these meetings, we conversed with national leaders and a few international experts. We received foundational briefings from experts and decision makers from the Canadian Space Agency (CSA) and the Expert Group itself. Executives and managers from other government departments as well as prominent stakeholders from industry and academia also presented on topics related to human spaceflight, healthcare and innovation.

The following is a listing of the presenters and their presentation topics.

Monday, September 18, 2017 – St-Hubert, QC (face-to-face)
Sylvain Laporte (CSA President) – The Canadian space program and the Government of Canada priorities

Gilles Leclerc (CSA Director General – Space Exploration) and Yves Gonthier (CSA Senior Engineer – Space Exploration Strategic Planning) – Overview of Global Exploration

Isabelle Tremblay (CSA Director – Astronauts Life Sciences and Space Medicine) – Humans in Space – Introduction

Dr. Nicole Buckley (CSA Chief Scientist, Life Science and ISS Utilization) – Human Spaceflight Planning for the Future And Health Sciences

Dr. Annie Martin and **Natalie Hirsch** (CSA Project Officers – Astronauts, Life Sciences and Space Medicine) – ISS Crew Healthcare Systems

Dr. Dave Williams (President/CEO Southlake Regional Hospital; former CSA Astronaut) – On-orbit experiences and insights about deep-space healthcare from the astronaut perspective

Tuesday, September 19, 2017 – St-Hubert, QC (face-to-face)
David Haight (CSA Chief Economist) – Overview of the global and domestic trends in the space sector

Dr. Bill Paloski (Director, NASA Human Research Program) – Human Research Program Overview

Dr. Jennifer Mindock (NASA Strategic Integration Scientist/Systems Engineer) – Crew Health and Performance - Integration with deep-space missions

Dr. Raffi Kuyumjian (CSA Flight Surgeon) – Crew health and performance Q&A

<u>Tuesday, October 17, 2017 (telecon)</u>
Dr. Yves Joanette (Scientific Director, CIHR Institute of Aging) and Dr. Alex Mihailidis (Scientific Director of the AGE-WELL Network of Centres of Excellence) – The State & Needs of Geriatric and Chronic Care Medicine

Dr. Ivar Mendez (Professor and Unified Head of Surgery, University of Saskatchewan) – The State and Needs of Rural, Northern & Remote Medicine

Dr. Jacques Corbeil (Professor of Molecular Medicine and the Big Data Research Centre, Université Laval) – A Functional Ecosystem for an Astronaut Healthcare Initiative

<u>Friday, October 27, 2017– Toronto, ON (face-to-face)</u>
Diane Côté (CEO of MEDTEQ) and Brian Lewis (President & CEO, MEDEC) - The State and Capabilities of the Canadian Medical Technology Sector

Dr. Evan Adams (Chief Medical Officer, First Nations Health Authority) - Indigenous Health in British Columbia

Dr. Don Brooks (Expert Panel member of the CCA State of Science & Technology and Industrial R&D in Canada 2017; Professor of Pathology and Chemistry, UBC) - Preliminary Data Update on Canadian Research Performance and International Reputation

Chantelle Dubois (Space Generation Advisory Council; Computer Engineering undergraduate student, University of Manitoba) – The Next Generation Space Workforce: Human Resources and Employment Opportunities

<u>Wednesday, November 15, 2017 (telecon)</u>
Mark Casselman (CEO, Digital Health Canada) – Digital Health in Canada

Iain Christie (Executive VP, Aerospace Industries Association of Canada) – Canadian Space Industry Capabilities

<u>Wednesday, November 29, 2017 (face-to-face)</u>
Dr. Pascal Michel (Chief Science Officer, Public Health Agency of Canada) – Space and Global Health

Dr. David Naylor (Professor of Medicine & President Emeritus, University of Toronto) – The State of Healthcare Innovation – The Future (2027) of Healthcare & Clinical Medicine

<u>Friday, December 8, 2017 (telecon)</u>
Dr. Ziad Kobti (Professor & Director of the School of Computer Science, University of Windsor; President, Canadian Artificial Intelligence Association) – Overview of Canadian Artificial Intelligence in Healthcare

Dr. Jack Stuster (NASA Principal Investigator, Anacapa Sciences, Santa Barbara) – Human performance considerations for deep-space missions and during isolation and confinement

Terminology, Acronyms and Abbreviations

Our name, Expert Group on the Potential Canadian Healthcare and Biomedical Roles for Deep-Space Human Spaceflight must set a record for the longest of any task force. We have resorted, therefore, to self-reference in the report as the "Expert Group" in order to conserve ink and trees!

This report includes terms, acronyms and abbreviations and that should be briefly clarified:

AI	Artificial Intelligence
CCA	Council of Canadian Academies
CSA	Canadian Space Agency
DSG	Deep Space Gateway
GER	Global Exploration Roadmap
ISS	International Space Station
IVADO	Institute for Data Valorization
LEO	Low Earth Orbit
NTU	National Taiwan University
OECD	Organisation for Economic Co-operation and Development
Point-of-Care Testing	Medical diagnostic testing performed outside the clinical laboratory, perhaps even at patient's bedside
STEM	Science, Technology, Engineering and Math disciplines