By Michael Mastromatteo

From niche player to

Canadian space engineering has made significant strides since the cancellation of a major aeronautics program nearly 50 years ago. In responding to identified need, and by taking advantage of new opportunities and partnerships, Canadian engineers are now key players in the next generation of space exploration.

key contributor

It is widely accepted that the federal government's 1959 decision to cancel the Avro Arrow aircraft production program was a low water mark for Canadian engineering. A politically motivated decision undercut the talent, ambition and dedication of leading aviation engineers and denied these practitioners an opportunity to showcase their expertise on a world stage.

But, as sometimes happens with unforeseen setbacks, the Avro experience led to other opportunities and potential to make a mark. Denied the opportunity to continue work on the state-of-the-art Arrow aircraft, a number of the Avro Canada engineering and technical workers headed south to become lead engineers with the National Aeronautics and Space Administration (NASA) in Houston, Texas.

These engineers, in turn, made significant contributions to the Mercury, Gemini and Apollo projects, which culminated in the 1969 moon landing, and brought untold prestige to America's space ambitions, and to engineering in general.

But as these engineers made inroads with NASA's space program, others who remained in the country began to develop expertise in such niche areas as space robotics, telecommunications, and advanced imaging and sensing systems.

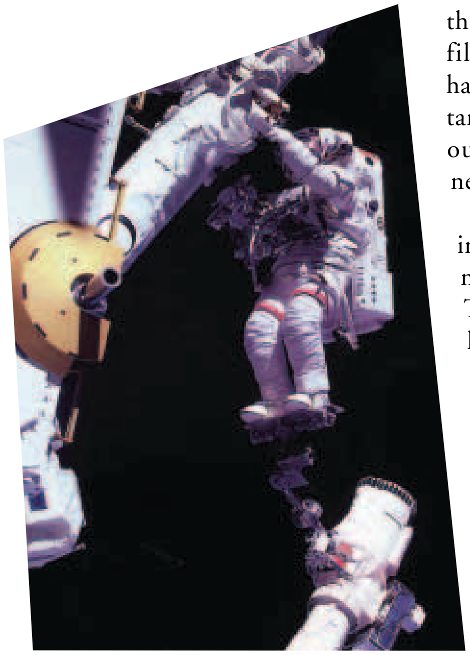
And if Canada is today regarded as a smaller partner in international space missions–as evidenced by total government spending–the country's space engineering achievements continue to make a significant impact.

Canadian astronaut Chris Hadfield, for example, suggested in a recent interview with *Engineering Dimensions* that many of today's breakthroughs with the space shuttle program, satellite and telescope retrieval and repair, and the International Space Station (ISS) assembly, would not be possible without a Canadian engineering contribution.

Hadfield served as a mission specialist on shuttle flights STS-74 (November 1995) and STS-100 (April 2001). It was during the second mission–to deliver and install the Canadarm 2 to the ISS–that Hadfield became the first Canadian to walk in space.

"We could not launch shuttles without the Canadian engineering that's on board," Hadfield said. "The only way we could convince ourselves to fly again after the [2003] *Columbia* accident was [because we had] the ability to do a detailed inspection of the outside of the shuttle before coming back into the Earth's atmosphere. And the best way to do that, and the way we are going to do it until the end of the shuttle program, is by using the Canadarm, and the cameras and lasers that are on the end of it. And the vast majority of all that equipment is the fruit of Canadian engineering design and building."

As one of the users of such Canadian space robotic technology as the Canadarm and Canadarm 2, Hadfield is in a good position to extol its virtues. Certainly, Canadian space engineering is generally thought of in connection with advanced robotics, satellite transmissions and optical-sensing equipment. However, the Canadian Space Agency (CSA), often in conjunction with leading manufacturers, vendors and universities, is also engaged in applying space-developed technology to what is called "terrestrial" uses. And as is now being seen in the health care field, technology being developed in one particular sector is soon applied across a wider spectrum, for the greater public good.



STS-100, April 2000–Astronaut Chris A. Hadfield stands on the Canadarm to work on Canadarm 2. Canadarm 2 was delivered to the orbital outpost by the STS-100 crew.

What follows are observations and insights from those in the know when it comes to appraising Canada's engineering contributions to ongoing space missions, and to those on the drawing board.

The astronauts

Bob Thirsk, P.Eng., is an engineer and medical doctor, who participated in the June-July 1996 shuttle mission (STS-78), which was devoted in part to "life and microgravity" experiments. He was later assigned by the CSA to NASA's Johnson Space Center in Houston to pursue mission specialist training. In an interview from Moscow, where he is undergoing training at the Gargarin Cosmonaut Training Centre, Thirsk shared some of his thoughts on Canadian engineering's contributions.

"Canada is the smallest partner in the International Space Station program, based on financial investment; however, the criticality of our robotic contribution to the program greatly exceeds our financial investment," Thirsk said. "In fact, the continued assembly of the ISS would not be possible without our robots. In a real sense, the fate of an international high-profile understanding rests in Canada's hands. Canada was granted this important role by the ISS partners based on our distinguished tradition of engineering excellence and reliability."

Thirsk's 1996 shuttle mission included conducting 34 experiments, many of which focused on life sciences. Through these efforts, space agencies learned more about the response of human muscle tissue to microgravity environments, which led to the introduction of aerobic and muscle toning regimes for crew members on future shuttle/extended-time space missions.

Thirsk is also active with medical experiments in unusual environments, such as space and deep undersea, in efforts to extend lessons learned from space to a wider clientele.

Fellow Canadian astronaut Julie Payette, ing., served as a mission specialist on STS-96, which ran from May 27 to June 6, 1999. Payette, who maintains her engineering licence with the Ordre des ingénieurs du Québec, helped operate the Canadarm as the shuttle completed a manual docking with the ISS.

> "Canada is the smallest partner in the International Space Station program, based on financial investment; however, the criticality of our robotic contribution to the program greatly exceeds our financial investment."
>
> *Bob Thirsk, P.Eng.*

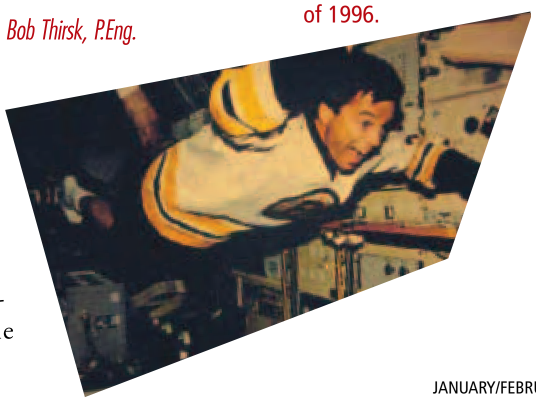
Now serving primarily as a capsule communicator (Capcom) at the Mission Control Center in Houston, Payette is quick to apply the engineers' "design under constraints" thinking to the challenges of space exploration.

"I often say to young people when I talk about engineering that the profession is very large and encompassing," Payette said in an interview from Houston. "And what people learn at engineering school, at NASA, and in the aerospace industry translates immediately into a system of problem-solving, designing, looking at situations, and picking out the pertinent parameters. You learn this way of thinking and a way of noting problems and developing solutions. As well, you can apply this almost anywhere in the world, and that's one reason why you can find engineers in hospitals, in business, in politics. It's an approach that is useful practically anywhere."

Marc Garneau, P.Eng., Canada's first astronaut (Shuttle mission G-41, October 1984), and former president of the Canadian Space Agency, maintains his engineering licence through the Association of Professional Engineers of Nova Scotia (APENS). A much-sought-after speaker on the Canadian space program, Garneau takes seriously an engineer's responsibility to communicate the benefits of technology, especially as it involves aerospace.

"Canada was the third country in the world with a satellite in space, with Alouette 1 in 1962. Canadians designed it from

Astronaut Bob Thirsk in a playful moment during shuttle flight STS-78 in the summer of 1996.



scratch and it was phenomenally successful in the scientific study of the ionosphere over a 10-year period. We are also leaders in communication satellite technology, synthetic aperture radar remote sensing and in building complex science instruments to study the atmosphere and the universe."

As someone who has flown extensively in space, Garneau also appreciates the Earth study made available by way of Canadian technology originally designed for a space environment. He cited navigation through the use of such systems as global positioning systems (GPS), and weather satellites that allow Canadian scientists to contribute to the worldwide effort to understand the universe, as two key initiatives. "This is only good business because it allows the Canadian space sector to grow and thrive," he said.

The Canadian Space Agency

In addition to the astronaut corps, engineers are well represented in government agencies and private-corporation-enabling space activity. Whether as designers, instructors or testers of space-bound equipment, Canadian engineers have extended the reach of technology.

Lindsay Evans, P.Eng., an astronaut training specialist with the CSA, devotes much of her time to training Canadian, American, Japanese, European and Russian astronauts to operate Canadian-built robots on the ISS. Although technically she is not practising engineering in the training role, Evans is well versed in the engineering challenges a space environment poses for robotic operations.

"One of the biggest challenges we have with space robotics is that you're launching a system into an environment in which it can't be previously tested," Evans said in an interview. "Whenever anyone makes a new engine or something, they can always go and test it in the environment and make sure it's going to work. The problem with space exploration is that you can't send a test bed or test unit up into space and test it without it costing a lot of money, so it's difficult to find a place where you can do all the testing."

Evans said the positive track record of Canadian robotic technology now has its emulators. "The Japanese and the Europeans are also providing robotic arms to the space station over the next couple of years, and the Japanese used part of the Canadian arm for their [equipment], because we've got a proven history."

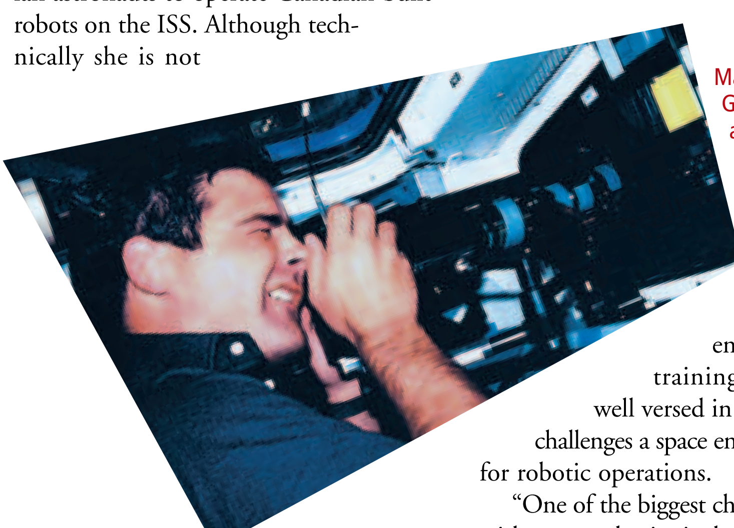
Taking advantage of a recipe that works might apply to the testing and qualifying components of Canada's overall space engineering expertise. Shabeer Ahmed, P.Eng., is director of the CSA's David Florida Lab in Ottawa. He describes the lab as a one-stop integration and test facility providing structural, thermal, radio frequency and electro-magnetic test services for space hardware.

"The testing [at DFL] includes all hardware destined for space. This includes instruments to full satellites related to telecommunications, Earth observation, and science missions, as well as robotics hardware, such as the Canadarms on NASA's space shuttle and the ISS," Ahmed told *Engineering*

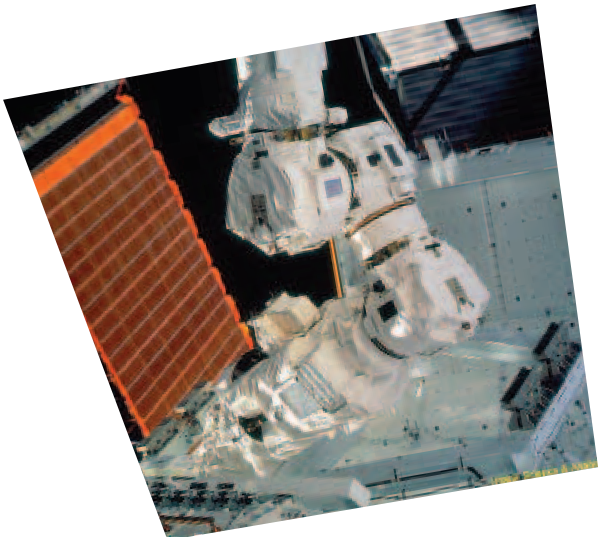
Julie Payette, ing., operates the Canadarm from the deck of the shuttle *Discovery*, 1999.

"Canada was the third country in the world with a satellite in space, with Alouette 1 in 1962. Canadians designed it from scratch and it was phenomenally successful in the scientific study of the ionosphere over a 10-year period."

Marc Garneau, P.Eng., Canada's first astronaut (Shuttle mission G-41, October 1984) and former president of the Canadian Space Agency



Marc Garneau aboard the *Challenger* shuttle, 1984.



This photo, taken by Astronaut Chris Hadfield, reveals something of the Canadarm's ability to connect objects in orbit.

Dimensions. "The assembly in the DFL's clean rooms ranges from sub-assemblies to full satellite systems destined for launch on one of the currently available rockets in the world."

Ahmed said the engineering challenges involved in DFL work are varied, especially as the integration and test programs are unique in their details. "The lab provides calibrated test equipment and qualified operators in support of clients' integration and test activities," he added. "To ensure a consistent and traceable support activity, the DFL follows ISO 9001-2000 standards. As such, the lab is subject to both an internal and external audit program on a periodic basis to maintain the ISO certification. Also, clients of the lab conduct their own audit to ensure the lab meets their quality, product and safety assurance requirements as part of their own due diligence."

As an engineering test specialist, Ahmed cited the Storable Tubular Extendible Member (STEM) and Radarsat-1 as just two examples of Canadian space engineering triumphs. STEM's derivatives are being used on antennas or to deploy solar arrays for such programs as the Hubble Space Telescope. Radarsat-1, the world's first operational and active microwave remote-sensing satellite, is used to penetrate clouds, fog, dust and other barriers to record land and water features. The microwave system can also assist in gas, oil or mineral exploration, environmental impact, sea ice tracking, and natural disaster monitoring.

Engineers at the CSA have also been instrumental in moving Canada to a leading position in telecommunications and satellite technology. Beginning with the Alouette and Anik systems, through to the more recent "Hermes" direct broadcast satellite, Canadian satellite technology is much sought after to establish similar systems around the world.

Other prominent CSA projects include the SCISAT system, designed to study the condition of the ozone layer around the Earth, and the Microsat MOST satellite, launched to study stars and predict their age.

The designers

Canada's reputation as an important niche player in space engineering rests largely on its experience with advanced robotic systems. Thanks in large measure to the CSA's partnership with high-technology private sector organizations like MDA, Optech and Neptec, unique Canadian space engineering is finding new outlets.

MDA (formerly Spar Aerospace), has been working with space agencies since the 1970s to develop the robotic components that would come to fruition with the Canadarm, Canadarm 2, the Mobile Base System and the latest Special Purpose Dexterous Manipulator (Dextre). MDA has also developed a Mobile Service System (MSS), which is the term for all the Canadian robotics in service on the ISS. MDA is involved with NASA, the CSA and other partners, such as Optech and Neptec, in the ambitious 2007 Phoenix Scout Mission to Mars. Phoenix is a "science-driven mission," aiming to land a sophisticated landing craft near the Mars pole region to study environmental and climatic patterns. Scheduled to land on Mars in 2008, the Phoenix is ultimately aimed at determining if life ever existed on Mars, and to help scientists reduce risk for eventual human travel to the Red Planet.

> "We are typically involved in designing systems to do complex tasks in challenging environments, with extremely high safety requirements."
>
> *Tim Fielding, P.Eng., senior systems engineer at MDA*

Tim Fielding, P.Eng., senior systems engineer at MDA, is involved in applying robotic systems to "terrestrial" applications, such as medicine and the nuclear industry. In telemedicine, for instance, robotics allows surgeons to perform operations without being physically present in the operating theatre.

Fielding suggests the experience gained in designing robotic systems for harsh environments encountered in space naturally leads to ways to apply the technology to unusual earth situations.

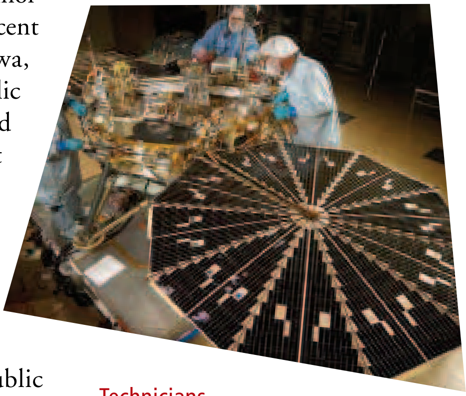
"We are typically involved in designing systems to do complex tasks in challenging environments, with extremely high safety requirements," Fielding said. "The details of the work change depending on the task, industry and environment. However, there are many common requirements that find their way into all the work we do. Considering system safety right from the initial concepts, taking a systematic approach to solving a complex problem, and design principles that result in robust, reliable solutions are some of the principles that have been honed on space programs, but are now being applied on Earth."

Fielding suggests an important milieu for developing robotics, whether for space or Earth use, comes from simulating as closely as possible any "real world" operations. "The more representative you can make your testing, the more likely you will catch issues with a new design. As environments get more extreme, representative testing becomes more difficult. In these cases, simulation can be a great aid or even the only way to check certain aspects of a design. However, until a simulation can be adequately validated, the results are always suspect. At this point, the experience that a company has built up over the years really makes the difference."

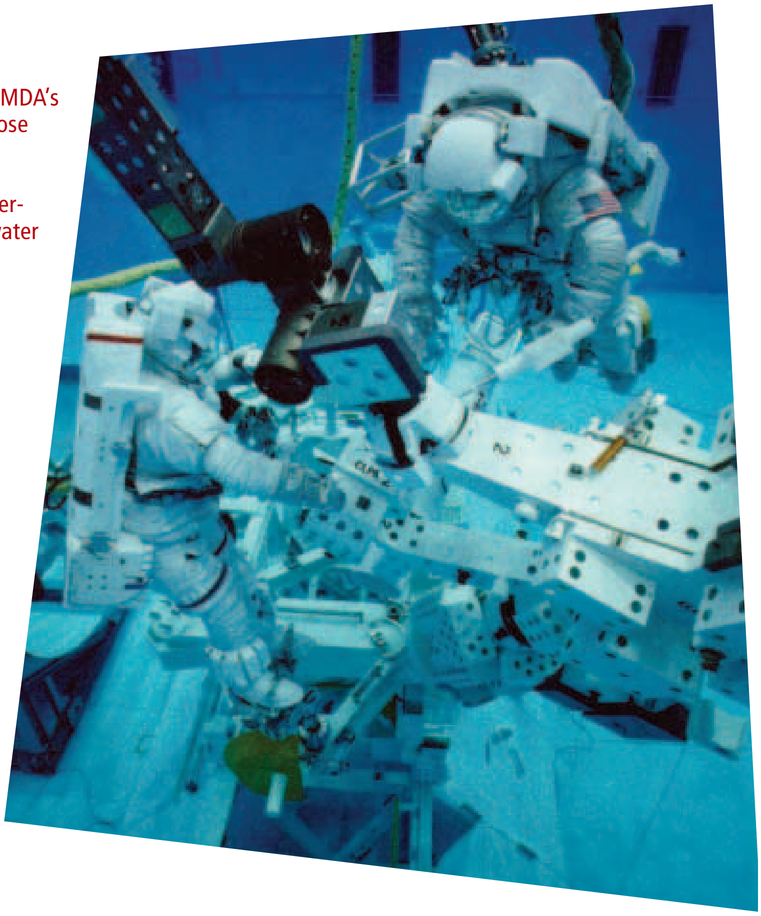
Eric Choi, P.Eng., a systems engineer at MDA, helped write the proposal that led to MDA's participation in the upcoming Phoenix-Mars mission. In addition to his responsibility for such "front-end" aspects of engineering work as requirements definition, operations concept development, and conceptual design, Choi is occasionally called on to discuss the significance of space-related technology and exploration. During the recent Canadian Space Summit in Ottawa, Choi's presentation focused on public attitudes toward space programs, and the need to build popular support for the often misunderstood rationale for such exercises.

"The support of the public is crucial in making sure such missions [as the Phoenix] go ahead, which is why I have been involved in the promotion and public awareness of space at venues like the [Ottawa] Space Summit for much of my professional career," Choi said. "I also recognize the importance of promoting space as a means of encouraging young people to consider careers in engineering."

Complementing the robotics-based work in Canadian space engineering are



Technicians work on the "Lidar" sensor head and temperature mast, which are integrated on the Phoenix Lander in preparation for the voyage to Mars in 2007.



A section of MDA's Special Purpose Dexterous Manipulator (Dextre) undergoes underwater testing.

groundbreaking efforts in the area of laser-based visioning and sensing devices.

Brampton-based Optech Incorporated, for example, is working with the CSA, NASA and other partners on the Phoenix-Mars mission. Using its proprietary light detection and ranging (Lidar) three-dimensional sensing system, Optech engineers have earned a berth for their technology on the Mars lander.

Robert Richards, head of the space and atmospheric division at Optech, described Lidar as a new niche technology for the Canadian space program. "[It] provides humans and robots the ability to sense the world around them in three dimensions. Working collaboratively with MDA, Optech engineers adapted the company's core Lidar technology to form the heart of Canada's contribution to NASA's Phoenix-Mars lander," Richards said.

Optech's expertise also includes lunar and planetary mapping, spacecraft rendezvous and docking enhancement, autonomous landing and hazard avoidance technology, and spacecraft imaging and inspection.

Canada's involvement with Phoenix comes by way of a meteorological station that will make studies of the Martian atmosphere. For the Phoenix mission, Lidar technology will allow the Mars craft to analyze aspects of the Mars atmosphere to help scientists understand what might have happened on the planet to render it in today's circumstances.

Using a robotic arm, the Phoenix craft will dig a trench and retrieve Martian samples for geological and chemical analysis. It is believed that by detecting even minute quantities of organic molecules, scientists can determine the "habitability" of the Martian ice layer for microbial life, in the past or present. The search will be carried out in conjunction with environmental studies to assess "water vapour flux" on and near the surface layer.

"This is Canada's first space exploration experience with a substantial subsystem destined for another planet," Richards said in an interview. "In many ways, we are cutting our teeth with the Phoenix program and this experience will help Canadian engineers take on an increasing leadership role in future international space missions."

In keeping with the theme of helping astronauts and robots see and feel their way around in space, Neptec Design Group, an Ottawa-based vendor of 3D vision systems, has also become an important niche player in the Canadian effort. With its unique laser camera and space vision systems, it is a prime contractor with NASA, particularly in providing advanced laser scanners for robotic inspection and servicing of shuttle craft. In fact, it was a Neptec laser camera system–mounted on an MDA-built Canadarm–that was used to inspect hard-to-reach areas of the shuttle craft and gave crews the ability to inspect shuttles for possible foam loss prior to re-entering the Earth's atmosphere.

Neptec has also pioneered its Advanced Space Vision System (ASVS), which allows astronauts to cope with rapidly changing light conditions in space, bringing new visibility to precise shuttle payload maneuvering. Neptec's more recent Tri-DAR system provides short-range inspection capability and long-range detection, orientation and tracking–the kinds of enhanced imaging required for satellite capture and retrieval. In addition, the company's Laser Metrology System (LMS) can be used for both in-line and stand-alone inspection of machined parts and assemblies, which, while not necessarily space-related, has made it an important inspection tool in the automotive and aerospace industries.

Christine Smith, P.Eng., principal engineer for Neptec Design Group, stands next to special dots crucial to the company's advanced vision systems used by NASA and the CSA.

Christine Smith, P.Eng., principal engineer with Neptec, described the application of the laser camera system to work on the space station. "The LCS is an integral part of the shuttle, which will continue to be the primary resupply system for the ISS until 2010," Smith said. "As new resupply vehicles, such as Orion and the Commercial On-orbit Transportation System come on line after 2010, Neptec expects that the TriDAR sensor will also be used aboard the space station to assist in the automation of the rendezvous and docking operations of these new vehicles."

The significance

The impression of Canadian engineers scrambling to develop expertise only in limited or niche areas of space exploration might not always do full justice to the profession's total contribution. Certainly, Canadian aerospace experts who wound up at NASA in the 1960s helped that organization fulfill its space-race and national prestige ambitions, which were realized by way of the 1969 moon landing. But as budgetary considerations and changing political priorities limited NASA's ambitions over the next three decades, Canadian engineers continued working in ways that would enhance space exploration as the sector began to take on a more international flavour. And now, with NASA and private sector groups talking of more ambitious space-related activity in the coming decades, Canada's niche contributions may be taking on even more weight.

As well, the entire engineering-space missions field seems to be unfolding as never before. Engineering instructors have seized on the microgravity properties of orbiting space station laboratories to conduct new research, while colleges and universities, including York University in Toronto, are opening space hardware testing facilities and developing new courses of study to emphasize the engineering-space exploration link.

These developments must be somewhat gratifying to any surviving Avro Arrow engineers who felt their ambitions thwarted by the political decisions of 1959. They must also be heartening to people such as Allen Carswell, P.Eng., president of Optech Inc., and professor (emeritus) of science and engineering at York University. "Canada's achievements in space to date demonstrate unequivocally that Canadian engineers have all of the necessary skills and abilities to participate in even the most demanding space-related tasks," Carswell reflected for *Engineering Dimensions*. "Canada's engineering education and training ranks with the best in the world. As the knowledge base and application requirements have expanded, Canadian engineering programs have broadened to provide the needed expertise."

Carswell also said Canada's achievements from the 1960s to today have provided a solid foundation to inspire engineers for future challenges. "Canadian engineers have performed and continue to contribute at the leading edge of international space activities. Space communications, robotics, remote sensing and Earth observations have benefited greatly from the outstanding capabilities of Canadian engineers."