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ENGINEERING HISTORY PAPER #57

"From Steam to Space Revisited"

by Andrew H. Wilson

(previously produced as Cedargrove Series #30/2014 – June 2014)

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EIC HISTORY AND ARCHIVES

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Abstract

This paper is based on the talk given by the author during the Special Engineering History Session of the International Conference of the Canadian Society for Mechanical Engineering at the University of Toronto in early June 2014.

The book that is being 'revisited' was published originally to commemorate the 25th Anniversary of the founding of CSME. The talk covered some of the background to its publication and brief descriptions of a half dozen of the mechanical engineering activities that were included in the book to illustrate mechanical engineering's contributions to Canada's development. This paper amplifies these.

While the talk made use of illustrations in a power-point presentation, with one exception (on page 2), these have not been included in this paper. They all appeared in the book.

This paper also makes the suggestion that preparations begin soon for a second book to help commemorate CSME's 50th Anniversary in 2020.

About the Series

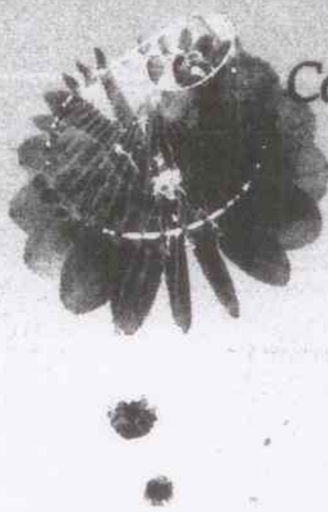
Principally, the Cedargrove Series is intended to preserve some of the research, writings and oral presentations that the author has completed over the past half-century or so but has not yet published. It is, therefore, a modern-day version of the privately-published books and pamphlets written by his forebears, such as his paternal grandfather and grandmother, and his grandfather's brother John.

About the Author

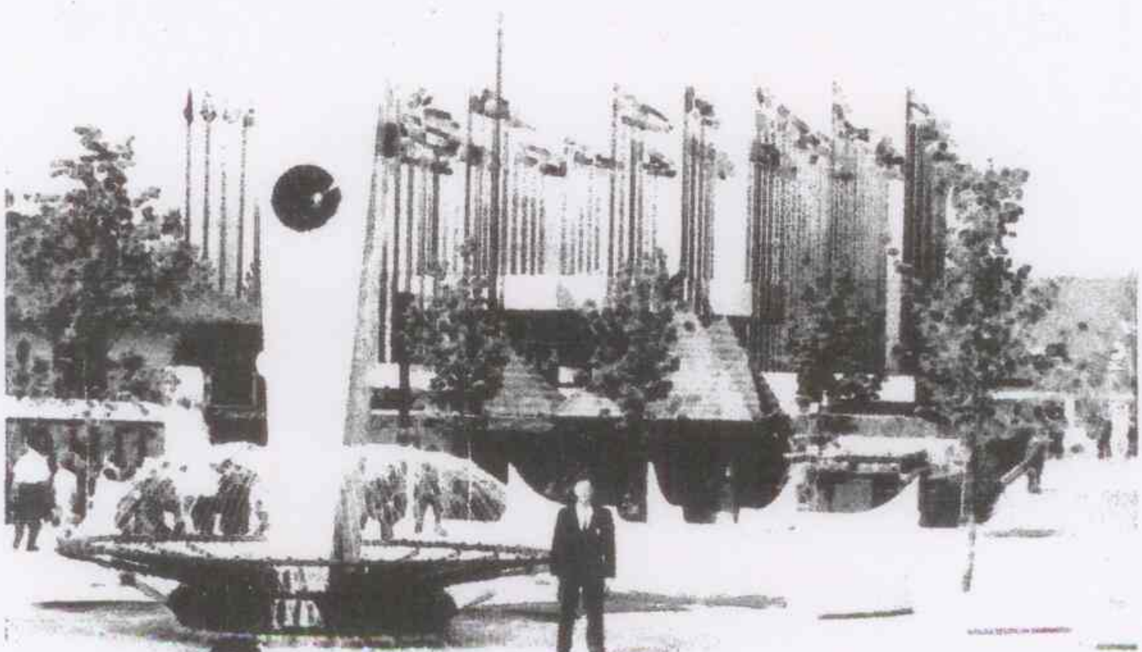
He is a graduate in mechanical engineering and the liberal arts and has held technical, administrative, research and management positions in industry in the United Kingdom and the public service of Canada, from which he retired over 25 years ago.

He became actively interested in the history of engineering on his appointment to chair the first history committee of the Canadian Society for Mechanical Engineering in 1975 and served both CSME and the Engineering Institute of Canada in this capacity for varying periods of time until 2003. He has researched, written and edited historical material for both organizations, as well as for the Canadian Society for Senior Engineers. He is also a past president of CSME and EIC.

From Steam to Space:



Contributions of Mechanical Engineering to Canadian Development



Canadian Society for Mechanical Engineering
1996

Introduction…

From Steam to Space was published by the CSME in October 1996 to commemorate the 25th Anniversary of the Society's founding in April 1970. Date-wise, it was a year late, due principally to the decision to include material originating during the Society's 25th year. Its production took all of four years, and was the responsibility of the Society's History Committee, of which I was chair and - consequently - became the book's editor. In 1993 I was joined by two assistant editors, Mounir Massoud, to look after the French texts, and Anne Moran, to take care of production details. The CSME Board of Directors received regular progress reports and requests for decisions during the years of preparation. The writers were all volunteers. The production costs were met by the Board. To ease the cash flow for these, members of the Society were invited to contribute to a Sponsorship Fund. A small number of hard-cover copies were also printed.

With regard to content, I already had a possible model: the history-based 25th Anniversary commemorative volume of the Canadian Society for Chemical Engineering, published in 1991 and edited by Leslie Shemilt. I decided that the CSME volume should be similar and would have two principal parts: the first to include essays on examples of Canadian mechanical engineering and their contributions to the country's development, along with a history of mechanical engineering education; and the second to include descriptions of CSME's founding, history and activities up until 1995, along with its honours lists.

The next step was to identify specific subjects and potential authors. A call went out to the Society for authors, but none came forward. However, prior to work beginning on the CSME book, there had been a number of papers and articles published in the CSME *Bulletin* or given at the History Committee's seminars that appeared to be suitable for adaptation for the book. For the rest, I approached members of the History Committee and other possible authors and received encouraging support. Suffice it to say that a great deal of my time as editor was spent acquiring, adapting and editing the incoming texts and preparing sub-sections of the book that had to be specially written.

What follows are brief comments on some of the 18 essays that describe mechanical engineering's contributions to Canada's development. I must emphasise 'brief' since this section of the book had over 200 pages. But if something I say appeals, you can always read the full story in the book itself!

To begin with steam…

The first essay in the book is by Larry McNally, on the subject of the steam engine founders in Eastern Canada in the 19th century, a subject you will be hearing more about from Larry himself in this Session. So let me simply quote parts of the introduction and the summary in this essay:

> Mechanical engineers were not the first to do mechanical engineering in Canada. Before they became established as professionals, a variety of craftsmen including mechanics, machinists, millwrights and founders were involved in designing and constructing machinery and mechanical systems such as stationary and marine steam engines, power systems, machines, implements and fittings for locomotives, ships, mills and other mechanical applications…
>
> Through the activities of the Canadian engine foundries (in the early 19th century), it is possible to see the origins of what has come to be known as

> 'heavy engineering' - the custom building of large machines and equipment. The engine foundries had the tools and techniques to fabricate these from smaller cast and wrought iron components...

Steam power came to Western Canada in the 1880s. In his essay, George Ford has this to say:

> The first use of steam traction engines for plowing in the West took place near Regina in 1883 and moved westward with settlement. However, it was soon noticed that the engines intended for plowing had to be heavier, stronger and very solidly constructed. Heavier greasing was also required. The Case 110 hp model was typical of the machines used to break the land...These machines were expensive and required a special knowledge of steam engineering, so that few homesteaders had one and this gave rise to the custom plowman. By 1907 over 400 breaking crews were at work, but as soon as the land was broken the custom plowman began to disappear. The farmer worked the newly broken land himself...

From steam to gasoline...

Heather-Anne Getson describes make-and-break engines as "deceptively simple two-cycle internal combustion engines." Single-cylindered, light-weight and powered by gasoline, their name came from their ignition mechanism. They were nicknamed 'one-lungers' and became the primary source of power for the Atlantic inshore fishing fleet, including Newfoundland, early in the 20th century. Prior to this, fishermen had to row or sail out to their fishing grounds, and row or sail back to harbour at the end of their day. The new engines were also much superior to muscle-power during storms. The less complicated low-voltage ignition system used by these engines was impervious to the damp marine conditions of sea fishing and therefore preferred to spark-plug ignition. Their construction also eliminated gears, cams and valves. They developed between 3 and 6 ½ hp. They allowed the fishermen to "putt-putt" out to their grounds quickly, do their fishing, and return home equally quickly. The fishermen were also able to catch the early market, and could have a second day job in the afternoons, if they wished.

The story goes that these engines could also be used as anchors during storms at sea. The engine was unbolted, the carburetor removed, and put over the side on a long line. When the storm was over, the engine was hauled back on board, drained of water, the carburetor put back, the engine bolted back in place and started again...!

Americans had a lot to do with the development of make-and-break engines, but so had Nova Scotians - for example, Winfred Ritcey, Forman Hawboldt and Daniel and Charles Young. The brand names included *Atlantic, Hawboldt, Fraser* and *Acadia*. Some were still in service in the 1970s.

From gasoline engines to boilers, rock drills...

Babcock-Wilcox Canada could trace its origins to two partnerships and a foundry in the mid-19th century. The Dumfries Foundry was established in Galt, Ontario, in 1844 by partners James Andrews and James Crombie. Andrews left in 1850. By the 1860s, partners John Goldie and Hugh McCulloch Sr. had joined Crombie. The firm by then made steam engines, and fitted up flour, saw and rolling mills. During the succeeding years the company, known for much of this time as Goldie & McCulloch, expanded its product lines to include woodworking equipment, fire engines, water wheels, safes, vaults, pumps, heat exchangers, condensers...and, by 1910, six-drum and other water tube boilers.

In 1923, the American and British Babcock & Wilcox boilermaker companies bought the controlling interest in Goldie & McCulloch, leaving the two families as minority owners, but retaining their names in the new company's title. A.S. Pratt of the U.S. B&W became chairman. Robert McCulloch and Alex Goldie remained president and vice-president.

In 1937, two significant boiler orders were received. The Brompton Pulp & Paper Company of East Angus, Québec, purchased a three-drum Stirling boiler to burn black liquor - a by-product of the pulping process. A similar unit was purchased by Crown Zellerbach for its mill at Ocean Falls, B.C.. These were the first recovery boilers installed in Canada and among the first in the world. To design them, B-W & G-M engineers worked closely with the originator of the recovery concept, Dr Tomlinson of Domtar.

By 1956, the company was supplying steam generators and heat exchangers to the new Canadian nuclear power industry. Babcock-Wilcox Canada was established in 1967, following the retirement of Hugh L. McCulloch as chairman. In 1968 the company's revenues were $25 million. By 1977 these had grown to $140 million. The stimuli for this growth were fossil and nuclear stations such as Nanticoke, Bruce and Pickering and two stations in Israel, the nuclear component having grown from zero to 14 per cent of the total. In 1977, B-W Canada and its American parent were merged with the McDermott Company of New Orleans.

The essay on Canadian Ingersoll-Rand air-driven rock drills was written by members of the academic staff at the Université de Sherbrooke who had connections with the company.

The Eastern Townships of Québec, centred on Sherbrooke, became an important mining area within Canada in the late 19th century. The construction of the CPR to British Columbia around the same time brought about the development of rock drill technology and compressed air systems. Demand for this equipment spurred the Jenckes brothers to found a company to manufacture compresed air machinery at Sherbrooke. But they needed partners with rock drill expertise and found them - the Rand brothers - in the United States. Their company was founded in 1890 and production of the machinery went ahead.

Meanwhile, patents in the same field were being exploited by Simon Ingersoll in the United States and, separately, in Montréal. In 1908, the Sherbrooke and Montréal companies merged their operations and formed the Canadian Ingersoll Rand Company (CIRC). After World War I, CIRC added pulp and paper machinery, mine hoists and braking drums to its production line and undertook its own development work, in association with the Ingersoll Rand Company in the U.S.. Among the products manufactured by the two companies were: single-acting, two-stage air cooled compressors in the fractional to 25 hp range; heavy duty compressors with water-jacketed cylinders; and vertical and horizontal, two-stage, double acting, water-jacketed 100 psi and 125 psi compressors ranging from 125 to 950 hp.

During the 1950s, CIRC developed air-operated vehicles with crust breakers that were used by Alcan to break the crusts of aluminum pots, as well as pipeline compressors and special gas compressors for refineries and chemical plants with horse-powers ranging from 150 to 10,000. They also built components for a line of large V-type natural gas engines with gas compressing cylinders for the IR American company. In the reverse direction, the U.S. company supplied components for CIRC's large, slow speed, two frame, double-acting PRE compressors, centrifugal and axial compressors, gas and steam turbines and jet powered centrifugal compressors.

In 1964, CIRC's facilities were enlarged when those of a U.S.-owned plant in Sherbooke became part of it, increasing the pulp and paper product line. In 1975, CIRC acquired the Canadian Machinery Company of Cambridge, Ontario, a manufacturer of metal-forming presses and foundry grinders.

In 1978 all of the Ingersoll Rand companies in Canada were amalgamated. Following this, the Sherbrooke plant supplied Ontario Hydro with pump unit for its nuclear facilities and built pumps for the Canadian frigate program. It also developed lines of reciprocating high speed air compressors, as well as high capacity centrifugal compressors.

and gas turbines...

Gordon Hardy wrote the essay on the Pratt & Whitney gas turbine engines manufactured at Longueuil, Québec, with special reference to the PT6 turboprop.

The Pratt & Whitney Aircraft Company (PWA) of Hartford, Connecticut established a Canadian subsidiary - Pratt & Whitney Canada (PWC) - which was incorporated as an engine assembly, test and overhaul facility in 1928. During World War II, this company expanded its capabilities to include manufacturing. In 1956, it was decided that, to 'grow' PWC, it would develop and market small gas turbine engines, with some initial help from Pratt & Whitney at Hartford, Connecticut. Hardy writes:

> During the summer of 1957 (a PWC) design team was sent to Hartford to work with U.S. colleagues on design studies for a small gas turbine engine for potential use in the Canadair CL-41 (*Tutor*) trainer, which might also be used in corporate executive jets. Six design layouts were prepared. A simple design, done by the Canadian team, was chosen over the five more sophisticated ones offered by the American teams. It subsequently became the JT12, and consisted of a 9-stage axial compressor, 8-can annular burners and a two-stage axial turbine. It had a compression ratio of 6.5:1, a specific fuel consumption (sfc) of 0.96, and weighed 436 lbs.

However, this engine was developed in the U.S., for American aircraft, although it was used in the early flights of the CL-41 *Tutor*. A turboshaft version, the JFTD12, was used in the Sikorsky S64 *Skycrane* and a marine version, the FT 12, was used for cruise power in the Canadian DDH-280 destroyers.

Around 1958, PWC was discussing the application of what became the PT6 turboprop engine with a number of aircraft manufacturers. Hardy notes that it had a free turbine configuration to allow for a simple and inexpensive propeller to be used, to avoid the problem of high propeller drag which was possible with single shaft engines, to allow for the selection of a wide range of propeller speeds, and to eliminate any clutch requirement for helicopter applications. Its bearing and shaft arrangements were also kept simple. It was decided that the take-off rating would be 500 hp, the compressor pressure ratio 6:1, for an sfc of 0.70 and a turbine inlet temperature of 2170 degrees Fahrenheit. The first complete engine first ran in February 1960. However, it was decided that it was overweight and redesign was completed in July. The first flight of an aircraft with the PT6 as its sole power plant was in 1961, in a Hillier *Ten 99* helicopter. The first of many non-aeronautical installations was in a high speed launch in 1962, and the first turboprop installation was in the de Havilland *Otter* STOL aircraft. However, early in

1962 it became clear that the engine's rating should be increased to 600 hp. This increased the compressor air mass flow by 13 per cent and the pressure ratio to 6.25:1, with a small increase in compressor efficiency.

The early production models of the PT6 were the A-6, the A-20 turboprop, and the B-9 turboshaft for helicopters. All had the same maximum power and temperature capability. The B-9 incorporated a single-stage reduction gear. In 1965, the A-20 replaced the A-6 on the production line. Over the years that followed, several more model series were introduced. For example, the A-40/50 was in the 1200 hp class, with a compressor having a 9:1 pressure ratio and increased air flow and efficiency. The A-41 had a strengthened gearbox, as had the A-45. The A-50 was designed to suit the de Havilland DHC-7 (*Dash-7*), and was certified in 1976. For twin-engined helicopters, the PT6T-3 and T-400 engines were developed, and the ST-6 for marine and industrial applications. The first air-cushion vehicle to adopt this engine was the British CC-7 *Cushioncraft*. Another was developed by Bell Aerospace in 1971. Its *Voyageur* used ST-6 *Twin Pacs* and remained in service in the St. Lawrence from 1972 until 1988. The first turbo trains were equipped with ST-6 engines.

Now to the National Research Council's Division of Mechanical Engineering...

and the essay by Ian Lowe, a past president of CSME, which is the longest (at almost 30 pages) in *From Steam to Space*.

The DME was 'born' in 1936, evolving from the original (1929) Division of Physics and Engineering Physics, in NRC's John Street Laboratories in Ottawa. Its principal equipment included specially designed wind tunnels, a hydrodynamic tank and an engine test laboratory. By 1940, the Division had moved into expanded facilities at the new NRC Campus on Montréal Road. Over the next few years its staff grew from around 40 to around 200, its work devoted principally to supporting the Canadian war effort and to the needs of the Armed Forces. However, DME was also involved in design work that culminated in the operation of the ZEEP nuclear reactor at Chalk River in 1945. It also participated in early work on gas turbine engines, with special reference to their operation in cold climates, and to the solution of aircraft icing problems.

Shortly after the WW II, the Division of Mechanical Engineering was reorganized into eight research sections, plus a flight research section (initially at Arnprior) and a workshop section. The eight were: aerodynamics; hydrodynamics and hydraulics; engines; gasoline and oil (later fuels and lubricants); gas dynamics; instruments; structures; and low temperatures. Since Canadian companies had few R&D facilities in the immediate post-war years, the DME was one part of NRC that built national facilities to help mitigate this problem. Its workshops provided assistance to other divisions of the Council as well as to industry.

Some examples of its post-war work...

The gas dynamics laboratory covered a broad spectrum of research that included work on plasmas, fans, compressors, turbomachinery, heat exchangers and industrial flues and furnaces. A major hydraulic model of the St. Lawrence was built prior to the construction of the Seaway. The Fraser River was also studied, but the model grew so big that it was moved to Vancouver, to the UBC campus. The engine work included studies of industrial, marine and aviation gas turbines. Aerodynamics included studies relating to V/STOL aircraft, cooperation with A.V. Roe in regard to the CF-100 aircraft. The engine laboratory collaborated in the development of the *Orenda* engine, and the structures group examined full-scale aircraft components. In 1950, the aeronautical work had grown to the extent that a separate National Aeronautical Establishment was formed. Several laboratories within the Division worked on problems associates with Canada's cold climate.

In 1971, DME participated in the establishment of an NRC laboratory at Vancouver, contributing initially to tribology research, computer-aided machine tools and CAD/CAM.

In response to the oil crises of the 1970s and to problems of pollution abatement, it added several major environmental projects to its list. It also made extensive use of the new NRC Computation Centre and, in time, developed its own capabilities in the computer field for modelling and other applications.

A new railway Laboratory was set up at NRC's site at the Uplands Airport. The Uplands site was also expanded to include wind tunnel work and a climate engineering facility.

In 1978 the Council formed a separate Division of Energy to manage research funding made available through the federal panel on Energy R&D on behalf of the Council and external R&D performers.

In 1981, NRC expanded its work on hydrodynamics and hydraulics with the establishment of a separate Institute of Marine Dynamics at St. John's, Newfoundland, and constructed an ice tank for studies of ships and shipping in the Arctic.

As NRC's computing facilities and expertise grew, subjects such as computational fluid dynamics - and modelling generally - received DME's increasing attention. As Ian Lowe notes, several DME laboratories not only utilized CFD, but developed unique software that pushed forward the state-of-the-art. It was also used in combustion research programs.

Perhaps the best known of the DME studies of the early 1980s was its participation in technical analyses for the *Ocean Ranger* oil rig disaster. The success of this work led to several other model studies of offshore platforms.

In the 1980s, also, the Division's recently expanded experimental workshops became the Manufacturing Technology Centre and began work, in support of Canadian industry, in areas such as numerically-controlled and electro-chemical machining, heat treatment, laser cutting, advanced CAD/CAM, quality assurance applications, and research into manufacturing processes.

Fiscal year 1985-86 was a watershed for both NRC and DME since it marked the beginning of budget cuts and staff reductions throughout the Council and general retrenchment of their programs. On the other side of the coin, these developments forced DME into closer cooperation with the industries it supported and 'industrial impact' became a criterion for program approvals.

In April 1990, the DME's laboratory sections were reconfigured into six programs: advanced manufacturing, coastal zone, cold regions, combustion and fluids, ground transportation, and machinery and engines. DME itself was renamed the Institute for Mechanical Engineering. At the same time, the activities of the Council's Western laboratory in Vancouver were expanded to include work previously the purview of DME, and was re-named the Institute for Machinery Research.

and to some nuclear engineering...

Philip Ross-Ross, another CSME past president, has three essays in the book - all on engineering problems associated with components of CANDU reactors. I will mention only one of them - on the investigation into the cracking of pressure tubes in Pickering Units 3 and 4.

Canada adopted the pressure tube type of power reactor in 1957. Starting with the NPD-2 reactor in the early 1960s, zirconium alloys were being used for these tubes. Mechanical engineering groups within AECL were tasked with evaluating their performance in service, including their reaction to hot pressurized water, the effectiveness of joints, the testing of spacers, as well as test equipment, inspection tools and the remote handling of radioactive materials. This work was done in collaboration with AECL's metallurgical groups and Ontario Hydro.

The first major crisis in regard to the performance of these tubes arose in August 1974 when water from the primary coolant circuit in the 500 MWe Unit 3 reactor at Pickering was found to have leaked into the gas annulus between the pressure and calandria tubes. These tubes were made from a zirconium-niobium alloy (Zr-Nb).

This essay discusses in detail the background to the use of zirconium and its alloys and the effects on them of irradiation, as well as the absorption of hydrogen, corrosion, fretting, burst testing of tubes to determine their strength, deformation of tubes and susceptibility to failure, cracks and their propagation, and residual stresses. The tests carried out on specific predecessor reactors to Unit 3 at Pickering are also discussed. Eventually, much of the investigation centred on the over-extension of the cold-rolling of pressure tubes into their end-fittings. The culprit turned out to be a little understood problem called 'DHC' or 'delayed hydrogen cracking.' Ross-Ross concludes:

> ...the failure of pressure tubes by DHC is an example of a problem that was slow to emerge, hard to identify and hard to rectify. The overextended rolling (of pressure tubes) was only the trigger in unveiling the real problem, and it was easily corrected. DHC in some ways vindicated the concerns of the metallurgists whose intuition had long told them that the corrosion and hydrogen pick-up were undesirable. DHC also appeared to be an evil associated only with the higher strength zirconium alloys, and cold-worked Zircaloy-2, as used in Pickering Units 1 and 2 for example, would be much less susceptible to it. Zr-Nb used in Units 3 and 4 could, in contrast, be questioned as an appropriate material for reactor pressure tubes.
>
> By 1976 both alloys had seen a reasonable amount of service, and both had been well researched. The decision to stay with Zr-Nb for the later reactors was primarily an economic one.

Now to some biomedical engineering...

Engineers Bryan Finlay and Orest Roy contributed the essay on Canadian engineers' contributions to medicine. In their introduction, they say that the interaction of various disciplines of engineering with biology and medicine has been extremely successful from the point of view of product innovation and development. Devices such as the cardiac pacemaker has been developed, as have new materials for orthopaedics and for dentistry, cardiovascular implants, muscle stimulators, robotics in surgery and technical help for the elderly and disabled.

One of the first formally structured medical engineering programs was at the National Research Council, under Jack Hopps who, himself, made significant contributions to the development of the pacemaker. Important work was also done at the Vancouver General Hospital, led by Jim McEwan, where tourniquet cuffs and micro-processor-based pressure monitors were developed. His groups at VGH and the University of British Columbia were also active in developing robots and other devices for use in operating theatres.

The authors comment that work at Queen's is in the forefront of the development and design of implantable electronic stimulators. They go on to say that these externally-powered RF devices have amazing potential for activating and controlling muscles whose nervous supply has been severed or impaired through trauma or disease. They warn, however, with regard to the establishment of centres that can make a major impact of this technology, and that not all cities can find the financial resources needed to make such centres effective.

Engineers in Canada and around the world have contributed to improvements in the techniques and materials for human joint replacements, of which hundreds of thousands are now being done annually. As the authors note, success in increasing the load-carrying capacities and working lives of these implants in the elderly has led to their increasing use in younger patients. Pioneered by Sir John Charnley in the U.K., notable Canadian contributions have been made by teams at the University of Toronto and at what was once known as the Ontario Research Foundation.

The authors also discuss the development and use of ultrasound devices. They go on to say:

> Further advances on orthopaedic fixation and replacement devices are being achieved with the use of computerized axial tomography (CT scanning). This provides detailed anatomical information on soft tissue structure and density. Under the direction of Aaron Fenster, the Advanced Imaging Group of the Robarts Research Institute in London, Ontario, has developed high-resolution volume-CT devices with a resolution of the order of 100 micrometres...Fenster's group is also using ultrasound to provide 3-D views of internal anatomical structures such as blood vessels.

To meet the needs of the disabled, custom devices need to be built and clinics employ rehabilitation engineers to assess and evaluate patients' abilities and work towards finding the best solution for the individual, applying kinesiology research tools to such problems as head-neck trauma experienced by players. One such clinic is the Hugh MacMillan Medical Centre in Toronto and at research facilities at the Universities of Waterloo and Calgary.

We began with steam...now to aircraft and space...

Gerald Marsters of the National Research Council has written in the book about the history of aeronautical engineering and aircraft production in Canada, covering bush aircraft, the CF-100, the *Arrow*, the various de Havilland and Canadair airplanes, as well as engines by Orenda and Pratt & Whitney and academic training at the University of Toronto.

As to the role of mechanical engineers in aero/astronautics, Marsters writes:

> While statistic concerning the proportions of (mechanical engineers) to other disciplines in the industry are difficult to obtain, one notes anecdotally that the

> proportion of mechanicals is high. In addition, government laboratories such as those of the National Research Council's Institute for Aerospace Research and departments such as Transport Canada's Airworthiness Branch employ significant numbers (of them). Many are also employed in military aeronautics roles, and a high proportion are graduates of the Royal Military College. And it is worth noting that the first degrees of two of Canada's astronaut corps, Bob Thirsk and Chris Hadfield, were in mechanical engineering

Peter Nikiforuk, of the University of Saskatchewan, writes about control systems, including those for space vehicles, attributing the initial development of these systems in Canada to military requirements. One such was the *Velvet Glove* air-to-air missile project, which was started in 1951 at the Valcartier Armament Research Establishment. He goes on to say:

> (It had) a semi-active guidance head, square cruciform wings and control surfaces, a solid rocket motor, a fuse and a warhead. In addition to the various feedback loops that were incorporated into the guidance head, the 'autopilot' consisted of high pressure electro-hydraulic control that were able to control the missile in yaw, pitch and roll. Also typical of that time, low power electrical signals from the guidance head commanded the yaw and pitch controls, while the output of a roll-rate gyro commanded roll control. The application of these signals to what are now called electro-hydraulic transfer valves allowed high-pressure oil to be ported to pistons activating the control surfaces. A number of Canadian companies worked on different aspects of this project...

Nikiforuk also discusses the *Canadarm*, manufactured by Spar Aerospace Ltd. - then, as now, Canada's symbol of excellence in engineering for space. He goes on to say with regard to the arm:

> ...the primary control mode is such that the operator has to consider only the end point required of the end effector and need not control the joints individually to achieve the desired position for releasing or retrieving the load. Despite its apparent size, the *Canadarm* weighs just slightly more than 400 kilograms on earth. Yet it can manipulate cargoes of 30,000 kilograms in space.

Finally, with regard to the future...

...and, in particular, to CSME's Semi-centennial in 2020. I would recommend that the Society considers preparing a second commemorative volume as part of its celebrations. Anniversaries are the occasions on which the engineering profession is in the habit of drawing the attention of wider publics to its history and achievements.

This volume should recognize that changes have taken place within the profession, professional education, and in the Society's activities since 1995. For example, the membership in the Society now appeals principally to academic members; those from industry and government having declined very significantly in numbers. Also, in this regard, there have been advances in the technology of mechanical engineering - robotics, space applications, CFD, mechatronics and nanotechnology come to mind - and some of these have affected teaching content and methods. There have been highlights specific to Canadian industry and governments that might well be discussed in the volume. There may even be historical applications of mechanical engineering not covered in *From Steam to Space*, along with their influence on Canadian industry and society. Lastly, there may be several historical events from earlier years that did not appear in *From Steam to Space* that might advantageously be included in the 2020 volume.

So, good luck with the next book, and thank you for your attention!

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