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Chapter 11

One Hundred Years of Aerospace History in Canada: From McCurdy to Hadfield*

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Abstract

This chapter is a brief synopsis of the history of astronautics in Canada.

I. Introduction

In 1861,William Leitch, a Scottish-Canadian astronomer and the Principal of Queen's University in Kingston, Ontario correctly suggested that rockets would be a viable engine for powering spaceflight. His proposal in the journal *Good Words* explicitly described how rockets, following Newtonian principles, would work more efficiently in space than in the atmosphere, and would outperform any other method of flight. His comment about rocket spaceflight remained in print for more than five decades but it is unknown if his insights were carried forward to future researchers. [Figure 11–1]

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† Apogee Books, Canada.

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§ Commercial Space Blog.

Figure 11–1: William Leitch (circa 1860). Leitch was Principal of Queen's University in Canada and proposed rockets for spaceflight in 1861. Credit: Thespacelibrary.com.

It is generally accepted that the world's preeminent pioneers in astronautics, Robert H. Goddard, Hermann Oberth, Konstantin Tsiolkovsky, and Robert Esnault-Pelterie were all nudged along their historic course by the writings of Jules Verne, and most specifically his serial *From the Earth to the Moon*. Verne's novel about mankind's first space launch holds a special place in the history of the space programs of Europe, Russia, and the United States, all of which within a hundred years had developed space launch capabilities. Since Canada has never had its own orbital launch capability, the student of Canadian astronautics needs to look more closely at the Canadian contributions to its forebears, aeronautics and astrophysics, and also, to a lesser degree, Canada's relationship with early science fiction.

II. Canada and Early Science Fiction

Robert Goddard, the eminent American rocket pioneer, often reported in his diary his affection for science fiction. As well as reading Verne he had also been inspired by H. G. Wells's *War of the Worlds* and its unauthorized sequel, *Edison's Conquest of Mars*. The sequel, written by American astronomer Garrett Putnam Serviss, appeared in a multitude of Hearst newspapers in early 1898 and, in its *Boston Post* iteration, the one which Goddard read, it featured many illustrations of spacecraft drawn by Canadian Pacific railway artist G. Y. Kaufman, making Kaufman one of the first in history to portray a fleet of spaceships. Goddard kept the original newspaper serial and referred to it as late as 1929.

As well as *From the Earth to the Moon*, Jules Verne wrote a novel set in the high Canadian arctic called *The Fur Country*, in which a scientist/astronomer travels to the North West Territories, above the 70th parallel, to study aurora and witness an important eclipse. It seems fitting that as early as 1873, Verne recognized that Canada's high latitudes offered a unique window for studying the sky and atmosphere. Indeed, geography and climate are what have propelled Canada's space program since its inception. [Figure 11–2]

Figure 11–2: Jules Verne's *The Fur Country* in which he sent a scientist to the Canadian arctic to study the sky. Credit: Thespacelibrary.com.

III. Aeronautics and Rockets

Canada became an early contributor to aeronautics when the Scottish born/American citizen/Canadian resident, Alexander Graham Bell, put his substantial personal resources into pioneering aviation. Shortly after the Wright Brothers famous first flight, two Canadians, Casey Baldwin and John McCurdy, teamed up in 1907 with Bell and Glenn Curtiss to form Canada's first cross-border alliance in aviation, The Aerial Experiment Association.[1] These pioneers shuttled back and forth between Hammondsport New York, and Bras d'Or Lake in Nova Scotia testing their designs before McCurdy became the first to fly an aircraft in Canada on February 23, 1909. McCurdy and Baldwin were pioneers in a long line of University of Toronto students who would conduct world-class research into aerodynamics. A little over a year after that first flight in Canada, Haden Herbert Bales of Ashcroft British Columbia patented the first design for what would become known as Jet-Assisted Take-Off (JATO). Bales proposed install-ing a battery of solid fuel rockets behind the center of gravity in an aircraft as a method of last resort if the main engine failed.[2]

In 1915 Glenn Curtiss continued his cross-border work when he set up a flying school at Long Branch, in the western suburbs of Toronto. This would be Canada's first aerodrome, where the Royal Flying Corps would train pilots to fly for the allies in World War I. Many Americans also trained there in the summer months. A little-known footnote to this story is that Amelia Earhart lived in Toronto where she trained as a nurse. She visited Long Branch in 1917 and later admitted that it was because of her time watching pilots at the Canadian National Exhibition in Toronto that she became interested in flying.[3]

Most of the pilots from Long Branch ended up operating from bases such as Eastchurch in England, where they were given a glimpse of the world's first aircraft machine shops, built under license from the Wright Brothers by the Short Brothers. They also were exposed to enterprising aviation stalwarts like Charles Rolls and Frederick Royce and also Geoffrey DeHavilland who tested his early aircraft at Eastchurch. In 1927 DeHavilland Aircraft announced that they would build a manufacturing plant in Toronto.[4] Thus began a triangle of aerospace correspondence between Canada, the USA, and England that continued for the rest of the 20th century.

IV. The Birth of Canadian Astrophysics and Rocketry

Canada's first practical study of space began in 1882, nine years after Jules Verne's book, during the first International Polar Year (IPY). Researchers from England, the United States, and Germany traveled to Baffin Island, Ellesmere Island, and the shores of the Great Slave Lake in the North West Territories (NWT) to study our planet and its weather.[5] These early atmospheric scientists represented the first stirrings of the astrophysics branch of Canada's space history. In 1932 a second IPY would spur a team led by Balfour Currie to set up a research station at Chesterfield Inlet (NWT) to study the aurora.[6] The research begun by Currie and others would set the course for Canada's principal role in space science which continues to this day; the study of space weather and its effects on climate and communications. The 75th anniversary of that first IPY would inspire the International Geophysical Year which of course led directly to the global Space Race competition and the launch of *Sputnik 1*. [Figure 11–3]

While Currie and his team were in the north, conducting high-altitude atmospheric studies, at least one Canadian, had moved south of the border to try his hand at building rockets.

Figure 11–3: Balfour Currie in the 1930s during his expedition to study the atmosphere for the International Polar Year. Credit: Apogee Books.

Lawrence E. Manning was born in New Brunswick and had served in World War I as a second lieutenant in the Canadian Air Force. In the late 1920s he grew interested in science fiction and began a part-time career as a writer of short stories. His fiction appeared in *Wonder Stories*, one of the all-science fiction magazines published in New York by Hugo Gernsback. On April 4, 1930, Manning was invited to the first meeting of what would become the American Interplanetary Society (AIS), a forerunner of today's American Institute of Aeronautics and Astronautics (AIAA) and the spawning ground for one of America's preeminent rocket manufacturers, Reaction Motors Inc.

Also on hand, for that evening of discussion on West 22nd street in New York, were Charles P. Mason, Adolph L. Fierst, Nathan Schachner, Warren Fitzgerald, Fletcher Pratt, William Lemkin, David Lasser, Charles W. van Devander, and the hosts for the evening, G. Edward Pendray and his wife, Lee Gregory Pendray.[7] Almost all of this small group would write science fiction for Gernsback, but they would soon turn their hands to more practical work; the construction of liquid fueled rockets. In April 1933, Manning became President of the AIS and was involved in the implementation of regenerative cooling on their early engines. A month into his presidency he constructed their launching stand at his house and acquired a launch site on Staten Island for the group to use.[8] He also presided the following spring when the AIS changed its name to the American Rocket Society (ARS).[9] All through 1934, he was part of a committee which

included John Shesta, Carl Ahrens, and Alfred Best, for Experimental Rocket #4 which subsequently became the first "really successful launch" of a liquid-fueled rocket by the ARS.[10] Manning was later given a medal by U.S. Vice President Lyndon Johnson and made an honorary lifetime member of the AIAA. [Figure 11–4]

Figure 11–4: Laurence E. Manning Canada's member of the American Interplanetary Society in 1934. Credit: Thespacelibrary.com.

The same year that Lawrence Manning and the ARS flew the ER#4, a fifteen-year-old high school student in Toronto decided to build a methane and oxygen liquid-fueled rocket in the biology lab at Toronto Central Technical High School. His name was Kurt Richard Stehling. When he was nine years old, his family had moved to Canada from Germany, just days before the great stock market crash of 1929.[11] He had spent much of his spare time reading those same Gernsback science fiction magazines to which Manning had contributed. His first experiment in the rocketry field seems to have been a qualified success when the rocket successfully launched out of the classroom window. However, the wind had blown the window shut just before ignition and the young man was disciplined for his unauthorized experiment. His Rocket and Space Study Club came to an abrupt end.[12] [Figure 11–5]

Figure 11–5: Kurt Stehling's high school year book image from the 1930s and an advert for the Canadian Rocket Society from the 1940s. Credit: Thespacelibrary.com.

When war broke out in 1939, Stehling returned to Europe in uniform to fight as part of the Canadian Armoured Corps. He witnessed the onslaught of the V-2 rockets as they fell on London and he was later injured in Holland.

In the post-war period, global aviation research was focused on the next great obstacle, supersonic, and by extension, hypersonic flight. The University of Toronto, where Stehling returned to study, was working with money from the Canadian government to install a supersonic wind-tunnel at a Department of Defence facility in Downsview, a suburb of North Toronto, in close proximity to the DeHavilland plant.[13] This wind tunnel was seen to be the next logical requirement for many of Canada's experiments in gasses, plasmas, and shock waves. Part of this facility was built by two young student geniuses named Gerald Bull and Irving Glass.[14]

The University of Toronto was the first of many institutes and industry partners who would benefit from government largesse. They would conduct ongoing studies in communications; atmospheric research (aurora, plasmas, hypersonic reentry, meteoroids, cosmic rays, fluid flows, aerodynamics etc); and weapons systems; optical and infrared tracking; electronics; mining and resources; remote sensing; instrumentation; tracking stations; ground stations, and sounding rockets.

Whereas the USA and Soviet Union's space programs had been initially funded predominantly for military reasons, Canada's military agenda was quickly superseded by the very real commercial prospects of better communications for the general public in remote communities.

Dozens of universities and corporations would soon get involved in studying the upper atmosphere and most specifically how the Earth's interaction with the Sun and other cosmic radiation sources affected short-wave communications. Canada's unique position of high latitude, as well as being located beneath the shortest route for Soviet missiles to reach the United States (and vice versa), created a political environment where money began to flow into Canada from institutions and governments from around the world, principally for research into the upper atmosphere. The United States would show a particular and understandable interest in how the atmosphere above the arctic affected both communications and the stability and reliability of anything moving at high velocities in the ionosphere and mesosphere.

While government involvement in this research inevitably centered on Ottawa, several hubs of institutional and industrial activity were established, most notably in Toronto, at the University of Toronto, DeHavilland aircraft, A. V. Roe, and York University; in Montreal at McGill University and RCA Canada; and at the Universities of Saskatchewan and of Western Ontario. In later years, British Columbia would also supply substantial industrial and academic contributions to Canada's space program.

V. The Canadian Rocket Society

In 1942 a group of enthusiasts, including Hillel Diamond, a music student at the University of Toronto, created The Canadian Rocket Society (CRS) which was modeled on the German Society for Space Travel (Verein für Raumschiffahrt, or VfR).[15] After the war, Kurt Stehling returned to Toronto where he soon became President and founder of The University of Toronto Rocket Society. In January 1948, Stehling publicly debated senior members of the Canadian astronomy community about the promise of spaceflight, and suggested that with its wide open spaces, Canada should become a leader in long-range rocket experiments.[16] In the Spring of 1948 it appears that these two competing societies merged under The Canadian Rocket Society banner.

Figure 11–6: Captain Edward Fox, chairman of the Canadian Rocket Society in the late 1940s. Credit: Thespacelibrary.com.

The CRS displayed designs for their "C-1" Moon rocket at the Canadian National Exhibition (CNE) in August 1948.[17] Their model was built by 49-year-old Sam Kernerman in his basement.[18] Kernerman died in 2000 at the age of 101 having lived in a world before the Wright Brothers all the way through to the International Space Station (ISS). Other members of the CRS included Captain Edward Cecil Evans Fox (Chair) [Figure 11–6], Kurt Stehling (President), Jack

Bird (VP), Boris Duke (VP), and John Wartman (Director), as well as Gordon Patterson, Dean of Aerospace at the University of Toronto.[19] Chairman Edward Evans Fox was an officer in the Royal Canadian Engineers. A fan of Jules Verne, one of his claims to fame was erecting the steel for the Royal York hotel in the 1920s. In August 1940 he wrote *Navigation for Emergencies* in which he invented new methods for celestial navigation, later used by the Royal Canadian Air Force (RCAF) and the United States Army Air Forces (USAAF). The success of his method even brought him to the attention of King George VI. By November 1946, he had generated so much publicity with his talk of Moon rockets that he appeared on a radio show named "Canadian Cavalcade" (at the time introduced by Lorne Greene.) During an interview, he stated that he expected men to land on the Moon within 20 years, and that he had written an 80,000 word sequel to his navigation treatise, this time for space navigation.[20] In June 1948, in front of a gathering of 100 attendees at the Royal Ontario Museum, he and Stehling outlined the aims of the society. Stehling stated, "We are interested in the peacetime use of rockets, not their development for war. We hope to interest the public not only in the mechanical side of rockets but in their social and economic significance."[21]

That December, the group again appeared in the newspapers with their predictions for a manned lunar vehicle to be built by 1960, costing about $5M, 200-ft high, nuclear powered, and taking four days to make the trip. The CRS attracted J. F. Heard, Chairman of the National Research Council, who spoke to their membership in March 1949 on interplanetary travel. Four months later, Fox took the plans for their Moon rocket to New York where he garnered the attention of the *New York Times*.

At this time, rocketry had become a semi-regular subject at the CNE in Toronto, culminating in the appearance of Canada's only captured V-2. The missile had been deftly spirited away from the British in Germany at the end of the war by a handful of Canadians determined to make sure that Canada not be shut out of this particular technological windfall. The V-2 attracted considerable attention at its only exhibit appearance that summer.[22]

VI. The End of the Canadian Rocket Society

Stehling married a girl from Buffalo New York in 1944. In April 1948, he gained resident status in the USA and in May 1950 he left for Buffalo and a position with Bell Aircraft's rocket division.[23] In 1951, Stehling wrote to James Van Allen and encouraged him to pursue the use of balloons to launch a rocket into space. Stehling understood large balloons, having been involved with them during his childhood in Germany; he also understood rockets, making him a rare breed at that time. Van Allen seems to be universally credited with the original idea of balloon launch, but it had been around since at least the 1930s and would become known as a "rockoon."[24] Stehling and Van Allen soon began a series of tests with rockoons with the University of Iowa.[25]

At the Second International Astronautical Congress (IAC) in London, England (September 3–8, 1951), U.S. Navy Lt. Fred Durant informed the delegates that the Canadian Rocket Society now had over 100 members (apparently making it the fifth largest such group in the west, behind the USA, UK, Germany, and France) and that they might well be interested in joining the newly-proposed International Astronautical Federation (IAF). Of the 13 countries in discussion at the Congress, only Canada (through the CRS) apparently did not commit to becoming a founding member of the IAF.[26]

In November 1951 Stehling attended the Sixth Annual Convention of the American Rocket Society in Atlantic City. He was there to advocate for the establishment of a Niagara ARS chapter due to the wealth of aerospace companies in the Buffalo area. He also stated that his Canadian Rocket Society appeared to welcome a tie-in with the ARS.[27] This proposed merger may have ultimately diluted the activities of the CRS, which seems to have gone into a prolonged period of decline from this point onwards. Canada's only serious rocket society was later resurrected by Hillel Diamond as an amateur rocket club in the 1960s, which in one form or another continues to this day.

VII. Kurt Stehling's Influence and Proposals for Satellites and Launch Systems

In early 1952, DeHavilland UK and DeHavilland Canada set up a Guided Missile Division at Downsview to build the Velvet Glove air-to-air missile. Twenty-four million dollars would be spent on this program over the next three years before it was scrapped in favor of the American manufactured Sparrow missile.[28] In July 1957 the Sparrow would also be canceled, as part of the new NORAD deal to protect North America.[29]

Despite these costly cancellations, the experience gained by DeHavilland's engineers while working on Velvet Glove would serve them well in the following years.

With the cancellation of two missile programs the name of DeHavilland's Guided Missile Division became anathema to the political climate, so the name was changed at Downsview to the Special Projects Division. This small unit of engineers and scientists represented the first seed of what would later become Canada's preeminent center of aerospace engineering.[30]

In 1953, while on short leave from Bell Aircraft, at the James Forrestal Research Center in Princeton, New Jersey, Stehling published a paper in which he described the advantages of using space-borne radar to "paint the surface of the Earth" and transmit the data back to the ground for study.[31] Stehling delivered his paper, titled "Earth Scanning Techniques for Orbital Rocket Vehicles," on January 26, 1953, at a technical session of the American Rocket Society in New York. He compared both optical and microwave systems, concluding that the optical systems at that time had the weight and resolving power advantage, but the microwave radar system didn't rely on daylight or good weather.[32] In the years ahead, space radar mapping technology would become one of Canada's main fortés in space science and astronautics.

In July 1955 Van Allen and Stehling's rockoons would be covered in *Time* magazine. Five months later, Stehling was recruited by the U.S. Navy to work on its proposed Earth satellite program.[33] In 1956, the U.S. government, in conjunction with the Canadian Defence Research Board, announced that rockoons would be fired from ships in Frobisher Bay, and from Fort Churchill Manitoba, and Baffin Island to study the upper atmosphere.[34] Indirectly Stehling was bringing about the very role in space science that he had advocated for Canada back in 1948. He continued his swift ascent in the U.S. space program and would establish a reputation for many progressive ideas, including inflatable space station modules. He was also the first to suggest that women astronauts, given equal training, would make better astronauts both physically and psychologically.[35] Perhaps most important, he also contributed to the establishment of a U.S. national space agency. Stehling was on the Rocket and Satellite Research Panel (along with Wernher von Braun, Krafft Ehricke, James Van Allen, Ernst Stuhlinger, Fred Whipple, and others) which urged U.S. President Dwight Eisenhower in 1957 to form NASA.[36]

VIII. The International Geophysical Year and Churchill Falls

Canada had played an important role in the two International Polar Years, and so, along with many other countries, Canadian researchers recognized the importance of contributing to the proposed International Geophysical Year. In this regard, Canada already offered a convenient vantage point for studying the high northern latitudes and particularly the Earth's magnetic field. Therefore an arrangement was made in 1955 to establish a permanent scientific research establishment at Fort Churchill, with funding provided by the U.S. Army.

The location selected at the mouth of the Churchill River had been used for vital observations as early as 1769, when astronomers William Wales and Joseph Dymond from the Royal Society traveled there to record a transit of Venus across the Sun. Wales and Dymond built two observatories at the Prince of Wales Fort which they used for the event.[37] One hundred and eighty-six years later, the Churchill Research Range came into existence as one of the world's key places for launching sounding rockets to the ionosphere and beyond.

The following year, about 12 months before the launch of *Sputnik 1*, the Canadian Armament Research and Development Establishment (CARDE) commissioned a domestic rocket program which would eventually be named Black Brant. This design and development program was to be undertaken by a Canadian-based branch supplier of components to the Air Force's CF-100 interceptor program named the British Bristol Aeroplane Company. The Black Brant rocket, derived from Britain's Skylark sounding rocket and later upgraded by Albert Fia of Alberta, would be the nearest thing to a space launcher that Canada would develop and over the next decade would become one of the two most expensive programs undertaken in Canadian space research.[38] [Figure 11–7]

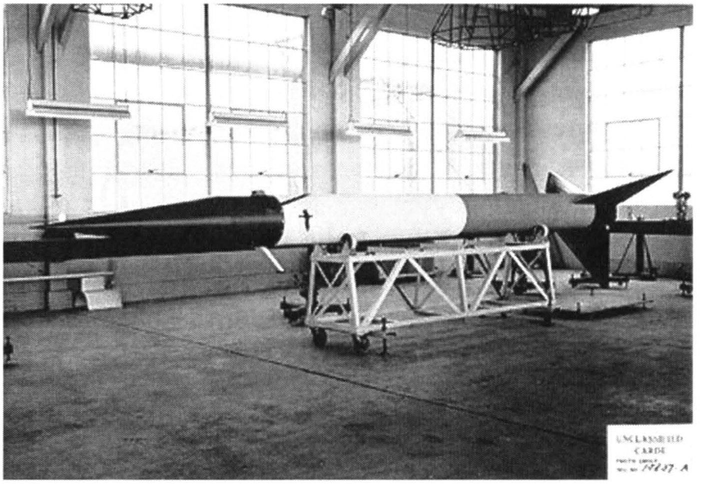

Figure 11–7: The Black Brant 1 sounding rocket. Canada's first serious launch vehicle. Credit: Government of Canada.

The launch facilities at Churchill would quickly evolve and be able to accommodate a variety of medium size U.S.-built rockets including the Arcas, Nike, Apache, Tomahawk, Astrobee, Aerobee, and Javelin, as well as the Canadian built and rapidly evolving Black Brant.

IX. The Canadian Astronautical Society

While things were getting up to speed at Churchill, back at Downsview, Dr. Phil Lapp, an engineer at DeHavilland, recognized the need for Canada to become more involved in the new science of astronautics. Immediately following the launch and consequent political shock of *Sputnik 1*, Lapp arranged for his colleagues at Downsview to start an informal astronautical group which he dubbed, The Canadian Astronautical Society (CAS). [Figure 11–8]

Figure 11–8: The seal and logo of the Canadian Astronautical Society, founded in 1958. Credit: Phil Lapp/The-spacelibrary.com.

The group had their first meeting on January 8, 1958, at the Special Projects office of DeHavilland in Downsview.[39] Over the next two years, many meetings of the CAS took place, usually with invited guest speakers. One such speaker that Dr. Lapp remembered with fondness was his old mentor Dr. Charles Draper, the famed MIT scientist. In 1950, Lapp had earned one of the coveted positions to study for his graduate work at Draper's labs in the United States. One of the first coordinated projects undertaken by Lapp's CAS was their participation in Operation Moonwatch, the Smithsonian Astrophysical Observatory study of the orbits of satellites. Members of the CAS stood out on the cold rooftop at DeHavilland in Downsview during the course of 1958 taking measurements and timings of the overflights of *Sputnik III*, *Explorer 1*, *Explorer IV*, and their various boosters. They published their findings in October 1958.

The CAS also published several other papers, most notably "Project CHARM" (Canadian High Altitude Research Missile) and "Project CLAMP" (Canadian Lunar Antenna Moon Probe), which was a proposal for a sort-of mini Arecibo radio telescope for studying the Moon's surface, to be built in a natural bowl near Guelph, Ontario.

X. 1959 and the Avro Arrow

The year 1959 would prove to be a watershed year in Canada's aeronautical and astronautical research. In January, work began at the Defence Research Telecommunications Establishment (DRTE) in Ottawa, under John Herbert

Chapman, to devise a "top-sounding" satellite for Canada which was designed to record how the aurora and interference from the Sun could lead to short-wave communications black-outs in the remote northern parts of the country. This satellite would bounce radio waves off the ionosphere from above, and would hopefully provide unique insights not available to researchers who were studying from below.

Also in February of that year, the A. V. Roe Company, based in Malton, a suburb of Toronto, was dealt a devastating blow when the CF-105 Arrow interceptor program was canceled. At the end of World War II, Sir Roy Dobson had borrowed $1,000 to incorporate Avro Canada and had also persuaded C. D. Howe, the so-called "minister of everything," to lend him the enormous factory where many Lancaster bombers had been built during the war. By 1957, Dobson's companies in Canada employed 25,000 people and had assets of $120 million. The company was managed by the dynamic and sometimes abrasive Crawford Gordon, who had persuaded the politicians and the military that Avro was capable of building a world-beating interceptor to defend Canada against any potential threat from the Soviet Union. Just as the first aircraft began to trundle off the production line, a new government, under Prime Minister John Diefenbaker, decided that Canada could not afford the extravagance of the Arrow and unceremoniously canceled the program. [Figure 11–9]

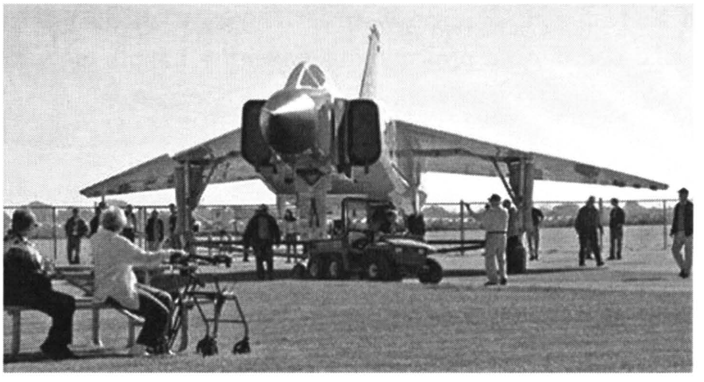

Figure 11–9: A full size replica of the Avro Arrow. Credit: Thespacelibrary.com.

Dr. Phil Lapp happened to be in the Prime Minister's office during one particularly inflammatory encounter between Gordon and Diefenbaker. A few weeks later, on 20 February 1959, Lapp listened in on the telephone as the cancellation announcement came in to Avro. This event became known as "Black Friday" because Gordon immediately announced the lay-off of approximately 13,000 employees.

The consequences of this moment have been discussed in great detail by many of the participants, and also by Arrow scholars, such as Chris Gainor[40] and Randall Whitcomb.[41]

The principle engineer at Avro, James C. Floyd, would soon leave Canada for England, where he would be instrumental in the birth of the Concorde supersonic transport. However, undoubtedly the most significant consequence was the immediate windfall for the newly formed NASA in the United States. Within hours of the lay-offs at Malton, Dr. Robert Gilruth, head of the Space Task Group in Langley, Virginia, landed at Toronto airport and immediately began recruiting the cream of the Avro engineering staff to assist in the recently announced United States' *Man in Space* program. This "brain drain" would ultimately be one of the many factors taken into consideration years later when considering the need for a Canadian national space agency.

The most notable recruits to NASA from Avro were James A. Chamberlin (he became Technical Assistant to Robert Gilruth); Owen E. Maynard and Rodney G. Rose (they went on to NASA's Systems Test Branch, Maynard to head up the lunar lander program); David D. Ewart (Aerodynamics Section); George E. Watts and James E. Farbridge (head and assistant of Loads Section); Eugene L. Duret and Richard B. Erb (Heat Transfer Section); Norman B. Farmer (Electrical Systems Section); Richard R. Carley, Thomas V. Chambers, and Stanley Galezowski (Flight Controls Section); John D. Hodge (Assistant to the Division Chief of Operations); Jack Cohen (Mission Analysis Branch); Stanley Cohn and John Shoosmith (Mathematical Analysis Section); Frank J. Chalmers, Dennis E. Fielder, John K. Hughes, C. Frederick Matthews, Leonard E. Packham, and Tecwyn Roberts (Control and Flight Safety Section); Bruce A. Aikenhead (Training Aids Section); and Peter J. Armitage (Recovery Operations Branch).[42]

As can be seen from this list, NASA's Space Task Group, which had been formed by Gilruth with only 36 people on October 5, 1958, inherited a ready-made team to assist the rapidly burgeoning program at Langley. The Canadians showed up for work at the Space Task Group on April 13, 1959, just three months after McDonnell Aircraft Corporation had been issued the contract to build the Mercury spacecraft and more than a year before the von Braun team would move over from the U.S. Army to NASA. For more than twelve months there were more Canadians than Germans at NASA!

Many theories have been postulated as to why the Canadian government decided to cancel the CF-105 program. But even Kurt Stehling, who had already moved over to the U.S. space program had spoken out a few months earlier against the expensive interceptor.[43] Stehling later admitted that he had chosen to move to the United States because of his frustration with the way funding was limited in Canada. Other engineers, such as Wilfred Dukes, had left Avro even earlier than the Arrow cancellation; lured by the seemingly unlimited funds south of the border. Dukes would write one of the first papers in the United States on hypersonic re-entry[44] and would join Walter Dornberger's team with Stehling at Bell Aircraft in Buffalo in the early 1950s. Duke's knowledge would be integrated into Bell's BoMi, a proposed winged space bomber under discussion at that time. Although Bell would not get the contract (Boeing won the bid and named it the X-20), Duke's know-how would be sought for many years and he would be on the commission to investigate the delays in the Space Shuttle program decades later.[45] Meanwhile, Stehling co-authored a patent at Bell, with famed rocket backpack pioneer Wendell Moore, for the reaction control system which later appeared on the X-15 and would ultimately evolve into the system on the Space Shuttle.

But in 1958, the prevailing attitude was that missiles would replace aircraft interceptors. U.S. President Eisenhower had convinced Prime Minister Diefenbaker to purchase the U.S.-made Bomarc missile. But having agreed to the purchase, Diefenbaker refused to allow the missile to be equipped with nuclear warheads. This led to a further opportunity for DeHavilland's Special Projects Division, again led by Phil Lapp, to sell their expertise in infrared tracking and fuses for the Bomarc. However, when Lester Pearson became Prime Minister in 1963, the nuclear warheads were allowed and DeHavilland was suddenly out of a contract again, since nuclear warheads did not need infrared capabilities.[46]

Towards the end of 1959, DeHavilland's profit margins in the Canadian aircraft division were dwindling. The workforce in Toronto had been reduced from more than 4,000 to just above 2,000. The devastating impact of the Arrow cancellation had left A. V. Roe reeling, and its parent company in England, Hawker-Siddeley, was blindsided in the aftermath. Big changes were inevitable, and on December 18, 1959, Hawker Siddeley purchased DeHavilland. This was a massive takeover, involving $37 million and tens of thousands of workers in factories on both sides of the Atlantic.[47]

XI. Alouette and STEM

A few months prior to the DeHavilland takeover, on 25 August 1959, the governments of the United States and Canada had signed an agreement to build and deploy Chapman's top-sounder satellite. The United States would launch it and Canada would design it and operate it.[48] Later it was agreed that Canada would also build the satellite because of the special needs required by Canadian researchers.

Just a few days after the top-sounder agreement was signed, Lapp's CAS showed off a mock-up of their CHARM sounding rocket at the highly visible Institute of Radio Engineers show at the Canadian National Exhibition in Toronto.[49] That November an entire page of the *Toronto Star* featured Lapp alongside the Dean of MIT and the Chair of the National Committee on Space being interviewed about the prospects of spaceflight.[50]

Chapman had realized that his team at the National Research Council did not have the mechanical design skills needed to build the structure of his proposed satellite, so he turned to Phil Lapp and the team at DeHavilland. Lapp maintains that this opportunity came about mainly due to the public attention that the CAS had garnered in the media.[51]

Lapp and his team at DeHavilland were given the task of building the main bus and the antennae for the satellite, soon to be known as *Alouette*. It was clearly understood that to sound the ionosphere in the frequencies of primary interest to the communications and defense industries would require the use of extremely long antennae on the satellite. No such antennae were available at this time. What was needed was something, light, long, and rapidly deployable.

Chapman and Lapp both knew immediately that so-called "spin-up" would not work to reliably deploy something many meters long. So Chapman suggested that Lapp take a trip to visit George Klein, at the National Research Council in Ottawa, who had developed a roll-up antenna for use on aircraft. Klein had figured out a way of heating a sheet of metal inside a tubular mold to make it emulate the shape. When deployed it popped out like a coiled metal tape measure. Klein had not given any further thought to his invention and had certainly not considered how to make one 22 meters long, which was what would be required for *Alouette*. [Figure 11–10]

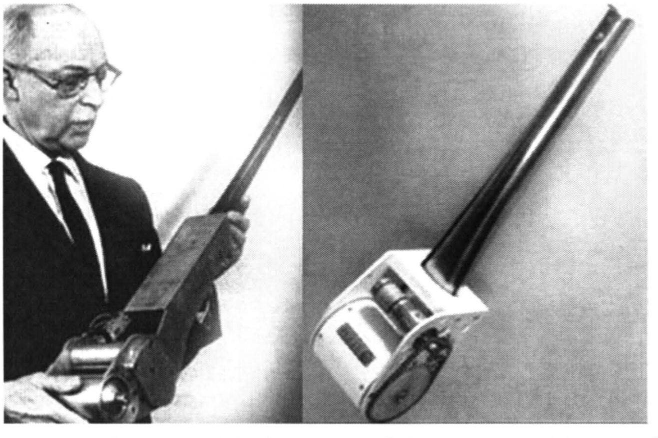

Figure 11–10: George Klein inventor of the STEM with two different STEM antennae. Credit: Government of Canada.

Lapp brought Klein's device back to DeHavilland where the in-house engineers, specifically Ernie Grosskopss, solved the length problem by using magnetic heating and a drawing process to make an antenna of almost any length.[52] The 22-m antenna needed for *Alouette* was now feasible. This device was given the name Storable Tubular Extendible Member, or STEM, and would quickly develop into Canada's most successful space product for many years to come.[53]

XII. The Formation of the Canadian Aeronautics and Space Institute and SPAR

While Canada's first satellite gradually developed on the drawing boards, Phil Lapp decided it was time to make his CAS into a more formal organization. He heard that the Canadian Aeronautical Institute (CAI) was considering adding astronautics to its purview. The CAI had formed in 1954 at Downsview to serve the technical side of the aeronautical community.[54] As a member of the CAI Lapp decided to approach his Board and offer a merger with the CAS. This offer was quickly accepted and in October 1961 CAS merged with the Canadian Aeronautical Institute to form the Canadian Aeronautics and Space Institute (CASI).[55]

Because of the CF-105 cancellation, one of the facilities now underutilized at the Avro Malton airport location, was the A. V. Roe Applied Research division. Phil Lapp had worked there in the 1950s, so when Avro and DeHavilland became one large organization, it was suggested that DeHavilland's Special Projects merge with the Applied Research Division of Avro to form Special Projects Applied Research or SPAR.[56] Once the merger was authorized by the Board, Lapp immediately set about turning the newly devised STEM antennae into a stand-alone business. The remarkably versatile STEM would soon evolve in capability and complexity, and the team would create BI-STEMs, and non-magnetic STEMs, and it would be used for everything from solar panel deployment mechanisms, to space structural elements, masts, a folding tool holder, and most notably, a primitive hand and arm.

On September 29, 1962, *Alouette* was launched from Vandenberg Air Force Base in California. Onboard the satellite were four STEM antennae which, when deployed, reached 45 m across. The main chassis for the satellite had been built and tested at the Downsview SPAR facility. [Figure 11–11]

Canada's first satellite would be launched using a relatively new booster, the Thor Agena B. John Chapman was on hand to watch and noted that the launch was delayed twice, once because an unexpected Southern Pacific fruit train came trundling along the railway tracks a mere 75 meters from the launch pad, and then again because of a faulty abort circuit that suggested that the booster's self-destruct might not work in the case of an emergency. To ensure safety, the tiny village of Surf, California, was ordered to be evacuated until the Canadians and their satellite were safely on their way.[57]

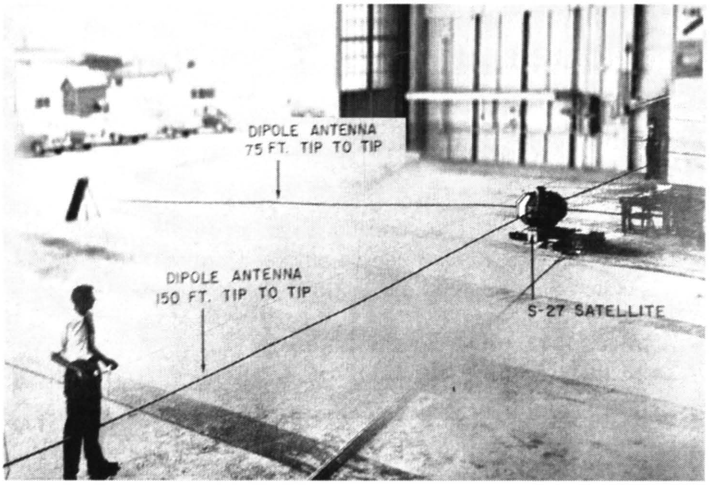

Figure 11–11: The Alouette satellite and its STEMs extended at the De Havilland factory in Downsview Ontario (1962). Credit: Government of Canada.

The launch was successful and Canada became only the third country to put a home-built satellite into orbit (the British had a satellite on orbit but it had been built in the United States.) The staff and management at SPAR were delighted to find out that the STEMs had performed perfectly and *Alouette* soon began to transmit data to the ground stations. [Figure 11–12]

Figure 11–12: John Herbert Chapman awaits the launch of the *Alouette*. Credit: Government of Canada.

All through the previous summer DeHavilland's business had continued to grow for the, as yet, untested STEM antenna. The design had been successfully sold to McDonnell for their upcoming Gemini spacecraft. After *Alouette*, at the very last minute, McDonnell decided they wanted to add STEMS to the last couple of Mercury flights. They would be tested immediately on America's third manned orbital flight, piloted by Wally Schirra.

Just four days after the successful launch of *Alouette*, STEM antennae flew into space onboard *Sigma 7*.[58] In a clear indication of the times, Lapp's team had built and shipped them on an emergency basis, they were installed by McDonnell and flown as a backup to Schirra's main comm-system. Communication was vastly improved by the dipole capability of STEM. Schirra later commented in his debrief,

> When I made HF checks, I'm sure that I was in dipole. I heard all sorts of stuff on the HF checks. I heard people talking all over the world. Frankly, I wasted too much time on other occasions trying to call people back saying I heard you.

One of the little known functions of *Alouette* was also to study the remnants of Starfish Prime, the United States' space detonation of a nuclear warhead, which had taken place the previous July.[59]

Some concern had been raised about launching Schirra into the region where the nuclear test had left a trail of radiation trapped by the Earth's magnetic field. Some satellites were completely disabled by this radiation and indeed the electro-magnetic pulse had caused black-outs in Hawaii. *Alouette* was the perfect instrument to study these artificially created radiation belts.

STEMs soon became integral to Gemini, America's two-man spacecraft, which had revolutionary design features provided by James Chamberlain of Avro. The STEMs for Gemini had to be stronger and more complex so they could be used as recovery antennae, which deployed after reentry, and could withstand the waves in the ocean. STEM was also highly visible on the Agena target vehicle.[60]

The many Canadians from Avro who had taken posts at NASA had now mostly moved to Houston. They were keeping very busy on the Gemini and fledgling Apollo programs. In the spring of 1962, Owen Maynard, one of the Avro Arrow team members was managing the lunar lander office for NASA. In April of that year, Maynard drew up his ideas for a manned lunar landing vehicle. Later that year, Grumman won the contract to build the Lunar Module (LM) and renowned Grumman President Tom Kelly would work closely with Maynard for the next seven years. Kelly's team often referred back to Maynard's original design during their legendary seven-year battle to build the LM. [Figure 11–13]

In 1964, noted Soviet space academician Leonid Sedov visited DeHavilland at Downsview and was given a briefing on STEM. At the time, Dr. Lapp was suspicious of Sedov's motives and found his questions about STEM to be "too penetrating," so he cut the tour short. Despite his sense of unease, Sedov was allowed to leave with a small piece of STEM beryllium/copper as a souvenir.

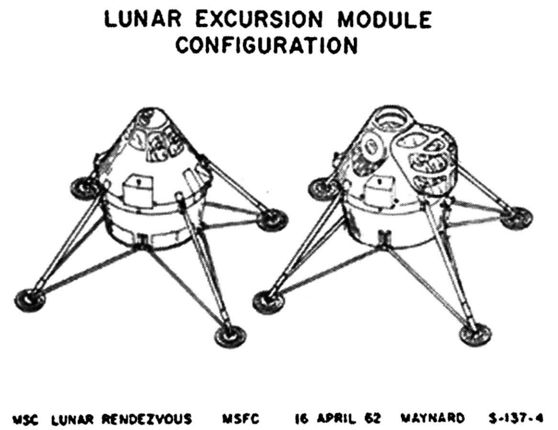

Figure 11–13: Owen Maynard's early drawing of a lunar lander for NASA (1962). Credit: NASA/Apogee Books.

Three years later, Dr. Lapp noticed that Sedov's team had reverse engineered the STEM and they were on display on all of the Soviet satellites at EXPO 67. Lapp later confronted their spokesman (who he felt had been making some unwarranted claims about superior Soviet technology) by pointing out on live television that all of their satellites had Canadian designed antennae.[61]

By the 1970s, thousands of STEMs of different shapes and composition were flying in space. Indeed, STEMs were attached to the early Soviet probes sent to Mars.

Later, STEMs would be installed on the *Hubble Space Telescope* and onboard the Service Modules of the last three Apollo Moon missions. John MacNaughton, VP of SPAR, would later say that STEM is what gave SPAR the influence and leverage to sell NASA on the Canadarm.[62]

XIII. Project HARP

In 1962, responsibility for Churchill was turned over to the U.S. Air Force. This was consistent with the trends in the United States in the early 1960s. The Army's role in missiles was rapidly diminishing. The von Braun missile team had been turned over to NASA on July 1, 1960. From that point forward, missile and rocket launching activities rapidly fell under the purview of the Air Force and NASA.

The schism between the Air Force and the Army over who should control missiles had first happened in Nazi Germany, then in the Soviet Union, and finally in the United States. In the case of the U.S., the Air Force and their contractor lobbyists had successfully pushed the Army out of the missile business. All that was left for the Army was artillery.[63]

While Canada's space program was now following the conventions already laid down by the Soviets and the Americans, at least one engineer had more ambitious plans for Canada.

As early as 1959 Gerald Bull, now a research scientist at CARDE, had entered discussions with the U.S. Army's Ballistic Research Laboratory to build a gun capable of high-velocity space launch capability. By 1962, Bull had moved to McGill University in Montreal and had persuaded the U.S. Army, which was now more-or-less out of the missile business, into financing his design for a gun launch system.

In the summer of 1962, a 16-inch gun, along with its requisite equipment, was transported to Barbados to be installed for test firings. A second 16-inch gun was later shipped to Quebec to be installed near the Vermont border to be used for horizontal test firings, while a third would later be installed in Yuma, Arizona.

Bull had increased his expertise in the field of large caliber artillery when he had helped in the development of the Avro Arrow. Bull had been firing sabots and missiles from Point Petre in Ontario in the mid to late 1950s.[64] He was also involved in the firing of large rockets carrying scale models of the Arrow, many of which landed in Lake Ontario.

Bull's large gun was christened Project HARP (for High Altitude Research Program). By 1966, HARP also had its installation in Yuma Arizona operational where a 120-ft long HARP gun was shooting payloads to altitudes of 180 km. There were not many useful payloads that could withstand the acceleration loads of a HARP launch, which under certain circumstances could exceed 60,000 g's. However, more than one payload successfully transmitted data from space after being launched by HARP. Delicate payloads were out of the question, but one experiment considered perfect for HARP was to explode a canister of dust, just before reentry, to simulate a nuclear reactor breakup in space. This was similar to Project High Water, an experiment conducted the same year, in which von Braun and NASA had exploded a tank of water at high altitude for research purposes.

As early as September 1963, a 3,000-acre solid fuel rocket plant had been established at Rockwood, Manitoba, for supplying rocket propellant to the Churchill launch site. The site was built by Bristol and Aerojet-General for $2 million.[65] U.S.A.F. expertise and money flowed into Churchill where a dedicated team of research scientists continued to launch ever more complex and sophisticated payloads into the upper atmosphere.

The Canadian built *Black Brant IV* would ultimately fly an 18-kg payload to 1,000 km, and it was determined that given a small increase in budget, it could have quickly been upgraded to orbital capability. A large "auroral" launch building was completed at the Churchill site which allowed the scientists to work on their payload while being sheltered from the climate. Black Brant would soon be competing with Bull's HARP for the limited Canadian government funds available. [Figure 11–14]

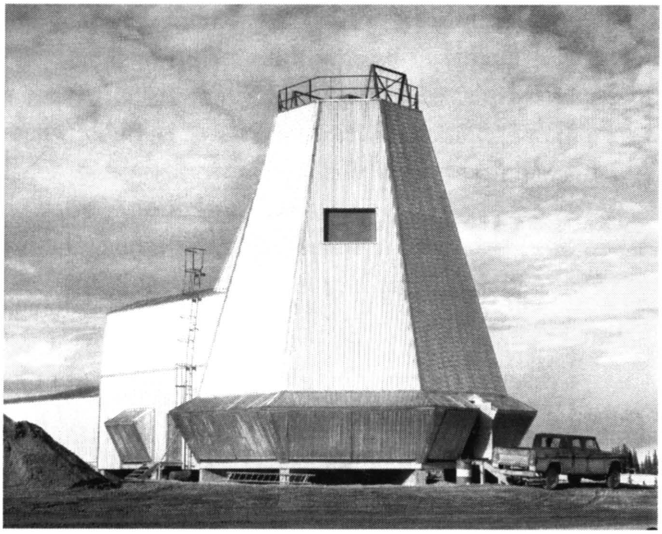

Figure 11–14: The "Auroral" launch building at Churchill Falls Manitoba. Credit: Apogee Books.

Gerald Bull used the media and all of his many intellectual assets to keep HARP's money flowing. Eventually by the summer of 1964 he managed to effectively embarrass the Canadian government into matching the U.S. Army funding for HARP.[66] At this point, the second HARP test site began construction in Highwater, Quebec.

Later in 1964, the Canadian government signed an agreement with the United States to place three more satellites into space, all from the launch site at Vandenberg. This project became known as the International Satellites for Ionospheric Studies (ISIS) and was successfully conducted over the ensuing seven years. The first ISIS satellite was named *Alouette II* and was launched November 29, 1965. RCA Victor was selected as prime contractor with SPAR as an associate. RCA Canada, based in Montreal, defined its role as "space research, satellite work, and Earth based facilities in support of satellites." RCA's checkered history in Canada has a heritage that goes all the way back to 1899 and Emile Berliner, who invented the flat phonograph record and the microphone used in Bell's telephones. Montreal became a nexus for electronics and communications technology, in part because Marconi also set up the Canadian Marconi Company there in 1903. Berliner was bought out in 1924 by Victor Talking Machine Company, which in turn was bought out in 1929 by the quasi-government Radio Corporation of America.[67] The fight over who would control trans-Atlantic communications, Britain or America, certainly spurred the development of the robust electronics industry in Montreal. The century-long battle evolved from cables to radio and ultimately to satellites. In 1977, RCA's Government and Commercial Systems Division was purchased by SPAR.[68] Berliner's factory built in 1920 on Rue Lenoir in Montreal played a major role until RCA closed it down in the 1980s.

XIV. The "Chapman Report"

In May 1966, while on a trip to France, Dr. Lapp was telephoned by John Chapman, who also happened to be in France at that moment. Chapman asked Lapp to meet him to discuss a new study group ordered by Dr. Omond Solandt of the Science Council of Canada (SCC). This study group was charged by the SCC to come up with proposals for the future course of Canada's space program, specifically towards developing policy for space communications, space and upper atmospheric research, and how these activities should be organized and funded.[69]

Lapp and Chapman spent that evening cruising down the Seine while discussing their plans for the future. Lapp later recalled that Chapman entered a singing contest with a group of "lively Australians" and won the day with a rousing version of *Alouette*. The only time he claims he ever saw Chapman "let his hair down."

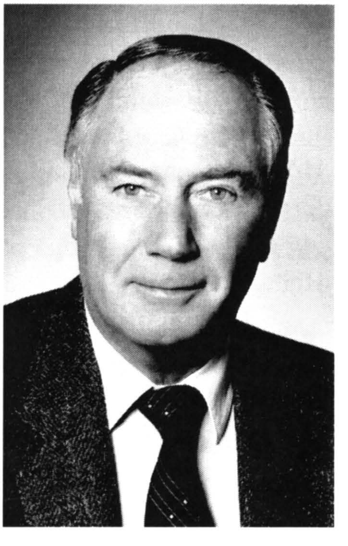

Figure 11–15: Dr. Phil Lapp, chief engineer at De Havilland Missile Division, Co-Founder of SPAR Aerospace, Founder of the Canadian Astronautical Society. Credit: Phil Lapp/Thespacelibrary.com.

The SCC study group included Chapman, Lapp, Gordon Patterson of the University of Toronto, and Peter Forsyth of the University of Western Ontario. Patterson, a U. of T. graduate and ex-member of Stehling's rocket club, had distinguished himself in the 1930s as scientific officer at the Royal Aircraft Establishment at Farnborough. Chapman's SCC group held meetings in eleven cities across Canada for four months in 1966 before heading south to meet with Robert Seamans at NASA and then traveling as far afield as Europe and Japan for consultations.[70]

"The final report was written by individual members of the Study Group and many others from across the country. I wrote Part III, HARP-McGill, the section dealing with Dr. Gerry Bull and his big guns, and the section on the Black Brant program," wrote Dr. Phil Lapp.[71] [Figure 11–15]

By this time, Black Brant and HARP were the two biggest projects in the Canadian aerospace budget. Many contractors around the country were involved, including Heroux of Quebec which made various probes for HARP, and later made the legs for the Apollo Lunar Module.

The SCC-sponsored report appeared in February 1967 under the title "Upper Atmosphere and Space Programs in Canada," but soon became known as simply "The Chapman Report," since that was the way it was described in the follow-up from the SCC, which was titled, "A Space Program for Canada."

The most notable recommendation from the group was the formation of a national space agency. This proposed new organization would be both a national advisory body and contracting agency. This was consistent with a recommendation which had been put forth by The Royal Commission on Government Organization as early as January 1963. Comments from all parts of industry and academia suggested that the consolidation of the national effort was the most useful solution to many of the problems inherent in the various programs underway. Despite this, that particular recommendation would still not be implemented for another 22 years.

One of the most problematic issues was the discrepancy between public and private budgets. At the time of the report, government researchers in Canada received ten times the compensation that their industry peers received.

Universities definitely wanted a national governing space body but they didn't see any use for Gerald Bull's HARP. Most of the experiments that were planned simply couldn't withstand the shock of a HARP launch. Despite Dr. Lapp's opinion that HARP could serve a meaningful purpose, the budget share that Bull had carved out from the Canadian government was simply too high.

Other important recommendations from Chapman's group included staking a claim to GEO locations between 75 degrees W and 115 degrees W for Canadian communications satellites. They also recommended that the government allocate the same percentage of the Gross National Product (GNP) to space as the United States (0.1 percent). Despite lower amounts of GNP allocated in other space-faring countries the Study Group felt that living so close to the United

States would create too much temptation for more of Canada's top scientific minds to move south in search of bigger budgets.

The Churchill Research Range (CRR) and the Black Brant were deemed by the Study Group to be good enough for orbital launches. They recommended that Canada should take over full responsibility for CRR (which they did until closing it in 1985) and that by strapping multiple Black Brants together or modifying the Scout launcher, or even giving Bull more money, Canada could quickly develop its own orbital launch capability. None of these recommendations were followed.

Other suggestions included building a robust satellite industry; changing the allocation of certain frequencies to allow for the possibility of direct satellite television transmissions; a coordinated effort to organize the different university programs; and if necessary in the future, encouraging life science researchers to cooperate with foreign programs.

However, the three most notable recommendations that Olandt took to the Minister were, 1) a national agency, 2) the need for comsats by 1971, and 3) a Canadian satellite launch capability. Of the three, the first two were eventually implemented.

The three sections of the Chapman Report were broken down into history, treaties, and Gerald Bull's HARP. Despite the special attention given to Bull's mega-project, by November 1967 the tide had begun to turn against HARP.

After the Chapman Report was published, Canada's fragmented space efforts continued much as before, with the notable exception of Bull's HARP, which was deprived of Canadian funding at the end of June 1967.

XV. Telesat Canada and UTIAS

In early 1968 SPAR became a publicly traded company. All of the contracts were transferred over to the new company from the SPAR division of DeHavilland. Dr. Lapp was inevitably appointed to the Board of the new company while simultaneously taking on the role of President of CASI. During his tenure as President of CASI, he presented Gerald Bull with the McCurdy Award for his work on big guns and the launching of so many of his Martlet payloads. At the ceremony Lapp dubbed Bull, "Sir Launchalot".[72] Bull's contribution rapidly diminished from this point forward. He left Canada and continued to work on large guns abroad until his assassination in 1990 outside his apartment in Brussels.

The newly minted public version of SPAR elected to move into more varied fields of opportunity including diving equipment, emergency equipment, gearing, foam making, battery chargers (which evolved from the ISIS satellite program) and many other spin-off products.

During 1969, SPAR moved from Downsview to the Avro facility at Malton, Ontario. Progress continued unabated with the ISIS program, and *ISIS-1* was launched in January. Later that year the government put into effect its first full response to the Chapman Report in the form of the Telesat Canada Act, which gave Canada a monopoly to provide satellite communications to Canadians.[73]

The act also stipulated that Telesat must derive goods and services from Canadian industry. This was an attempt to fulfill the other recommendation of the SCC—that Canada should build a robust satellite construction industry. Despite this, Telesat chose to give the contract for Canada's first communication satellite, *Anik-A*, to Hughes Aircraft Company in California. This led to a protracted and highly public debate, wherein SPAR and RCA Canada lobbied to get the decision over-turned. The television publicity over this dispute ultimately led to Hughes Aircraft sub-contracting the space-frame and internal support structures to SPAR. This decision evolved into a windfall for SPAR when Hughes' management realized the capabilities of the SPAR team in the manufacturing arena. Soon, a production line of Hughes satellites went into operation at SPAR. *Anik-A* would be launched in 1972, making Canada the first country to operate a geostationary domestic communications system.[74]

Canada's work in atmospheric science, and the University of Toronto's knowledge about gasses and plasmas, was by this time almost unparalleled anywhere else in the world. This remarkable knowledge came to the forefront in one of the most unexpected ways in April 1970 when the Apollo management team contacted the University of Toronto Institute for Aerospace Studies (UTIAS) to ask for their help solving a problem with the incapacitated *Apollo 13* spacecraft. It was generally accepted that if you wanted someone to figure out what could or could not be expected to happen when gasses, and by extension explosives, expanded, you turned to the team at UTIAS led by Professor Ben Etkin. The team was given a few hours to calculate what NASA could expect if they used the pressure in the tunnel to separate the *Odyssey* and *Aquarius* spacecrafts instead of the usual rockets. Etkin, along with Doctors Phil Sullivan, Irving Glass, Rod Tennyson, Peter Hughes, and Barry French, provided the necessary calculations to help bring the crew safely home. Their efforts would not be recognized until forty years later when they received the Canadian Air & Space Pioneer Award. [Figure 11–16]

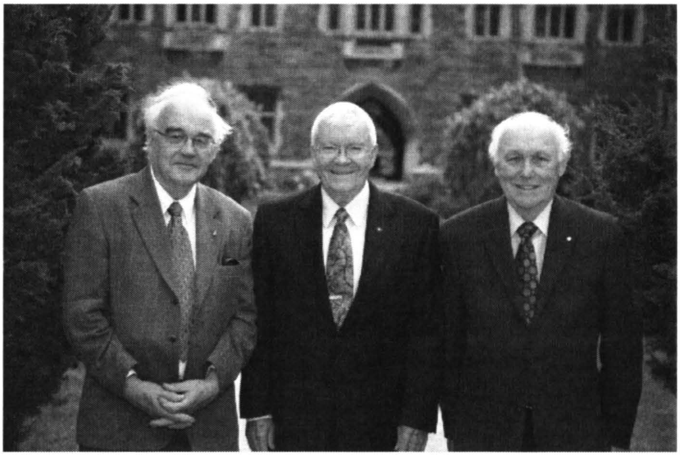

Figure 11–16: Dr. Phil Sullivan (left) and Dr. Barry French (right) of UTIAS with Fred Haise of *Apollo 13* meet for the first time in 2010. Credit: Thespacelibrary.com.

XVI. Direct TV and Hermes

The final ISIS top sounding satellite had been launched in 1971. It was the first built entirely by Canadian Industry.[75] Later that year Canada's Communications Research Centre (formerly the DRTE) had begun work on a revolutionary communications satellite in conjunction with NASA and ESA, called the *Communications Technology Satellite* (CTS). SPAR and RCA would again be contractors on the project. CTS would provide a new kind of direct communication for telemedicine and community television in remote areas. It would have a powerful transmitter allowing for much smaller receivers on the ground.[76] It was launched in 1976 and renamed *Hermes,* becoming the world's first direct-to-home satellite TV relay. The technology was quickly adopted by public television in Ontario, British Columbia, Alberta, and Saskatchewan. Special receiving stations were installed in remote communities to test the new system. *Hermes* would be the first satellite capable of being received by dishes as small as 0.6 m and would lead to the Anik C and D series of broadcast satellites launched in the 1980s by the Space Shuttle.

Later, in 1971, the U.S. government decreed that STEM was so important to American space goals that they listed it as a "strategic" piece of technology and ordered Raymond Engineering in the U.S. to reverse engineer it so that the U.S. wouldn't have to purchase STEMS from Canada. The only solution to this almost existential threat to Canada's top space company was to purchase an American company and license the technology to it. In 1972 SPAR acquired Astro Research Corporation of Santa Barbara, California and STEM production for many American satellites left Canada. Ultimately this acquisition would have an impact on the decision to give Astro the contract, many years later, to build the Mobile Transporter System for the International Space Station.[77]

Throughout the 1970s, the research continued unabated out of the Churchill range. The Canadian Centre for Space Science juggled budgets to keep the science teams in place. Dr. Gordon Shepherd and others pursued hard scientific data in the ionosphere with an aggressive campaign of rocket launches. To be able to study events during solar eclipses, the teams would have to establish launch sites in different locations. In 1974 a decision was made to establish a launch site at Cape Parry in the Northwest Territories to study daytime aurora.[78] In keeping with his apparent knack for predicting important space locations, this launch site was a mere 120 km away, straight across the bay, from where Jules Verne had sent his fictional astronomer/scientist in 1873. [Figure 11–17]

Figure 11–17: Dr. Gordon Shepherd prepares a payload for launch at Churchill Falls (1970s). Credit: Apogee Books.

Dr. Shepherd was responsible for the Black Brant V launched from this location. Consistent with a multitude of other launches this rocket carried experiments from all across Canada including Shepherd's own home-base York University, as well as Environment Canada, the University of Saskatchewan, and the National Research Council, which still represented the main oversight for these events.

The launches at Churchill, and elsewhere, demanded enormous effort from the small teams dispatched to these remote locations. Just a handful of men would prepare the payloads, assemble and fuel the launch vehicle, monitor the environment (often, as in the case of the Cape Parry launches, critical to the success of the experiment), and retrieve the data. These purely scientific launches were soon to be overshadowed by the rebirth of American manned spaceflight, which came in the form of the Space Shuttle program.

A few years later, when a new government came into office, the National Research Council offered to close Churchill as part of the cutbacks proposed at that time. Shortly thereafter, the rockets were silenced in Canada, and the research moved south or west into Alaska.[79] [Figure 11–18]

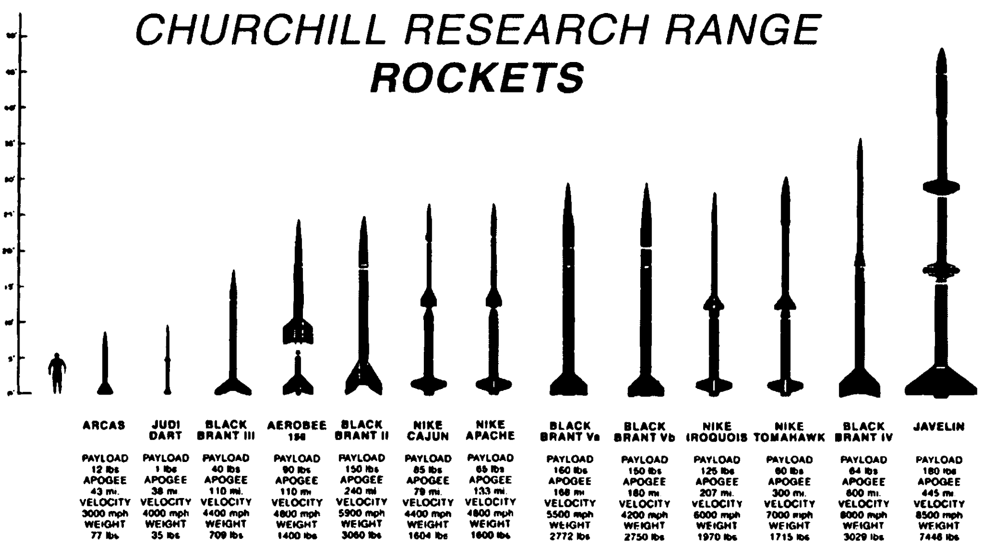

Figure 11–18: A chart of launches from Churchill Falls. Over 3500 launches took place there before it was closed down in 1985 for budget cutbacks. Credit: Apogee Books.

Scientists throughout government and academic research facilities, including Shepherd, now turned their attention to creating experiments that might fly onboard the Space Shuttle. This new orbiting manned space laboratory offered entirely new opportunities throughout the aerospace community; a fact not missed by Phil Lapp and the team at SPAR.

XVII. SPAR, Robotics and Canadarm

The story of SPAR's evolution into the world's leading purveyor of space robotics begins once again with the STEM. SPAR's management had been looking for other applications for STEM beyond its most popular use as a long antenna. Dr. Lapp later wrote,

> One of the applications had been as a miniature steam shovel or backhoe. Wires were run down the centre of the STEM tube and attached to a gripper or shovel at its tip. This could then be used to take samples for analysis or Earth return. A rudimentary unit was used on the Surveyor spacecraft that

went to the moon in advance of Apollo. Clearly this was a precursor to the arm on the shuttle.[80]

One of the principle uses for robotic arms at this time was to handle nuclear elements such as hot fuel rods. The United States had even built an enormous armed vehicle called "The Beetle" for just this purpose on the Project Rover nuclear rocket engine program. By 1972, Canada was at the forefront of nuclear reactor design and Atomic Energy of Canada had issued contracts to SPAR to make STEM devices for assisting in fueling CANDU (CANada Deuterium Uranium) reactors. Phil Lapp recorded that the "Cartesian" approach of using X and Y controls for these handling devices led to the anthropomorphic arm on the shuttle.

When the Space Shuttle program first began to evolve in the United States, the consideration of costs was paramount and it was decided to defray some of these costs by inviting international partners to the table. A Canadian firm named Dilworth, Secord and Meagher (DSMA) had been at the root of the CANDU rod handling system and they approached NASA to consider their ideas for the proposed orbiting space telescope then under consideration. Because DSMA had no manufacturing capability they approached Dr. Lapp about having SPAR take on their construction work. As the project evolved, John MacNaughton, VP of SPAR, persuaded the National Research Council that Canada should also bid on an arm for the shuttle system. SPAR would be prime contractor, RCA would do the electronics, CAE Industries would come in to handle simulations and human factors, and DSMA would handle the test equipment.[81]

Despite NASA having invited this foreign involvement in the shuttle, American industry was dead set against the idea and began to lobby Congress to shut Canada out. In the end, MacNaughton had to fight fire with fire and hired a lobbying firm to work on behalf of SPAR in Washington. SPAR ultimately prevailed, and work began on the arm project in the early 1970s.

Pressure was enormous on the SPAR team, which was expected to deliver cutting-edge technology in time for a drop-dead date for first launch, while simultaneously keeping the Canadian government happy by evolving the spin-off businesses for Canadian industry. SPAR met almost all of their goals on time, including passing a critical design review by NASA in 1978. While the details seemed to all be in order, some very big questions fell through the cracks. For example, towards the end of development, NASA thought they were only obliged to buy two arms from SPAR while SPAR thought it was four. Then an argument ensued over who would pay the duty at customs and whether the arms were even liable for duty since they would be leaving the country! NASA did not want to pay the tax, which on a $15 million arm was substantial. However, many of the components for the arm had been made in the United States in order to placate U.S. industry into allowing Canadian involvement. The Canadian government agreed to waive the duties on those American parts, which left NASA to pay the duties on the rest of the arm that had originated in Canada.[82]

Needless to say, these problems were resolved and the Remote Manipulator System, nick-named the Canadarm, flew into space in 1981 and continued to provide stellar service to Space Shuttle crews for the next thirty years.

XVIII. Seasat and RADARSAT

Kurt Stehling had been extremely busy since relocating to the United States in 1950. At the IAC in 1953, he had again proposed the use of radar on a satellite to study the Earth's surface.[83] He went on to write a white paper on a project which would later become known as *Seasat*. This project proposed the use of radar altimetry for monitoring ocean currents and resources. This was a subject already of keen interest to Canada. Mapping the high arctic in detail was of considerable importance to the government and to resource industries. By 1966, Stehling was working with U.S. Vice President Hubert Humphrey in an organization which was the precursor to the National Oceanic and Atmospheric Administration (NOAA), where he wrote more papers promoting the concept of a radar satellite to study the ocean and sea ice. When *Seasat* launched in 1978 it was the first satellite to use Synthetic Aperture Radar (SAR), and it unveiled the topography of the ocean for the first time. Despite the unanticipated early shutdown of *Seasat* and the tantalizing initial results, NASA decided not to launch *Seasat-2*. The Canadian Working Group on Satellites and Ground Station Engineering decided that Canada should take up the challenge of building the next generation of radar equipped satellites.

In 1980 an office was established to house this project. Government approval seems to have come quickly and the contracting companies were SPAR (again thanks to Phil Lapp's ability to strip down the proposal to something affordable), COM DEV, and MacDonald Dettwiler and Associates (MDA), which would handle the synthetic aperture radar data. This project would evolve over the next fifteen years during which time many things would change, not least being the passing of the Canadian Space Agency Act, which finally gave Canada its own central space agency.

Now christened *RADARSAT*, this new satellite would operate on some of the principles already well understood from the *ISIS* and *Alouette* top-sounders. Certainly the wavelengths were different, but the principle of reflecting an electromagnetic wave down from above was in keeping with many of the things in

Canada's aerospace repertoire. *RADARSAT* would become a staggeringly expensive undertaking for a country as small (economically) as Canada, but was considered essential for a country so large (geographically). The rewards from a successful mission would quickly become self evident. Dr. Gordon Shepherd, who had done such sterling work at Churchill, later became one of the principle scientists involved with *RADARSAT*. Despite early estimates of $279M to build it, Shepherd estimated that the total budget came in closer to $620 million which was spread around 100 international and Canadian organizations. About 80 percent of that money came from the Canadian Federal Government, which gives some indication of the importance attributed to the mission.[84] The SAR system developed for *RADARSAT* used a unique system of multiple beams with variable resolution, and was the result of eight years of research by government agencies and Intera Technologies of Ottawa.[85]

XIX. COM DEV and MDA

SPAR's partners on *RADARSAT*—COM DEV and MDA—would both play substantial roles in Canada's space engineering future. COM DEV had been founded by Valentine O'Donovan, an Irish immigrant who had worked at RCA in Montreal. O'Donovan had invented a new type of microwave multiplexer. He and several partners established COM DEV in Dorval, Quebec and quickly built a company with a global presence, claiming to have hardware onboard 80 percent of the world's communication satellites. In 1974, their first contract was to provide microwave components to *SATCOM 1*. In April 1979, Donovan announced his intention to move the company and its 100 employees to a four acre site in Cambridge, Ontario. In 1985, in their first bid to get involved with the newly proposed space station, COM DEV offered to build a debris detection radar.

COM DEV was subcontracted by SPAR to contribute to the *European Remote Sensing Satellite* as the supplier of microwave components. Later that year, despite some multimillion dollar contracts, the company was forced to lay off dozens of employees, in part due to a downturn in the industry. By the early 1990s, COM DEV still received contracts from the government, but they started to shift their focus from project-driven to product-driven. By 1996, COM DEV had partnered with Motorola to mass-produce components for the new low-altitude satellite constellation named *Iridium*. This rapid turnover allowed the company to develop a commercial production strategy it had previously been lacking. By 2013, their sales were $216 million, with approximately half the sales public and half private. They also received their biggest contract that year,

$65 million, to provide microwave switchers and multiplexers for a fleet of comsats.

MDA was formed in Richmond, British Columbia, in 1969 by John S. MacDonald and Werner Dettwiler. Like Lapp, MacDonald had received part of his education at MIT. Dettwiler was a Swiss immigrant who earned his degree at the University of British Columbia. In 1971, MDA gained a small government contract to supply components to a ground station in Prince Albert, Saskatchewan. The $10 million facility had been opened in June 1959 by Prime Minister Diefenbaker. As a publicity stunt, Diefenbaker and President Eisenhower had used the 25 m dish to bounce a greeting to each other off the surface of the Moon.[86] In 1974, MDA was awarded a $1.3 million contract by the Federal government of Canada to build a full prototype ground station for receiving data from weather satellites being operated by NASA, and outputting the data to imagery or computer tape.[87] All through the mid-1970s MDA concentrated on the impending digital revolution, hiring software and computer engineers. By the late 1970s, MDA was exporting world-class processing facilities for Landsat data to places as far afield as, Brazil, Iran, Sweden, Italy, Hong Kong, and Australia. [Figure 11–19]

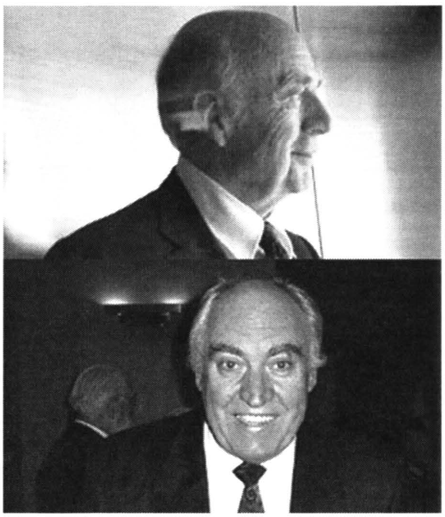

Figure 11–19: John MacDonald and Wernher Dettwiler, co-founders of MDA. Credit: MDA.

By 1978, MDA employed 100 people, with no manufacturing capability, and had sales of $5.5 million.[88] MDA moved into other technologies including Synthetic Aperture Radar and computerized flight planning systems. In 1978 they produced the first digital image using the SAR data from *Seasat*. In the early 1980s, the company would have financial difficulty due to over-spending on a job, but found financial support from various venture capital companies, as well as the government in Ottawa, and Swissair. In 1985 they garnered their first contract with the European Space Agency to provide a SAR system for the European Remote Sensing Satellite. Sales that year were $26 million and they employed 450 people.[89]

In 1987, when SPAR became a prime contractor for Canada's involvement in the ISS, MDA was brought on board to handle software needs. That same year was also when SPAR and MDA combined forces on *RADARSAT*, with MDA providing the SAR data processing.[90] In July 1992, the shareholders of MDA rejected a $50 million buy-out offer from SPAR. However, in September 1995, MDA was sold to Orbital Sciences Corporation in Dulles, Virginia for $67 million. Although the process was approved as a merger rather than a straight takeover MDA became a wholly owned subsidiary of Orbital.[91] In March 1999, MDA purchased SPAR's robotics division, and with it the Canadarm contracts.[92] That same year, Orbital sold its interests in MDA.

MDA would go from strength to strength, acquiring other companies with skills in robotics and sensing. By 2008, MDA had its hands in insurance, land titles and mortgages, and was allocated almost half of the CSA budget, with contracts worth $430 million. Alliant Techsystems Inc. (ATK) of Arlington, Virginia attempted to purchase MDA but the takeover was blocked by the government in Ottawa. A schism developed between the original founders, with MacDonald issuing dire warnings that MDA wouldn't survive if it couldn't penetrate the veil of U.S. government contracts, while Vern Dettwiler expressed his desire that the company not become an arm of a foreign defense contractor. The government held fast on its decision and the deal was stymied. However, only four years later, MDA purchased Space System/Loral for $875 million, transforming John MacDonald and Vern Dettwiler's little start-up into a global giant in space technology.

In 2005 work began on a replacement and upgrade to the *RADARSAT* that had been on orbit since 1995. In 2007, *RADARSAT-2*, built by MDA, took over, but a new *RADARSAT* constellation is now slated to fly in 2018. This will consist of at least three, and possibly as many as six, *RADARSAT*s, designed to keep a close eye on Canada's northern waters.

XX. Canadian Astronauts

Long before the establishment of a national space agency, Canadian astronauts began training to fly in space. On July 14, 1983, the National Research Council placed an advertisement in newspapers inviting candidates to apply for a position as an astronaut to fly aboard the Space Shuttle. Over 4,400 people applied and six were selected. A second group of three was then added nine years later. Dr. Marc Garneau was the first Canadian selected to fly, aboard STS-41G, the thirteenth shuttle mission, on October 5, 1984. Garneau was aboard as a payload specialist and would be involved with a synthetic aperture radar experiment placed in the cargo bay and aimed down. This mission helped to reinforce the value of SAR for studying the Earth. Garneau also conducted two atmospheric experiments as well as eight other Canadian-derived experiments. He would also be the first Canadian to work with the Canadarm system in space. [Figure 11–20]

Figure 11–20: Canada's first six astronauts. (left to right) Dr. Ken Money, Dr. Robert Thirsk, Dr. Marc Garneau, Steve Maclean, Dr. Roberta Bondar, and Bjarni Trygvasson. Credit: NASA/CSA.

Due to the *Challenger* accident in 1986 another eight years would pass before a Canadian would again fly in space. This time Dr. Roberta Bondar became the first Canadian woman in space aboard STS-42 in January 1992. Dr. Bondar would be a payload specialist for the first mission of the International Microgravity Laboratory, which carried experiments from over 200 scientists in 16 countries.

Steve Maclean would follow Dr. Bondar into space in October of that year; flying aboard STS-52. Dr. Maclean conducted the CANex-2, which was a package of seven experiments in technology, materials processing, and life sciences. Dr. Maclean would return to space in September 2006 aboard STS-115, during which he would be the first Canadian to operate the Mobile Servicing System (MSS) aboard the International Space Station.

XXI. Canadarm2

Work on the MSS, later known as Canadarm2, had begun at SPAR in 1985, when SPAR had contracts to supply parts and end-effectors for Canadarm to NASA. The Canadian government then contracted SPAR to put its expertise to good use in creating Canada's contribution to the multi-billion-dollar International Space Station. The Canadian government would spend about $1.5 billion on the ISS program.[93]

Canadarm2 was to consist of several components, including the Mobile Servicing System (MSS), the Mobile Base System (MBS), the actual arm, known as the Space Station Remote Manipulator System (SSRMS), and the hand, or Special Purpose Dexterous Manipulator (SPDM), affectionately known as "Dextre." [Figure 11–21]

Figure 11–21: Dr. Dave Williams on the end of Canadarm2 during a mission to ISS. Credit: NASA.

Canadarm2 would be launched into space in April 2001 and was able to handle loads up to 116,000 kg. The MBS would provide the base for the arm and would be built in California by the SPAR subsidiary, Astro Aerospace. It was launched in June 2002. Six years would then pass before Dextre would complete the system, being launched in March 2008.

All of the Canadarm2 system would be launched after SPAR's robotics division had been purchased in 1999 by MDA.

XXII. The Demise of SPAR

SPAR had gone through a long period of expansion and growth during the 1980s and early 1990s. Their collaboration with Hughes Aerospace had resulted in a string of satellite successes including the ANIK series, the Brasilsat series, and the revolutionary MSAT built for TMI Communications & Company Ltd. of Ottawa.

However, at the end of 1993, the Board had elected to give more autonomy to the four separate sectors of the company, removing some of the immediate decision making from the executive management. By 1995, Space represented only 41 percent of SPAR's total revenue, the rest being divided amongst Communications, Aviation, and Defense and Informatics.[94]

At one point in the early 1990s, it appeared that SPAR might purchase MDA, which was itself struggling at that time; but MDA resolved their problems and soon the restructuring of SPAR's internal processes began to cause problems for Canada's top aerospace company. By 1996, the problems became evident when sales dropped by $25 million over the previous year and their share price dropped by almost half. Many of the problems had stemmed from the SPAR Comstream Division in California which was expected to go public, but then lost its primary customer.[95]

Between January 1998 and March 1999 an assortment of purchases and sales led to the deconstruction of SPAR Aerospace, including the aforementioned purchase of the robotics division by MDA. Hawker-Siddeley had already sold some of the fragments of Avro to Magellan Aerospace in 1995, including the Orenda engine plant. Two years later, Magellan also added Bristol Aerospace to its portfolio of companies, elevating them to the fourth largest aerospace company in Canada behind SPAR, Bombardier, and CAE Industries.[96]

In early 2000, just before the successful launch of Canadarm2, SPAR would finally be reduced to nothing more than a service company to the aviation industry, thus ending perhaps the single most important story in Canadian space industry. Dr. Lapp noted: "SPAR, before its deconstruction, became a huge unmanageable conglomerate with so many moving parts that it became impossible to control effectively."[97]

The STEM, however, continued on unabated. Astro Aerospace, the California based company that SPAR had purchased to circumvent the U.S. Congress, is currently a division of Northrop Grumman. The STEMs built there are slated to appear on the multi-billion-dollar James Webb Telescope.

Despite this serious blow to Canada's aerospace engineering capacity, the space program, now firmly centered on the CSA in Quebec, continued onwards in many areas. The most highly visible aspect, of course, was the continuing presence of Canadian astronauts aboard the Space Shuttle and ISS.

XXIII. More Canadians in Space

Steve Maclean would retire from the astronaut corps and would later assume the role of President of the Canadian Space Agency. His original back-up for his first mission, Bjarni Tryggvason, would fly in August 1997. Dr. Garneau would return to space twice more, once in 1996 and again in 2000, and would also take on the role of President of the CSA before being elected as a Member of Parliament. Julie Payette would become Canada's most traveled female astronaut with flights in May 1999 and again in July 2009. Robert Thirsk would fly on STS-78 in 1996 before becoming Canada's first member of an ISS Expedition crew in May 2009. Dr. Thirsk would establish a new record for long duration spaceflight for a Canadian, before returning home aboard a Russian Soyuz.

Dafydd Rhys "Dave" Williams flew twice, once in April 1998, during which he conducted many medical experiments with the Neurolab. He then returned to space in August of 2007 and conducted three spacewalks, assisting in the construction of the ISS. After return to Earth, he became the first foreign national to assume a senior management position at NASA's Johnson Space Center.

Dr. Ken Money had the longest standing relationship with the space program, having consulted for NASA as early as the Mercury days in 1962. He was selected as one of Canada's first astronauts but never flew in space, returning to the private sector in 1992.

Finally, Dr. Chris Hadfield would fly in November 1995 and again in April 2001. From 2001–2003, Hadfield was the Director of Operations for NASA at the Yuri Gagarin Cosmonaut Training Center in Star City, Russia. From May 10–23, 2010, Hadfield was the Commander of NEEMO 14, a NASA undersea mission to test exploration concepts while living in an underwater facility off the Florida coast. Hadfield would be the only Canadian to board the Russian *Mir* space station. He would also be the first Canadian to operate the Canadarm in space. He installed the Canadarm2 system onboard ISS becoming Canada's first space walker. In 2013, he launched to ISS aboard the Soyuz TMA 07M, to join Expedition 34. After three months, he took over as Commander, becoming the first Canadian to command a spacecraft.

As Canada's most traveled and experienced astronaut, much was expected of Hadfield, who certainly did not disappoint. During his command of ISS Expedition 35, Hadfield created a media storm with the regular transmissions to Earth of his daily activities, which included recording a David Bowie song and video while in space.

In January 2001, Geoff Sheerin, an Ontario based engineer, announced his plans to build a modern version of the infamous V-2 missile. Sheerin re-imagined the single-engine rocket as a vehicle for space tourism. Over the next three years his team worked around the clock to construct a viable entry in the X-Prize competition, which they named the "Canadian Arrow." Incredibly Sheerin also set about building his own rocket engine capable of boosting a passenger into suborbital space. By July of 2002 Sheerin successfully fired a 57,000 lb liquid fueled rocket engine, the largest ever built in Canada. In August of 2004 his team conducted a successful drop-test of their crew-cabin into the waters of Lake Ontario. Unfortunately when *SpaceShipOne* won the X-Prize in October 2004, the funding dried up for Canada's most ambitious attempt at a manned space program.

Despite the termination of Sheerin's noble efforts Canada's astronaut story continues, with two more recruits added to the CSA program in 2009, David Saint-Jacques and Jeremy Hansen. While they wait for the next generation of spacecraft to be built, Canadian space science continued onwards. *Scisat*, launched in 2003, was placed in orbit specifically to monitor stratospheric ozone levels, while *MOST*, a micro-satellite, became Canada's first space telescope, looking up instead of down. Meanwhile, a device perfected at York University in Toronto discovered snow falling on Mars.

XXIV. LIDAR and Snow on Mars

According to Dr. Gordon Shepherd this particular success of Canadian technology begins at RCA in Montreal in the late 1960s. Allan Carswell left RCA to join the faculty at York University in Toronto. Carswell immediately applied his knowledge of lasers and microwaves to the burgeoning atmospheric science department at York. Specifically, he began to look at LIDAR as a possible candidate for studying atmospheric movements, density, and disturbances. As the team at York developed ever more sophisticated uses for LIDAR, Carswell recognized a commercial opportunity. In 1974 he formed a company he named Optech, which rapidly grew into the leading LIDAR company in the world. In 1999, the Jet Propulsion Laboratory approached Optech to provide a LIDAR instrument for one of their proposed Mars landers. Over the next few years, the involvement of Canadians in what would become the *Phoenix Mars Lander*, expanded rapidly, despite some ups and downs caused by the loss of an earlier Mars mission. By 2001, Optech and York University worked studiously on developing both the technology and the proposals for sending a Canadian LIDAR weather station to Mars. In the summer of 2003, the University of Arizona's Peter Smith received news that his Phoenix mission would go ahead. It would be launched in 2007. In September 2008, shortly after landing on Mars, the LIDAR recorded snow falling on another planet.[98]

Although the media had some fun with the idea of Canadians being the first to discover snowfall on another world, as can be seen by the preceding short history, there was inevitability about this. Canada is the home of the world's leading space weather researchers. Canada's space program, from the very beginning, has been concerned with the environment.

XXV. The Emerson Report and Canadian Military Satellite *Sapphire*

In November 2012, a federally-appointed commission on Canada's space future delivered its results to the government. In stark contrast to the Chapman Report, which concentrated on the programs at hand and had steered Canada's official space program for 45 years, the Emerson Commission's report concentrated on policy. The eight recommendations in the executive summary made no mention of any specific program or hardware.[99] The days of giant cannons and isolated rocket research centers were a thing of the past, replaced by budgets, advisory councils, and the politics of international competition.

In 2013 MDA and COM DEV teamed up with the Canadian Air Force to build the first Canadian military satellite, named *Sapphire*. Designed to monitor and track space debris, it was also the first major Canadian spacecraft to be launched by the Indian Space Research Organisation, ISRO.

In February 2014 the government of Canada announced that it would provide more funding to the CSA, but with the proviso that more of Canada's space efforts be undertaken by the private sector. This announcement was met with cautious optimism by the official opposition spokesman, Dr. Marc Garneau. The future of Canada's space program continues to be as unpredictable as that of its southern neighbor.

XXVI. Conclusions

As can be seen Canada's space history is inextricably entwined with that of the United States. The United States financed Churchill and HARP; launched Canadian satellites and astronauts; purchased Canadian technology such as STEM and the Canadarm, and partnered with Canada on hundreds of programs and projects. Technology has flowed both ways. The attraction of bigger budgets lured Canadian pioneers like Lawrence Manning, Kurt Stehling, Wilfred Dukes, and many Avro engineers to move south of the border. Many, like Phil Lapp and John MacDonald, completed their further education in the U.S. and then moved back to Canada. Space exploration is an expensive undertaking, but like all good scientific endeavors, it is trans-national. In science, borders are just lines on a map and this unique relationship will undoubtedly continue for many years to come.

As a final footnote to this story, on July 7, 2014, scientists at the Jet Propulsion Laboratory in Pasadena issued a press release that the *Voyager 1* spacecraft, launched in 1977, had encountered a series of tsunami-like waves of plasma on the edge of the heliosphere. This phenomenon was detected by the Plasma Wave experiment (PWA) installed onboard the spacecraft. The PWA operates by studying the plasma around the spacecraft using two 1¼-cm diameter by 10-m long STEM antennae installed on the spacecraft in 1975.[100]

It seems a fitting conclusion that over eight decades after Balfour Currie traveled into one of the most inhospitable places on Earth to study the weather, that the most distant place that man-made machinery has ever traveled is discovering unforeseen weather using Canadian technology.

Acknowledgment

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