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Chapter 6

The Early History of Canadian Planetary Exploration*

Kieran A. Carroll†

Abstract

While much of the history of the Canadian space program has been well-documented in numerous places, most of the written history has to do with activities carried out in Earth orbit—various Earth satellites, Canadarms, the astronaut program, etc. Here I report on Canadian activities *beyond* Earth orbit—which is to say, planetary exploration—with a particular focus on early activities. It is well-known that Canada was an early participant in space activities, starting with the launch of Alouette 1 in 1962, only five years into the Space Age. However, for many decades the Canadian government's space program focused entirely on missions in Earth orbit; Canada was very much a late-comer to the field of deep-space missions. Prior to the late-1990s, the Canadian Space Agency's budget did not include an explicit planetary exploration program component, which resulted in very little support for deep-space exploration proposals. Despite this, numerous individual Canadians were involved in planetary exploration projects prior to that—projects carried out by other countries' space agencies, with Canadians participating directly, with no Canadian government involvement. In one case,

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the Apollo program, the involvement of many Canadians in various roles in the Apollo Spacecraft Program has been described in several publications. The participation of Canadians in other planetary projects, including Viking, Ulysses, Magellan, Galileo, Cassini, and Juno, is less well-known. Through the course of my own career, I have had the good fortune to know several of these Canadian planetary exploration participants, and to hear their stories firsthand. Here I list some of those pioneers and discuss the projects in which they participated. In Canada, early interest in planetary exploration was centered in non-government space advocacy organizations, particularly the Canadian Space Society, of which I am a founder and past-President. I describe how the CSS played an important role in the CSA's Long Term Space Plan 3 process in 1996/97, leading to the Canadian Space Agency's adoption of planetary exploration as one of its core activities.

I. Introduction

This chapter is something of a personal narrative, serving largely to record a compendium of stories that I have collected over the course of my career, on the topic of Canadians who have participated in planetary exploration missions in some way. I know/knew many of the people involved and heard many of these stories directly from them; indeed, I was a participant in some of those stories. Because of that, I include here descriptions of how I came to know these people and hear their stories—along with some relevant information about myself, and my career as a Canadian space systems engineer. In addition to describing the actual planetary exploration work done by the people discussed here, I also provide biographical information about some of them, and (in some cases) descriptions of interesting follow-on work that resulted from their planetary exploration work.

My own involvement with planetary exploration began with the founding of the Canadian Space Society (CSS), which (as discussed in Section VIII) started in the mid-1980s. At that time, while most of the major space-faring nations of the world were supporting planetary exploration activities, Canada's space program was notable in its on-going failure to do so. Campaigning for Canada to become involved in planetary exploration became an on-going cause at the CSS, which (as discussed in Section XIII) eventually resulted in success, with the creation in 1999 of a planetary exploration program within the Canadian Space Agency. The scope of this chapter is mainly limited to the activities initiated prior to that date, as Canadian-funded activities since then are documented fairly well elsewhere.

The discussion here is particularly limited to *Planetary Exploration* activities. By that I mean, quite simply, *space missions to explore any planets other than the Earth, (including asteroids and moons, including our own Moon)*. This reflects the pre-1998 “blind spot” of the Canadian space program, which included many satellites and astronauts in Earth orbit, including science satellite programs to study the Sun and the stars—in effect, the scope of the Canadian “space exploration” program back then included *everything in the universe except for the Moon and the other planets of our solar system*. During that period of time, Canadians who wanted to participate in planetary exploration either had to go abroad to do so, or (in a few cases) seek funding from abroad. The early history of (non-planetary) space activities that *were* funded by the Canadian government during that period is well-documented elsewhere, and so I will not cover that here.

Topics are included here roughly chronologically, by the date of the start of each activity.

II. 1959: The NASA Canadians

II.1. Background

The earliest involvement that I know, of Canadians involved in planetary exploration, is in NASA’s Apollo lunar exploration program. Despite this being an entirely American program, there was a surprisingly large number of Canadians involved as NASA employees. This came about as a result of the Canadian government’s infamous cancellation of the Avro Arrow supersonic interceptor aircraft program in 1959, which led to a massive layoff of Canadian aviation engineers (among others), some of whom were highly talented and capable. At the same time, NASA was starting its manned spaceflight program, and was seeking many engineers with experience in advanced flight systems development and test. As part of what was known in Canada at the time as “the Brain Drain,” NASA recruited twenty-five of the top Avro engineers (a combination of Canadians and British) to join their Mercury project team (the famous Space Task Group) in Langley, Virginia—upon their arrival, they made up 20 percent of the Project Mercury team at NASA. Most of them stayed with NASA for the Gemini and Apollo programs.

This story has been well-documented in *Arrows to the Moon* by Gainor [1], which is devoted entirely to this topic, as well as in the first chapter of Murray and Cox’s *Apollo: The Race to the Moon* [2]. I highly recommend these excellent books to the interested reader!

While the story of this group of "NASA Canadians" was well-known in Canada during the 1960s, it faded from public consciousness after the Apollo program ended. I heard of it from Bryan Erb (see Section II.4) in the early 1990s, when he was working for the Canadian Space Agency, having retired from NASA. At the time, I was President of the CSS, which was planning to cohost (with the National Space Society, of course) the 1994 International Space Development Conference in Toronto. I organized a "NASA Canadians Reunion" at that conference, aided greatly by Bryan and by Owen Maynard (see Section II.3). A total of thirty-five NASA Canadians were identified (see Section II.5 for a list of them), of whom twelve attended the reunion at the conference. (It was this event that led Chris Gainor to write his book on the topic [1].)

II.2. James A. Chamberlin

The leader of this group was Jim Chamberlin (born May 23, 1915, in Kamloops, British Columbia, died March 8, 1981) (OC) [3][4], who at Avro was chief of technical design for the Arrow. Aerodynamic testing of Arrow models on sounding rockets had led to a technical interface being developed between Chamberlin's Arrow design team and Dr. Robert Gilruth's Pilotless Aircraft Research Division of NACA at Wallops Island, Virginia. After the Arrow cancellation, Chamberlin approached Gilruth to seek out temporary employment of his core engineering team—in the hope that the Canadian government and Avro would eventually find a way to save the company and the team. Chamberlin organized the process of Gilruth's then-NASA STG interviewing the top Arrow engineers at Avro in Toronto, leading to twenty-five of them being officially "loaned" to NASA for a period of two years (a formula meant to save the Canadian government from embarrassment—few of these engineers returned back to Canada after that two-year period). A further ten engineers and others followed over the next few years.

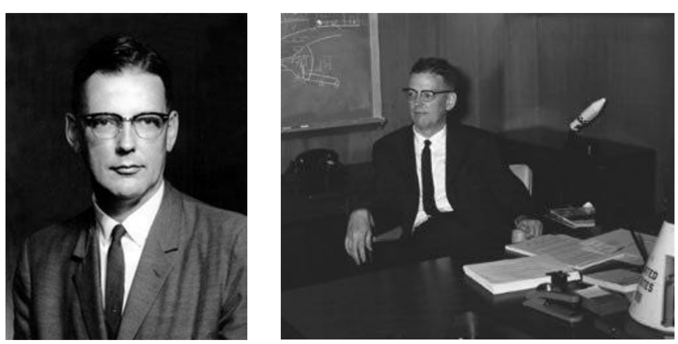

Figure 6–1: Jim Chamberlin.

Chamberlin led this contingent down to the STG's Langley, Virginia site, where he became Head of Engineering for Project Mercury. While much has been written about his role in Mercury, and his subsequent role as initiator and Project Manager for Project Gemini, our focus here is on planetary exploration, and so we will move on to Project Apollo, NASA's Moon exploration program.

Chamberlin did not have a senior role in Apollo, as he had his hands full with running Gemini when Apollo was being started. However, to quote Gainor [4]

> Chamberlin made many direct contributions to the success of Apollo. He was one of the first people at NASA to see that Apollo would succeed by using the lunar orbit rendezvous flight mode, rather than the direct flight mode favoured at NASA in 1961, when President Kennedy launched the Moon program. After he left Gemini in 1963, Chamberlin became one of NASA's top trouble-shooters in Apollo. He helped solve problems with the Apollo Command and Service Modules, the Lunar Module, the extravehicular mobility unit used by astronauts to walk on the Moon, and the Saturn rockets.

He stayed with NASA until 1970, thus seeing the first manned lunar landing program succeed, before joining McDonnell Douglas Astronautics to work on the Space Shuttle program.

Chamberlin died in 1981; he is one of the few people described here whom I did not have a chance to meet.

II.3. Owen E. Maynard, D.Eng.

Owen Eugene Maynard (born October 27, 1924, in Sarnia, Ontario, died July 15, 2000) [5][6] began his career in aerospace by becoming one of the youngest pilots of the Mosquito fighter-bomber in WWII, serving with the RCAF in England. Post-war he earned his Engineering Physics degree from the University of Toronto, then joined Avro Canada where he became Senior Stress Engineer on the Arrow. On moving to Virginia to join the STG in 1959, he was assigned as Project Engineer for first flight-test Mercury capsule.

In 1960, Owen joined the small Advanced Vehicle Team (led by Robert O. Piland), which was tasked by Dr. Gilruth to define options for post-Mercury NASA vehicles. This group went on to become the nucleus of the Apollo spacecraft engineering team, for which Owen was the lead systems engineer. There, he made initial sketches of what became the Apollo spacecraft. Figure 6–2 is one such drawing, from a 1961 memo given to me by Owen; this is for the Apollo mission baseline at the time, which was based on the Direct Ascent mission mode.

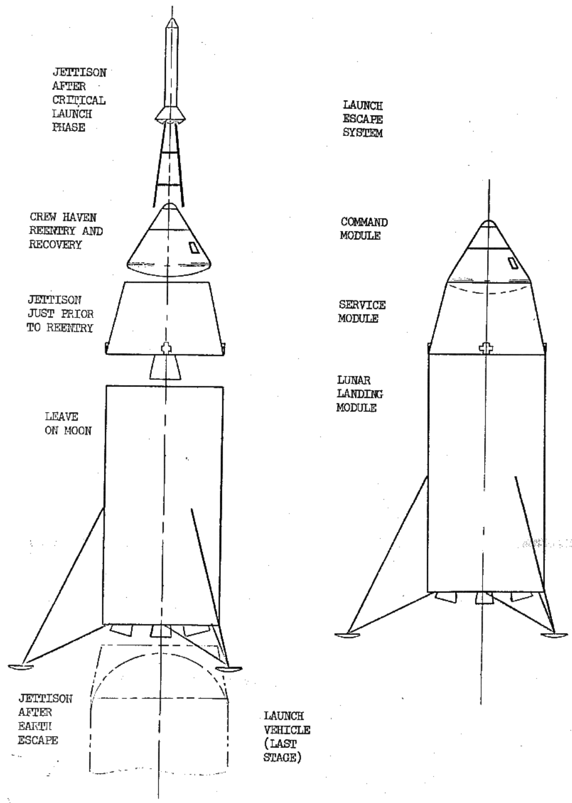

Figure 1.- Lunar landing modular arrangement.

Figure 6–2: Maynard Sketch of a "Direct Ascent" Apollo Spacecraft Configuration [7].

In 1963, after the Lunar Orbit Rendezvous mission mode had been adopted, creating the necessity for a separate Lunar Module, Owen became Chief of LM Engineering Office. There he led LM development, working closely with Grumman's lead LM engineer Tom Kelly, for whom Owen was "the customer." Again, quoting Gainor [8],

> Kelly, who today is known as the father of the LM, acknowledges that Maynard was the person at NASA most responsible for the design of the LM. In later years, the two would joke about how Maynard had a drawing of the LM hidden in his desk that Kelly and his team would work to match.

In 1964, Owen handed that job off, and took over as Chief of both the Systems Engineering and the Mission Operations Divisions of Apollo Spacecraft Program Office—he was the only Chief in ASPO to be "double-hatted." With that amount of responsibility, I make the case for Owen being the closest that the Apollo spacecraft had to a "Chief Engineer" (which was not actually a job title in that program). He stayed in that position through the landing of Apollo 12 on the

Moon, after which he followed his pre-Apollo 1 fire boss Joe Shea to Raytheon Corporation in Massachusetts. At Raytheon he worked on the Solar Power Satellite program in the 1970s; in the early 1990s he retired and moved back to Canada, where I met him. I was a youngish space systems engineer at the time; Owen became a close friend and mentor of mine until his death in 2000.

Figure 6–3: (top) Owen Maynard at NASA (on right, with Tom Kelly in the Apollo 11 SPAN Room), (bottom) in 1996 with Apollo and Arrow models.

Owen was a compulsive raconteur, well-known among his friends and colleagues for his enormous fund of stories drawn from his long and rather amazing career—stories that were usually quite lengthy, and told with great relish and animation, always (in my experience) chosen to make a specific and relevant point. I had the great privilege of hearing many dozens (perhaps hundreds) of hours of those stories, and this brief description of Owen's career would not be complete without me retelling at least a few of them—I've chosen two here, and one a bit later on, that bear particularly on the Planetary Exploration theme, and that are otherwise not well-known.

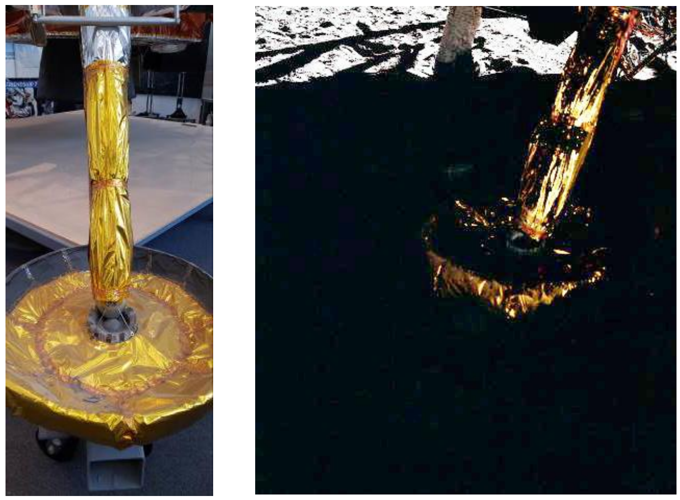

Figure 6–4: Maynard's kapton tape on Apollo 11 LM leg.

The first has to do with the one piece of "touch-labor" technician work that Owen did on Apollo 11. Of course, his role as Division Chief, a very senior engineering management role, mostly involved planning, supervising, meetings and reports, with almost all actual engineering work delegated to engineering staff at lower levels, let alone actually *building* the spacecraft! However, Owen told me a story (confirmed by Paul Fjeld, whose story is in Section VI) about the days just prior to the launch of Apollo 11, in mid-July 1969, which involves just that. By that point, the work of the Apollo 11 spacecraft designers and developers had been completed; the spacecraft had been handed over to the launch team at Cape Kennedy and the spacecraft operators in Mission Control. Of course, development continued for the spacecraft for the follow-on Apollo missions, but that was hard to focus on with the first Moon landing attempt about to happen.

As Owen told it, the Apollo Program Director (General Samuel C. Phillips, Owen's boss) decided to distract his senior staff from becoming too nervous about the upcoming launch, by assigning them "manual therapy" tasks. Owen was assigned to go to Cape Kennedy, to help out with the LM closeout activities on the launch pad. Analysis of the LM thermal coatings was underway until the last moment, and apparently an issue was raised regarding the potential for kapton blankets in the vicinity of the LM's descent engine become damaged during lunar landing, from the hot gas from the engine's jet. A decision was made to "touch up" the thermal coverings as Owen was onsite, he participated in that.

The LM was of course stowed in the Spacecraft-lunar module adapter (SLA) atop the Saturn V launch vehicle, with the Command/Service Module (CSM) above it. There were hatches in the SLA for technicians to access the LM on the pad, and Owen joined one of those technicians inside the SLA, where they made the final adjustments to the thermal blankets. Owen told me that he personally applied kapton tape to blankets “in the vicinity of the descent engine,” after which he and the technician left the SLA, and the hatch was closed, with launch happening soon afterwards—making Owen one of the last people to actually touch the outside of the Apollo 11 LM, prior to it leaving for the Moon.

Recently (at the 2019 IAC in DC, in fact) I met with Paul Fjeld, who confirmed that Owen had told him the same story. As Paul was working on a book on the LM at the time, and had copious drawings of the LM with him, he pulled those out and asked Owen to show him just where he applied that tape. The answer is shown in Figure 6–4—which shows a band of tape around the LM’s +Z leg (shown circled in red), presumably to help ensure that the kapton blanket surrounding the lower leg remained place when subjected to the blast from the descent-engine’s plume (Owen presumably also similarly wrapped tape about the other three LM legs). When we met at IAC, Paul pointed this out to me on the LM in the Smithsonian Air and Space Museum (LM-2, whose restoration Paul recently oversaw). He confirmed that the Grumman engineering drawings for thermal coatings for the Apollo 11 LM (LM-5) do *not* show that band of Kapton tape, whereas the flight photos of LM-5 *do* show that—the image on the right (NASA photo AS11-40-5896) shows the tape which Owen applied (and that the blanket around the lower leg remained intact). Paul made sure that his LM-2 restoration, which he restored into the LM-5 configuration, included that detail, as shown in the image on the left!

The second planetary-exploration-related Maynard anecdote has to do with Mars exploration. Condensing Owen’s story somewhat, he told me that when he joined the Advanced Vehicles Team in 1960, there was no clear idea as to what (if any) post-Mercury missions might get approval and funding. So, the AVT worked up designs for three different missions, based on mission concepts that were being widely discussed both inside and outside NASA at the time:

- A space station in low Earth orbit
- A manned Moon landing and return mission
- A manned Mars landing and return mission

According to Owen, designs were roughed-out to about the same level of detail for each of these options, in order to do the sizing and to identify the technologies needed to estimate launch vehicle sizes, upper stage sizes, costs and schedules. Presumably these formed a core part of the information that flowed up to NASA HQ, and from there to the White House, during those early days of the space race—this would have been the most technically detailed work done, and provided the best engineering forecast as to what was actually possible, prepared by some of the best engineers and managers amongst the team that were carrying out Project Mercury, and that would be tasked with accomplishing whatever goal was chosen for America's post-Mercury manned space program.

President Kennedy famously posed the question, in his April 20, 1961, memo [9] to Vice President Johnson,

> Do we have a chance of beating the Soviets by putting a laboratory in space, or by a trip around the Moon, or by a rocket to land on the Moon, or by a rocket to go to the Moon and back with a man? Is there any other space program which promises dramatic results in which we could win?

After sounding out his advisors, Kennedy chose the Moon-landing-and-return goal, and the rest (as they say) is history.

However, it is intriguing to think about the alternative history in which it was deemed that the USSR was likely to be able to beat the USA to the Moon and back. In which case, given the political tenor of the times, perhaps President Kennedy might have chosen the manned Mars mission as the goal with which to challenge America's great geopolitical rival. That option was available for consideration—"in the next file folder over" from the Moon-landing mission, speaking figuratively (and quite possibly literally!). At that point in time, the Mars mission was in a sense as feasible as the Moon mission.

Figure 6–5 shows, on the left, drawings from the manned Mars mission design, for which Owen was co-inventor on a US patent [10] that was granted a few years later (when NASA was encouraging its employees to patent space-related inventions). Owen described this, and the story behind it, to me (and others at the CSS) at some length; I include here only a subset of those details, as space permits. This was intended to be a trans-Mars spacecraft, to be launched into Earth orbit using a Nova launcher (which if developed was to have been rather larger than the Saturn V). The spacecraft was designed to provide artificial gravity for its crew during the extended trip to and from Mars by spinning; the three radial arms were to be stowed along-side each other for launch, then deployed via 90-degree hinges once in space. A nuclear-powered NERVA upper stage was to be used to provide propulsion on the way to Mars, and back to Earth. As with all of the concepts studied by the AVT at the time, Apollo-style Command and Service modules were to be used to provide the means for the crew to return to Earth. This patent document, however, does not go into details associated with using this design for Mars; in particular, there is no mention of any means that might be used for descent to the Mars surface, and return to orbit around Mars (perhaps this mission concept was intended as a Mars orbital rendezvous mission, rather than a Mars landing mission).

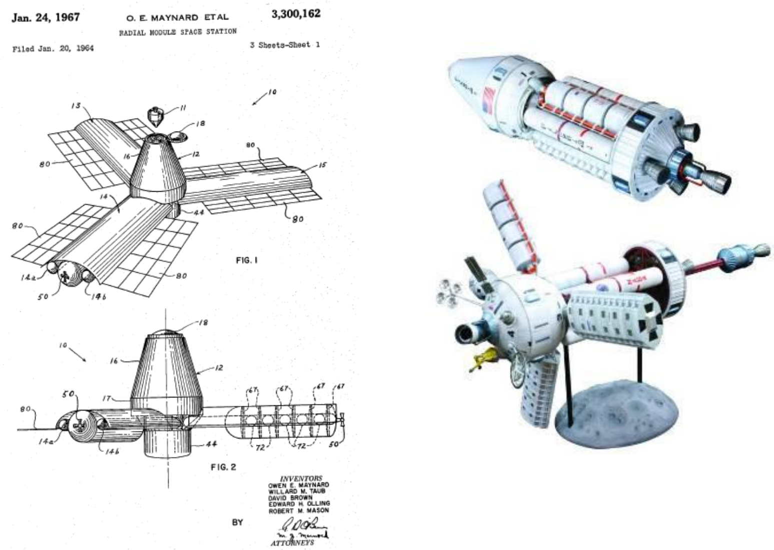

Figure 6–5: Maynard's Radial Module Space Station.

Somewhat entertainingly, a maker of plastic spacecraft hobby model kits chose this design for one of their products: the "MPC Pilgrim Observer" pictured on the right side of that figure. Described as a "Nuclear Powered Interplanetary Spacecraft," this presumably was based on the trans-Mars version of the design.

To wrap up the stories regarding Jim Chamberlin and Owen Maynard, note that the "NASA Canadians" story, while mostly forgotten in Canada for many years, was brought back to the public consciousness in 2019. In recognition of the fiftieth anniversary of the landing on the Moon of Apollo 11, Canada Post issued a pair of commemorative postal stamps in July 2019, as shown in Figure 6–6. The presentation card for the stamps, along with a corresponding first-day cover, both include photos of Chamberlin and Maynard, as well as some of their design sketches, and a brief description of the Apollo part of their stories.

II.4. R. Bryan Erb, PhD

Richard Bryan Erb (born April 12, 1931, in Calgary, Alberta) [11] was the other Canadian assigned to Piland's Advanced Vehicle Team in 1960. With an academic background in aerodynamics and fluid mechanics, he worked on the design of the Mercury heat-shield, and later took on the same role as subsystem manager for the Apollo heat-shield—a much harder task, because of Apollo's much-higher re-entry speed, due to its trajectory upon returning from the Moon). His job titles from 1962–1967 in ASPO were “Head, Thermal Analysis Section,” “Chief, Thermo-Structures Branch” and “Assistant Chief, Structures and Mechanics Division.”

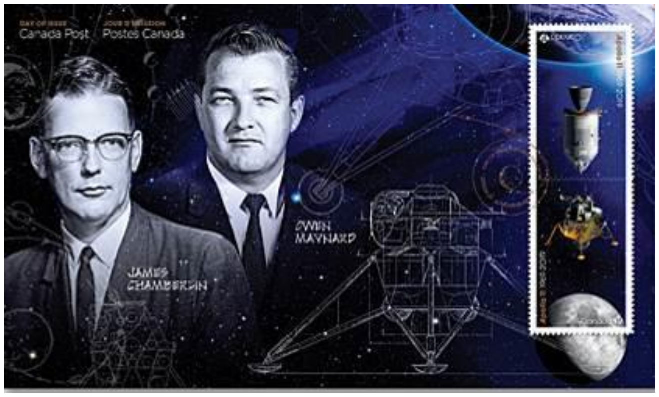

Figure 6–6: July 2019 Canada Post Commemorative Apollo 11 50th Anniversary Stamps.

Figure 6–7: Bryan Erb.

Bryan had one more lunar exploration task to perform at NASA: from 1969–1970, he was the Manager for the Lunar Receiving Laboratory. In that role, he led the development of the facilities at JSC which were to house the rocks and dust that were returned to Earth by the Apollo astronauts, and the myriad scientists who were to use that lab to analyze them. This also involved developing the quarantine protocols for the astronauts, equipment and samples coming back from the Moon, the most publicly well-known of which was the Mobile Quarantine Facility which housed the Apollo 11 astronauts from arrival aboard the aircraft carrier which picked them up, until they arrived in Houston.

In 1971, Bryan moved on to the new Earth Observation Division of NASA, eventually becoming a senior manager in the Earth Resources Program office, working to develop what became known as the Landsats. After that, in 1986 he retired from NASA, going to work for Canada's National Research Council (later Canadian Space Agency) as "our man in Houston," setting up and running the Canadian liaison office for the Space Station program, at Johnson Space Center. That is where I came to know him (when I was a young space systems engineer, also working on that program). We have subsequently worked together to promote the development of Solar Power Satellites (along with Owen Maynard in his retirement).

Figure 6–8: Bruce Aikenhead, with first Canadian astronaut Marc Garneau.

II.5. List of NASA Canadians

For reference, a complete list of the "NASA Canadians" is provided here. A key is provided after this list, specifying the meaning of the various acronyms used here. A great deal of information about each of these men has been compiled by Chris Gainor in his book *Arrows to the Moon* [1].

- Bruce A. Aikenhead: born 22/9/23 in Didsburg, Alberta, died 5/8/19; E&D, FCOD (training). Back in Canada he drew on that experience when called on to lead the development of Canada's astronaut program, starting in 1986.
- Peter J. Armitage: born 5/3/29 in Yorkshire, England; FOD (landing and recovery), Flight Sciences, LRL.
- David N. Brown: born 1/9/27 in South Croyden, Surrey, England; E&D.
- Richard R. Carley: born 27/4/27 in Saskatoon, Saskatchewan; E&D (guidance, navigation, and control expert).
- William R. Carpentier: Medical and Recovery.
- Frank Chalmers: FOD (flight control).

- James A. Chamberlin: born 23/5/15 in Kamloops, British Columbia, died 8/3/81; PMO (Mercury PM, Gemini PM, Apollo advisor and Boards chairman, Shuttle expert).
- Jack N. Cohen: FOD.
- Thomas V. Chambers: E&D.
- Stanley H. Cohn: FOD.
- D. Owen Coons: Medical---Chief (Apollo Boards, Engineering and Operations Interface).
- Burton G. Cour-Palais: born 18/4/25 in Nagpur, India, died 20/7/04; E&D, Life Sciences.
- Eugene L. Duret: born 25/5/24 in Creelman, Saskatchewan.
- R. Bryan Erb: born 12/4/31 in Calgary, Alberta; E&D, Life Sciences, LRL.
- David D. Ewart: born 8/2/27 in Stoke-on-Trent, Staffordshire, England; E&D, PMO (at North American).
- Joseph Farbridge: E&D (loads expert, and Operations at GSFC).
- Norman B. Farmer: born 16/12/27 in London, England; E&D.
- Dennis E. Fielder: born 26/8/30 in London, England; FOD.
- Stanley H. Galezowski: born 2/12/33 in Toronto, Ontario; E&D.
- George Harris: E&D.
- John D. Hodge: born 10/2/29 in Leigh-on-Sea, Essex, England; FOD (flight control).
- John K. Hughes: FOD.
- Morris V. Jenkins: born 3/5/23 in Southampton, England; FOD (mission planning and analysis), ALLM (presenter).
- Robert Lindley: facilitated selection of AVRO personnel for STG; later went to MDAC, NASA HQ and GSFC.
- C. Frederick Matthews: born 28/11/22 in Guelph, Ontario; FOD.
- Owen E. Maynard: born 27/10/24 in Sarnia, Ontario, died 15/7/00; E&D (Project Engineering, S/C Design Integration), PMO--ASPO (engineering and project management, systems engineering, Mission Operations, Operations Management), ALLM (manager and presenter).
- John Meson: FOD & FCOD.
- Leonard E. Packham: born 24/1/22 in Saskatoon, Saskatchewan; FOD, E&D.
- Tecwyn Roberts: born 10/10/25 in Liverpool, England; FOD & Goddard Networks.
- Rodney G. Rose: born 10/8/27 in Huntington Hunts, England; E&D (through Little Joe for Mercury), PMO (Gemini).

- John N. Shoosmith: born 9/10/34 in London, England; FOD (trajectory software).
- Leslie G. St. Leger: born 6/2/22 in Calcutta, India; E&D.
- Robert E. Vale: born 8/12/22 in Toronto, Ontario; E&D, Science Payload, Structures and Mechanics Chief, ALLM (presenter).
- George A. Watts: born 3/9/28 in Trail, British Columbia; E&D (loads and structures).

Figure 6–9: John Hodge.

Figure 6–10: Morris Jenkins.

Figure 6–11: Tecwyn Roberts.

Figure 6–12: Rodney Rose.

Key to acronyms in the above list:

- ALLM: 1966 MSC Apollo Lunar Landing Mission Symposium
- E&D: Engineering and Development Directorate (under Max Faget)
- FCOD: Flight Crew Operations Directorate (under Deke Slayton)
- FOD: Flight Operations Directorate (under Chris Kraft)
- LRL: Lunar Receiving Laboratory
- PMO: Program Management Office (for Apollo, under Bob Piland, Charlie Frick, Joe Shea, George Low, Jim McDivitt)
- STG: Space Task Group

- MSC: Manned Spacecraft Center (later Johnson Space Center in Houston)
- MSFC: Marshall Space Flight Center (Huntsville, Alabama)

III. 1960: DHC, SPAR and STEM Tubes for Apollo

III.1. George Klein

George Johann Klein (born August 15, 1904, in Hamilton, Ontario, died November 4, 1992) (OC, MBE) was a mechanical engineer who worked at the National Research Council in Ottawa from 1929–1969 [12]. A prolific inventor, one of his inventions was a compactly-stowable, deployable metal tube structure. He conceived this in 1951, and (as related in [13]) developed it for use (with NRC's Harry Stevinson) in a self-righting ejectable aircraft emergency beacon. It was subsequently developed by DeHavilland Canada into a deployable antenna for use on satellites, as well as many other space applications, as described in Section III.2. Several of those devices found their way into Apollo spacecraft. While Klein was not directly involved in that Apollo application of his invention, he deserves credit for making that possible.

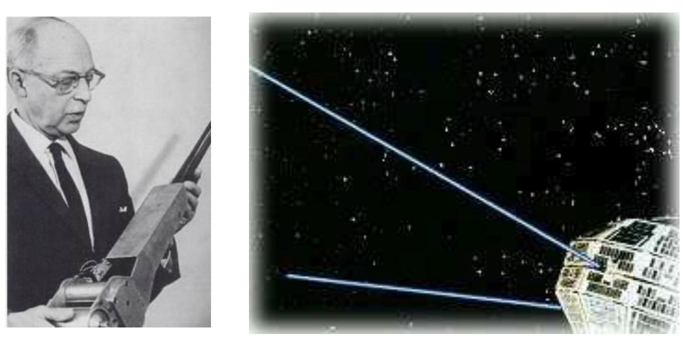

Figure 6–13: George Klein with early STEM prototype, STEMs on Alouette satellite.

III.2. Philip A. Lapp, PhD

Dr. Philip Alexander Lapp (OC, ScD, FRSC) [14] (born May 12, 1928, in Toronto, Ontario, died Sept. 25, 2013) earned his Engineering Physics degree from the University of Toronto in 1950, and his PhD from MIT in 1954, after which he went to work for DeHavilland Canada. In the 1950s, DHC (located immediately north of Toronto) was one of Canada's major aircraft manufacturers—having produced very many Mosquito fighter-bombers and Merlin engines during WWII, in the post-war period DHC was focusing on civil aviation, developing bush-planes among other products. Phil was hired to work in their new

Guided Missile Division, as systems engineer on the Velvet Glove air-to-air missile being developed for use on the CF-100 Avro Arrow supersonic interceptor. That group morphed into DHC's Special Products division in 1957. In 1959, that division was selected to develop the satellite bus and deployable antennas for the Canadian Defence Research Telecommunications Establishment's Alouette satellite, an ionospheric topside sounder, and Canada's first satellite.

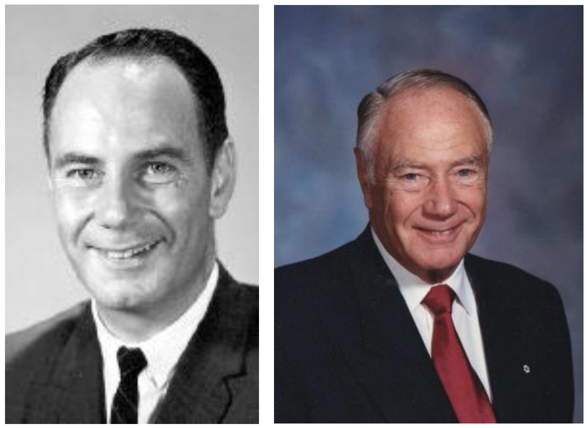

Figure 6–14: Phil Lapp, in the 1960s and the 2010s.

DRTE put Lapp's team in touch with George Klein at NRC, where they learned about his storable antenna. While NRC's antennas were limited by their production process to a length of about 18 feet, Lapp's team developed an improved production process allowing them to be made arbitrarily long—Alouette needed two antennas 37.5 feet long, and two others 75 feet long. Packaging these antennas with a motor-driven mechanism for stowing and deploying the antennas on a motorized reel, DHC called the resulting device the "Storable Tubular Extendable Member" (STEM).

The STEMS on Alouette worked very well, and DHC made a very successful business selling STEMs for many other space applications; by the 1970s, it was estimated that there were over 1000 STEMs in orbit on various spacecraft. In 1962 Phil assigned John MacNaughton, Chief Mechanical Engineer of what was by then known as DHC's Special Products and Applied Research (SPAR) division, the task of turning STEMs into a stand-alone business. Under MacNaughton, STEM sales were made into NASA's Mercury, Gemini, and Apollo programs. For Mercury and Gemini, they were used as deployable antennas. For Apollo, they were used as deployable masts to extend (and then later retract) scientific instruments (a gamma-ray spectrometer and a mass spectrometer instrument) from the Instrument Bay of Apollo 15 and 17; the STEMs carrying those instruments on Apollo 17 did double-duty as antennas for a lunar radio sounder experiment (see section “The STEM Under MacNaughton” in [14]). These Apollo STEMs are shown in Figure 6–15.

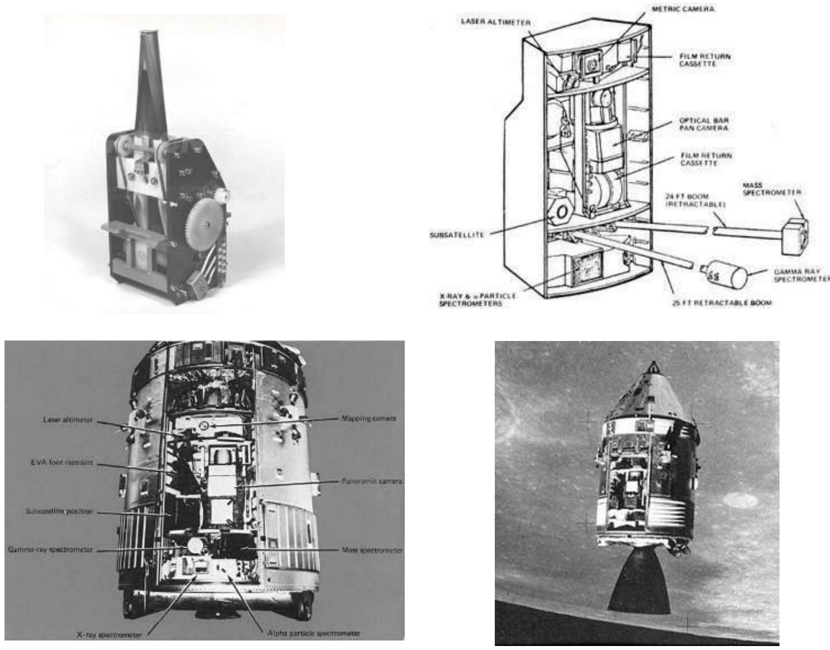

Figure 6–15: STEMS used to deploy instruments from the Apollo Service Module.

In 1967, Phil was part of a group of DHC employees who spun the SPAR division of DHC out into a separate company; Phil became Senior Vice-President of SPAR Aerospace Products Limited. STEMs went on to form the foundation for much of Canada’s space program and industry, when in the 1970s Canada was chosen to develop the Remote Manipulator System—later known as the Canadarm—for NASA’s Space Shuttles, and SPAR was chosen by NRC to be prime contractor for developing the RMS. (By this point, Phil had left SPAR’s employ, striking out on his own as a consultant, but he remained on SPAR’s board of directors for many years, and via his Board position remained intimately involved with the company’s growth.) Canada’s and SPAR’s ability to be selected by NASA to provide this essential Space Shuttle subsystem was certainly based on the extensive experience and success that SPAR had developed in supplying a vast number of STEM products into many space projects. The Space Shuttle RMS was followed by the Space Station Mobile Servicing System, including “Canadarm2.” Today, SPAR’s successor company (Maxar’s Canadian division, MDA) is positioned to potentially provide a Canadarm3 as part of Canada's contribution to the Lunar Gateway space station, part of NASA's Artemis crewed lunar exploration program.

(I first met Phil in 2006, when we both found agreed to be advisors for a Toronto-area rocketry startup company. We bonded over our mutual love of space systems engineering, and Phil and I remained close friends until his death in 2013.)

III.3. Owen Maynard and STEM Tubes

This brings me to a final Owen Maynard anecdote, this one about STEMs and Mercury, and ultimately Apollo.

Owen told me this story on the occasion of the "NASA Canadians" reunion that he helped me organize for ISDC '94 in Toronto, mentioned in Section II.1. One of the activities that I had organized for the twelve NASA Canadians who attended that event, was to visit SPAR's plant in Brampton, north of Toronto's main airport, for a tour of Canada's premier space engineering company. (We also toured the old A.V. Roe Canada plant near the airport, where they had worked until 1959, which at that point was owned by McDonnell Douglas, manufacturing airliner wings.) The SPAR tour included a preliminary briefing in the company's main conference room, describing the company's history; as was usual with such talks at SPAR in those days, the speaker brought out a sample of a STEM tube to illustrate the company's founding product—as usual, he tossed the compactly rolled-up tube into the air, whereupon it instantly (and loudly!) uncoiled into a 6-foot long tube, an inch in diameter, a spectacularly attention-seizing demo. After the tour was over, Owen told me the following story.

After WWII, Owen left his full-time position in the RCAF, but stayed in the RCAF reserves, where he was posted to Toronto Squadron, located at Downsview Airport north of Toronto, at the same airfield where DHC was located (and where the Mosquitos that Owen flew in the war had been built). Owen related that one day, he and fellow pilots in the reserve squadron were hanging around one of the hangars, when they were approached by an engineer who wanted to show them a demonstration. That fellow stood at one side of the open hangar door, holding a box with a handle on its side. He cranked the handle, whereupon a tube began to emerge from the box, eventually extending in length all the way across the hangar door opening. Clearly the engineer was trying to impress the pilots, and it worked, for Owen remembered this vividly decades later.

When Owen joined Project Mercury in 1959, he mentioned this deployable-tube gizmo to Caldwell Johnson (the lead Mercury designer) as a potentially useful device—after which, Owen gave it no further thought. While Owen didn't know for sure, he said it seemed likely to him that Johnson (or one of the engineers working for him on the Mercury team) approached DHC to ask about the device. Which may have played a part in STEMs being chosen to fly in Mercury, Gemini, and Apollo. If that's the case, then Owen may have played a small but important part in planting a seed that over the years flourished into SPAR Aerospace, the Canadarms, and Canada's astronaut program.

The timing of that Downsview Airport demonstration makes it possible that it was a DHC engineer demonstrating an actual STEM to those pilots, just prior to Owen departing for the USA in 1959 (assuming that he still maintained his reserve commission up until then), the same year that DHC won the Alouette contract and began its own STEM work. Alternately, he might have seen it demonstrated before then, by someone from NRC. According to [13], the initial aircraft beacon developed by Klein and Stevinson at NRC "was officially a product of the NRC's Flight Research Section at the RCAF airport outside of Arnprior, a then rural area north of Ottawa. It was demonstrated there on a number of occasions to defense department officials, army officers, pilots, engineers, and scientists." It is possible that the deployment demo that Owen saw at Downsview was done rather earlier than 1959, by someone from NRC showing off their aircraft-beacon deployable antenna design.

(As far as I know, I may be the only person to whom Owen told this particular story—since it was prompted by the peculiar circumstances of the SPAR plant tour in 1994. I include it here for posterity.)

IV. 1960s/70s: Lunar Module Landing Gear

Returning to the topic of Apollo, major portions of the landing gear for the Apollo Lunar Modules (in particular, the legs and feet) were built in Canada, by Héroux Limited, an aviation landing-gear manufacturing company in Longueuil, Quebec (near Montreal)—they are still in business today, under the name Héroux Devtek, still making aviation landing gear. Unlike with the later Space Shuttle and Space Station programs, on the Apollo program the Canadian government had no involvement; Héroux was hired as a supplier by Apollo LM manufacturer Grumman, and so was funded out of NASA's Apollo program budget.

Figure 6–16: Apollo Lunar Module landing gear developed by Héroux.

V. 1960s/70s: Canadian Apollo Lunar Scientists

A Canadian geoscientist who played a very prominent role on the Science side of the Apollo program was Dr. David Strangway (OC, PhD, FRSC) (born June 7, 1934, in Simcoe, Ontario, died Dec. 13, 2016) [15]. He studied at the University of Toronto, earning a B.A. in Physics and Geology in 1956, an MA in physics and a PhD in physics in 1960. He spent 1961–1964 as a Professor of Geology at the University of Colorado, and 1965–1968 as an Assistant Professor of Geophysics and Researcher at MIT. In 1970, he joined NASA as the Chief of the Geophysics Branch and was responsible for the geophysical aspects of the Apollo missions (e.g., see [16]).

In addition to this senior science management role during Apollo, he was also Principal Investigator for one of the Apollo 17 surface experiments—the Surface Electrical Properties (SEP) experiment, which probed the Moon's subsurface using a geophysical electromagnetic technique [17]. This involved a 1-32 MHz radio transmitter on the ALSEP station, and a radio receiver on the Lunar Roving Vehicle. Its measurements established the dielectric constant of the subsurface across the Taurus Littrow Valley area, determined that the electrical structure in that area was not simple horizontal layering, and did not detect any liquid water in the top 2 km of that region.

Dr. Strangway subsequently went on to a highly distinguished career in Canadian academia. He authored or co-authored more than 165 research papers, including results of lunar sample studies and experiments, his research focusing on magnetic studies and electromagnetic sounding, both terrestrially for exploration and mapping and in lunar mapping and exploration.

He was the Director of the Lunar Science Institute in Houston (now known as the Lunar and Planetary Institute) in 1973. After being a vice-president and chair of the geology department at the University of Toronto from 1973–1983, he became that university's eleventh President 1983; then from 1985–1997 was the tenth President of the University of British Columbia. He subsequently served on numerous science and technical boards, committees, and panels in Canada, including roles advising federal and provincial governments.

One of Dr. Strangway's students during the Apollo period was Peter Annan. He earned his degrees at the University of Toronto and Memorial University, in engineering/geophysics. His early analytic work was the basis for the Apollo 17 SEP experiment (he is a co-author on [17]). Dr. Annan went on to work at the Geological Survey of Canada (now part of Natural Resources Canada), and became a leading developer of Ground Penetrating Radar instruments, via his company Sensors and Software, located near Toronto.

Figure 6–17: David Strangway, Peter Ann.

VI. Early 1970s: Paul Fjeld and Apollo Art

Paul Fjeld (born 1955 in Oslo, Norway) is an aerospace artist. His family moved to Canada (Montreal) when he was a child; as a teenager, de developed strong interests in both art and space, which led him to becoming a participant in NASA's Art Program—as an Observer on Apollo 17 and Skylab 1 and 2 (in Cape Canaveral and Houston), and as an official NASA Artist on the Apollo/Soyuz Test Project (ASTP), where he worked in Mission Control, Houston. During that period he produced numerous space paintings on Apollo, Skylab, ASTP, and Space Shuttle used by NASA, CBS News, National Geographic Magazine, Aviation Week and Space Technology, and other publications; his work is notable for its exceptionally high accuracy, as well (in my opinion) for its great beauty.

Paul played a small part in supporting the Apollo 17 mission, as described in the story on his website [18] titled “In the Apollo Simulator.” After a tour of the Apollo Command Module crew training simulator in Building 5 at JSC, he became an unofficial assistant to the simulator operators, spending time inside the simulated CM cabin, configuring switches on the control panel when requested.

In later years, Paul spent some time living in Toronto, and became a member of the Canadian Space Society, where he was part of the CSS’s Mars Solar Sail design project (Section VIII.1) and Moon/Mars Workshop (Section VIII.2). During the 1990s he was hired by the Canadian Space Agency to produce numerous paintings, along with designs for mission patches, and also the original CSA logo.

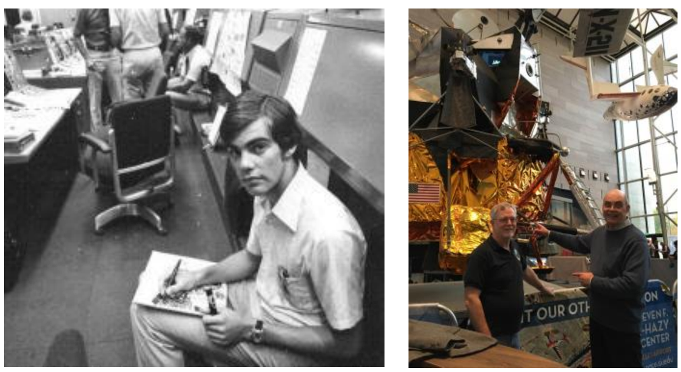

Figure 6–18: Paul Fjeld, on left in MOCR at JSC during Apollo-Soyuz, on right next to restored LM-2 in the NASM in 2019.

During the 1990s, Paul began collaborating with noted Canadian amateur astronomer Randy Attwood (who is currently Executive Director of the Royal Astronomical Society of Canada) on a book (as yet unpublished) on the Apollo Lunar Module. This led to him and Randy collecting vast amounts of information about the LM, and interviewing many of the people involved in its development, including Owen Maynard (Section II.3), and Grumman LM technical lead Tom Kelly.

Paul subsequently moved to the USA, where the deep knowledge that he gained in working on the LM book, and his meticulous attention to accuracy in depicting spacecraft, were both brought to bear when he was hired to participate in the restoration of several of the Lunar Modules that remain in museums. Most notably, the National Air and Space Museum hired Paul to lead the complete restoration of LM-2 in 2015–2016, during which that early-version LM was re-fitted to the configuration of Apollo 11's LM-5. Figure 6–18 includes a very recent (on the last day of IAC 2019) photograph of Paul and me in the lobby of the NASM, standing in front of the restored LM-2.

VII. Early 1970s: Apollo 13, and the Viking Upper-Atmosphere Mass Spectrometer to Mars

Dr. John Barry French (CM, PhD, FRSC) (born Aug. 22, 1931, in Mimico, Ontario) [19] is a Canadian chemical engineer (BASc in 1955, PhD 1961, both from the University of Toronto), who became a professor at the University of Toronto Institute for Aerospace Studies (UTIAS), specializing in rarefied gas dynamics. He became well-known in that research community in the 1960s, developing unique lab facilities for experimental investigations into atmospheric drag on spacecraft at the extremely high speeds and extremely low densities encountered by orbiting satellites.

Barry played a very brief but interesting role in the Apollo program, when he received an unexpected telephone call on April 13, 1970. That was the day that Apollo 13 returned to Earth, after the catastrophic explosion of its Service Module en-route to the Moon a few days earlier. The call was from a colleague of Barry's at Grumman, who were supporting NASA's Mission Control throughout that flight. An issue had arisen related to the separation of the Lunar Module from the Command Module prior to re-entry, which was to be accomplished by leaving the tunnel between the two partly pressurized when a pyrotechnic actuator explosively separated the two spacecraft. NASA wanted there to be enough atmosphere left in the tunnel to provide a large enough separation force, in order to actively separate the two spacecraft by a large enough distance, so that they would not collide during re-entry. The issue was that if the pressure in the tunnel was too high, a shock wave from the pyro device could damage the CM hatch, causing it to leak or even to fail. An earlier test had accidentally demonstrated this possibility, but had not been followed up, because the normal approach to jettisoning the LM (in lunar orbit) was to leave the tunnel unpressurized, in which case the shock-wave issue would not arise. Detailed planning had not been done in advance for the Apollo 13 separate-with-the-tunnel-pressurized scenario.

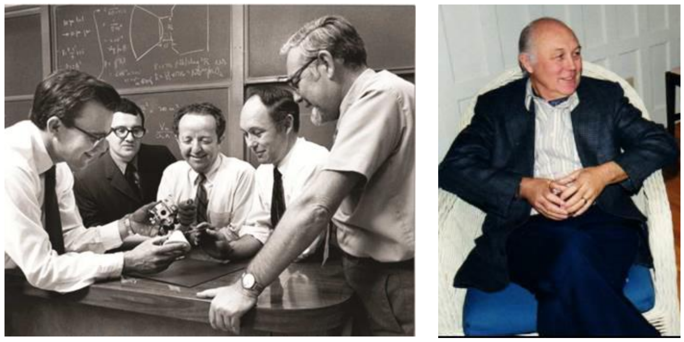

Figure 6–19: Barry French and UTIAS colleagues.

The Apollo 13 rescue was a several-day exercise in dealing with numerous unplanned scenarios and issues on an emergency basis, with a completely inflexible schedule dictated by the rapidly-depleting supply of resources in the spacecraft, and by the cold equations of orbital mechanics. The tunnel-shock-wave issue was identified only hours before re-entry was going to happen. The LM developer Grumman set about trying to determine how high a gas pressure would be safe. One of their rarefied-gas experts (Richard Oman), having met Barry at rarefied-gas conferences, recalled his expertise in this area, and called him to help make that decision.

The call came during a UTIAS staff meeting, and Barry and several of his colleagues there (Phil Sullivan, Rod Tennyson, Irvine Glass, Ben Etkin, and Peter C. Hughes) immediately set to work making calculations, in a story that has been recorded on the UTIAS website [20]. After very few hours of analysis, they provided their answer, specifying a pressure they thought would be safe yet effective. Barry told me they expected that Grumman would double-check their result before using it. However, they found out after the fact that, due to the extreme schedule pressure, Grumman immediately relayed that pressure number to Mission Control in Houston, who in turn immediately relayed it to the astronauts, who fairly soon thereafter dialed-in that pressure setting and ejected the LM. Fortunately, the results were good! The CM hatch did not get damaged, the LM did not collide with the CM after separation, and the Apollo 13 crew returned home safely.

Barry subsequently became involved, in a much more prolonged and substantial way, with NASA's flagship Mars exploration mission of the 1970s, Viking. This involved sending two spacecraft to enter Mars orbit in 1976, each deploying a Mars entry vehicle carrying a lander. One of the instruments to be carried on each entry vehicle was the Upper-Atmosphere Mass Spectrometer (UAMS), whose development was led by physicist and mass-spectrometry pioneer Alfred O.C. Nier from the University of Minnesota. The objective of these instruments was to measure the composition of Mars' atmosphere during atmospheric entry, from 200 km down to about 100 km altitude; this is described in [21].

This instrument required testing, and it turned out that Barry's "space simulator" at UTIAS was the test facility best suited for reproducing (as closely as possible) Mars entry speeds and densities. NASA approached Barry in 1969 to ask if he would be willing to make that available, inviting him to join the instrument science team; Barry was giving talks quite a bit at that point at rarefied gas dynamics conferences, and knew people in Grumman, who (he thinks) provided that link. Barry's hypersonic beam simulator was able to produce Mach 15 beams of test-gases, half the speed of Mars entry. Having that facility ready saved NASA two to three years in development time. Quoting Barry regarding some of the key technical details, "Al Nier needed to calibrate his instrument, and didn't know how to do it, because it was an open source, not an equilibrium one. Fortunately, the molecules coming in gave the same spectrum as the ones bouncing off the wall [of the test chamber]."

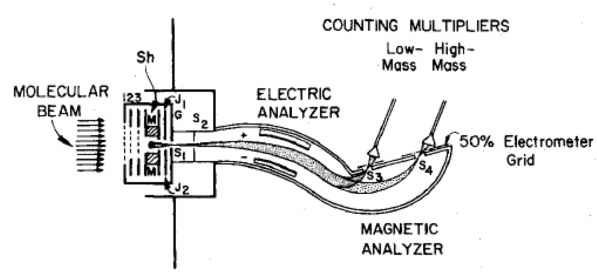

Fig. 1 Ion source and mass spectrometer schematic.

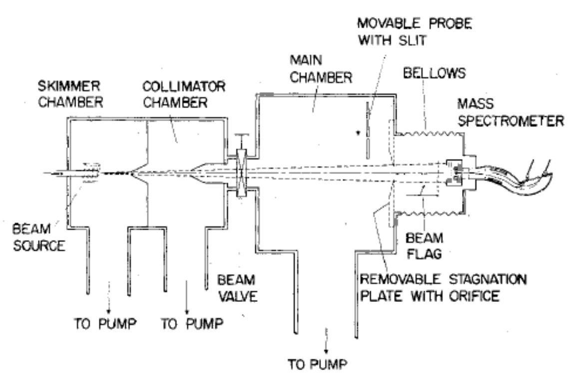

Fig. 2 Molecular beam simulation system.

Figure 6–20: UAMS, and UTIAS test facility.

The UAMS instrument and Barry's test facility at UTIAS are sketched in Figure 6–20, and the composition of Mars' atmosphere as measured by UAMS on Viking 1 and 2 is shown in Figure 6–21.

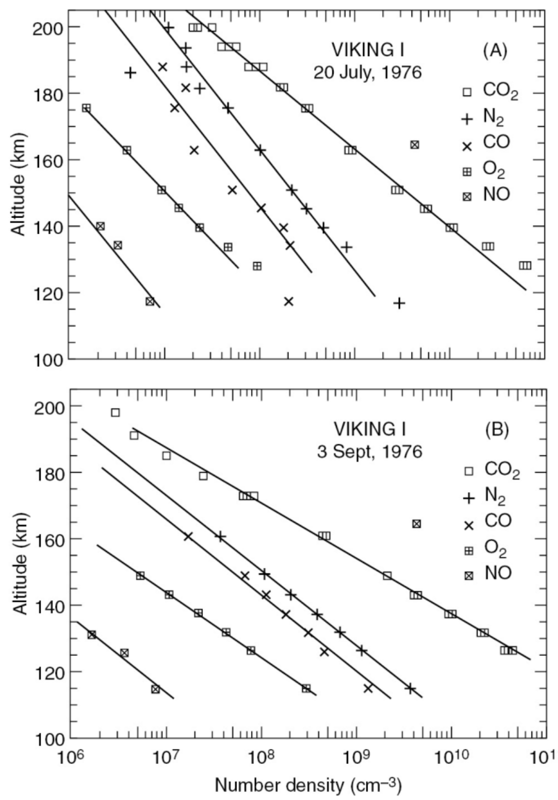

Figure 6–21: Mars atmosphere composition as measured by UAMS, from [21].

Barry's participation in UAMS came about because he was a skilled and experienced researcher in the hypervelocity field, and there were very few people in the field at the time. UTIAS had been founded (by founding Director Dr. Gordon R. Patterson) in 1949 to become a world-leading research institution in the field of supersonic and hypersonic aerodynamics; Barry had developed his facility as part of an interest in developing a low-drag satellite, which involved extending that expertise into the then-brand-new field of extremely high-altitude flight.

Funding support for Barry's facility was from NASA and the US Naval Ordnance Lab, not from the Canadian government. Following the publication of the first systematic review of the Canadian space sector in 1967 by Chapman, Patterson, Lapp and Forsyth [22], the Canadian government acted on the primary recommendation of that report: to develop an indigenous Canadian communications satellite system and industry. While that initiative was extremely successful in accomplishing that objective, it was pursued at the expense of essentially all other space activities in the country. From the late 1960s, onwards, Canadian federal funding support was withdrawn from basically all space activities but commsats; work on most other space exploration programs in the country (e.g., Gerald Bull's Project HARP gun-launched rockets, and upper-atmospheric science satellites of the Alouette/ISIS type) collapsed. All government funding for space-related facilities was steered to the new Communications Research Centre in Ottawa (headed up by Chapman), and so space researchers like Barry had to look abroad for funding. In this way, the story of Barry's involvement in the Viking UAMS instrument is archetypal of the overall state of space research in Canada in the late 1960s and early 1970s.

Following his Viking experience, Barry developed an interest in mass spectrometry, which became his major research focus for the remainder of his career at UTIAS. Along with a classmate of his from undergrad years (Bill Breukelman), he cofounded Sciex Ltd. In Toronto, a Canadian instrumentation manufacturer formed to develop and market mass spectrometers as trace gas analysis instruments. Barry developed several key innovations in that field, particularly related to quadrupole mass spectrometers. Sciex has since gone on to become one of the world's leading providers of mass spectrometers, a tremendously successful research-based Canadian industry, whose toots trace back to Barry's involvement with Mars exploration via the Viking UAMS instrument.

Barry was one of my professors at the University of Toronto when I was studying undergraduate aerospace engineering in 1981, in charge of the spacecraft design course. I got to know him somewhat during my years as a graduate researcher at UTIAS (under Peter Hughes). Many years later he recruited me into a start-up company of his (Gedex) to work on advanced gravity sensing geophysical instruments. During the ten years that we worked together at Gedex, I got to know Barry very well indeed, and heard the above stories from him.

VIII. 1983: The Canadian Space Society/la Société Canadienne de l'espace

In 1983, Toronto-area members of what was then called the L5 Society (which later merged with the National Space Institute to form the National Space Society, NSS) were invited to a meeting in downtown Toronto, which was the inaugural meeting of a new Toronto L5 chapter; I was one of the fifty or so attendees. Over the next two years it became clear that the group's objective, of promoting space exploration and development in Canada, was being hampered by affiliation with what was viewed as an American political lobbying group. Accordingly, the Toronto group struck out on its own, forming the Canadian Space Society (CSS), which was incorporated as a not-for-profit Canadian corporation in 1986 (I was a founding Director, and later held several offices, including President for five years, preceded by Paul Swift, and followed by Steve Horvath), with the principal objective being "to sponsor and promote the involvement of Canadians in the development of Space." The CSS (*www.css.ca*) has since grown to become a national organization, with chapters in many cities across Canada. It has retained an alignment and affiliation with the NSS, due to the two organizations have such similar objectives; joint activities have involved CSS being the local host for the NSS's International Space Development Conference twice, both times in Toronto, in 1994 and 2015.

A central focus of the CSS has been to advocate for Canadian involvement in planetary exploration; during the period of the 1980s and the 1990s, the CSS was virtually the only Canadian organization doing so. In this section, I summarize two notable CSS activities in this regard during that period. A third activity, even more notable, is described in Section XII.

VIII.1. 1988: Canadian Solar Sail Project

The year 1992 was the 500th anniversary of Columbus' first voyage to the Americas, and around that time numerous activities in various countries were planned to mark that event. One such activity was a "Solar Sail Race to Mars," sponsored by a US organization called the Christopher Columbus Quincentenary Jubilee Commission (CCQJC). In 1998 this group announced a spacecraft design competition, whose purpose was to encourage private (non-government-funded) teams from around the world to develop solar-sail propelled spacecraft. The CCQJC offered cash prizes of US$10M to winning design proposals, one each to be selected from teams in the Americas, Europe and Asia; winning teams would then build and launch their spacecraft, which would then deploy their solar sails, and race from Earth to Mars—the "Columbus 500 Space Sail Cup" [23].

This design competition attracted *ca.* twenty entries from teams from around the world (laying the conceptual groundwork for the later X-Prize competitions). The CSS decided to enter this contest; with several members who were aerospace engineers, the group had enough technical background to pursue this in a somewhat credible way. A volunteer design team was formed, with Istvan (Steve) Horvath as project manager, and me as Deputy PM; other key participants were Peter Stibrany (who at the time was a full-time satellite systems engineer at

SPAR in Montreal, and by far the most experienced spacecraft designer and project organizer on the team), Henry Spencer, Andrew Williams and Karl Horacsek. Multiple design workshops were held over a period for three years, with (at its peak) about 100 people participating. A proposal was submitted to the CCQJC's design competition, earning an "honorable mention." A second, improved design was developed after that, as shown in Figure 6–22 (as painted by team member Paul Fjeld); it was designed to be launched into Earth orbit, raise its orbit by solar sailing to escape from Earth orbit, and then spiral out from the Sun, eventually to cross Mars' orbit. This design is described in [24].

Figure 6–22: Painting by Paul Fjeld of the final CSSP Solar Sail design.

By 1991, preliminary design was complete, and the cost to complete the project was estimated to be $20M. Sponsorships had been secured for about half that amount. Unable to close the project's budget, the CSS decided to terminate the project.

While this spacecraft never flew, it was a fairly serious (although insufficiently funded) spacecraft design project, undertaken by a team led by a core of trained Canadian space systems engineers. As far as I know, it was the very first even-vaguely-serious attempt to develop a Canadian-led planetary exploration mission. Other Canadian-led planetary mission designs have been attempted since then, mostly led by CSSP alumni (myself and Henry Spencer); Canada has yet to lead a planetary exploration mission.

There is a direct connection between the CSSP and another project that I led about ten years later—MOST, which was Canada's first microsatellite mission (described in Section XIV). This in turn led to the founding of the Space Flight Laboratory at UTIAS, which has gone on to become one of the world's most prolific developers of high-capability nanosatellite and microsatellite missions.

VIII.2. 1991: CSA Moon/Mars Working Group Submission

On July 20, 1989, the 20th anniversary of the Apollo 11 Moon landing, US President George H. W. Bush announced (on the steps of the National Air and Space Museum) a new “Space Exploration Initiative (SEI),” whereby NASA was to resume crewed missions to the Moon, and continue on to Mars. In Canada, the Canadian Space Agency was formed in 1990, and one of its first new activities was to begin considering how Canada might participate in NASA’s SEI. A CSA-internal Moon/Mars Working Group was formed, and that group sought ideas regarding possible Canadian contributions.

As President of the CSS at the time, I approached the MMWG, offering that CSS put together a set of recommendations; that offer was viewed positively. Accordingly, at CSS we held a series of workshops in late 1990 and early 1991 in Toronto, attended by more than twenty CSS members. Individual teams examined different areas of possible participation by Canada in SEI: lunar resource extraction, teleoperated rover vehicles, space propulsion, and others. Case studies were written up for each of these, along with a rationale for why Canada should participate in SEI, into a report that was submitted to CSA’s MMWG.

This activity did not result in any particular Canadian planetary exploration missions—Bush failed to convince Congress to fund SEI, which died, and CSA’s interest in the Moon and Mars died with it. However, this did “get the CSS onto the CSA’s radar screen,” which led to later, more-successful lobbying efforts by CSS (see Section XIII).

Also, notable among the workshop’s recommendations was that Canada undertake the development of robotic lunar rovers, as a logical follow-on to the Space Shuttle and Space Station robotic Canadarm programs; as far as I can tell, this was the first time that anyone had suggested that Canada’s space program begin developing planetary rovers—now, thirty years later, Moon and Mars rovers have become a key part of Canada’s planetary exploration program. This particular concept was conceived by Henry Spencer; he was assisted in its development and write-up by Steve Horvath, Keith McEwen, and Ron Wessels. Henry (born in 1955 in Saskatchewan), a software developer internationally well-known in UNIX circles, was a stalwart member of the CSS, having started attending its meetings in 1983, and contributing significantly to all CSS projects and activities; he has gone on to be a developer of embedded software on numerous Canadian microsatellites and nanosatellites.

Figure 6–23: Younger versions of (left) Kieran A. Carroll, (right) Henry Spencer.

Key CSS participants in this Workshop and reporting activity were:

- Kieran A. Carroll (CSS President)
- Mark Lozowski (workshop organizer)
- Marion Adams
- Drew Allen
- Jocelyn Boily
- Dev Gossain
- Susan Gropp
- Paul Fjeld
- Steve Horvath
- Robert Kelly
- Keith McEwen
- Ted Molczan
- Christopher Neufeld
- Wayne Rhodes
- Wolfgang Riechmann
- Neil Roger
- Richard Simm
- Henry Spencer
- Paul Swift
- Scott Wall
- Ron Wessels
- H. Peter White

IX. Early 1980s: Gordon Walker and Bruce Campbell, Exoplanets

Prior to 2000, the only planets known to exist in the universe were those in our solar system. There had been considerable speculation for many years about the prospects of planets around other stars, but astronomical observing techniques up to that time were not sensitive enough to make any detections of such "exoplanets."


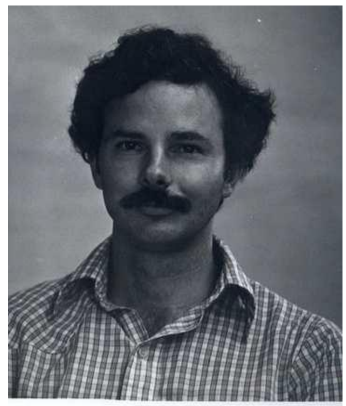

Figure 6–24: Gordon Walker and Bruce Campbell.

Some of the first tentative exoplanet detections were made by a Canadian team led by Bruce Campbell, Gordon Walker and Stephenson Yang, at the University of British Columbia, who invented a new ultra-sensitive instrument, which involved placing a hydrogen fluoride absorption cell in front of a spectrograph, to impose wavelength fiducials directly on observed starlight, to detect changes in the radial velocities of stars caused by their planets "tugging" them alternately towards and away from Earth [25]. Using this, in 1988 they made a tentative discovery of one or more planets around the star Gamma Cephei, and later did the same for the star Epsilon Eridani. However, for those initial observations the planetary signal for Gamma Cephei was overlain by a weak stellar chromospheric activity variation in sync with the planetary period, which suggested the "planetary" signal might instead be due to rotation variability of the star, leading the astronomers to decide not to claim an actual discovery of a planet at that point. Later, the weak chromospheric signal faded out in more extensive subsequent observations, and detections of exoplanets orbiting each of these stars was eventually confirmed. (This story is described in [25b].)

X. Early 1980s: Janis and Paul Chodas, JPL Planetary Missions

Janis and Paul Chodas are Canadian aerospace engineers who both carried out graduate research at the University of Toronto Institute for Aerospace Studies (UTIAS), in Prof. Peter Hughes' Spacecraft Dynamics and Control research group (of which I also became a member, in 1982)—where they met, and married. Janis completed her MASc degree in 1980, and Paul his PhD in 1986. They both joined NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California after completing their degrees, and both have since been involved in numerous NASA planetary exploration missions.

Figure 6–25: Janis and Paul Chodas.

Janis was a controls engineer on the Galileo mission to Jupiter, a technical manager for the attitude control system on the Cassini mission to Saturn, a manager on the Mars Exploration Rovers (Spirit and Opportunity), and Project Manager for the Juno mission to Jupiter. She is currently the Project Manager for the Europa Clipper mission (her third mission to the Jupiter system!). Prior to becoming the Europa Clipper Project Manager, Janis managed JPL's Engineering and Science Directorate, a ~4000 person organization of engineers, scientists and technologists who formulate, develop and operate JPL's robotic spacecraft missions that explore our Earth, the solar system and beyond.

Paul has worked on the orbital dynamics of comets and asteroids for his entire career, including making impact predictions for Comet Shoemaker-Levy 9 on Jupiter and a few small asteroids on Earth. Along the way he has worked on some mission teams, including the Magellan Venus radar mapper, and the proposed Asteroid Redirect Mission (ARM). He is now Manager of NASA's Center for Near-Earth Object (NEO) Studies and is involved in many NASA asteroid exploration activities.

XI. 1980s: Ulysses High Flux Telescope

The NASA/ESA Ulysses spacecraft [26] was launched on Oct. 6, 1990, on a mission to study the Sun from a vantage point alternately over its north and south poles. In order to accomplish the plane change needed to reach its design orbit inclination of 79.11°, the spacecraft was launched on a trajectory towards Jupiter; a gravity assist maneuver at Jupiter provided the enormous ΔV needed. While Ulysses' main mission was to study the Sun, its instruments were also suitable for making some observations of Jupiter while in that planet's vicinity. It also subsequently made observations of the comets C/1996 B2 (Hyakutake), C/1999 T1 (McNaught–Hartley) and C/2006 P1 (McNaught), in each case when the spacecraft passed through those comets' tails.

Ulysses carried a set of Canadian-provided instruments: the High-Flux telescope (HFT), which was part of the mission's the COsmic ray and Solar Particle INvestigation (COSPIN) suite of instruments. The COSPIN Principal Investigator was Dr. R. Bruce McKibben of the University of New Hampshire; the HFT Co-Investigator was Dr. John David Anglin, Herzberg Institute for Astrophysics, National Research Council of Canada. HFT was designed to measure ~0.3–7 MeV protons, and 0.4–4 MeV/n He with a small aperture single detector telescope for use in very high flux situations. The HFT project is described in [27], and the HFT instruments are shown in Figure 6–26.

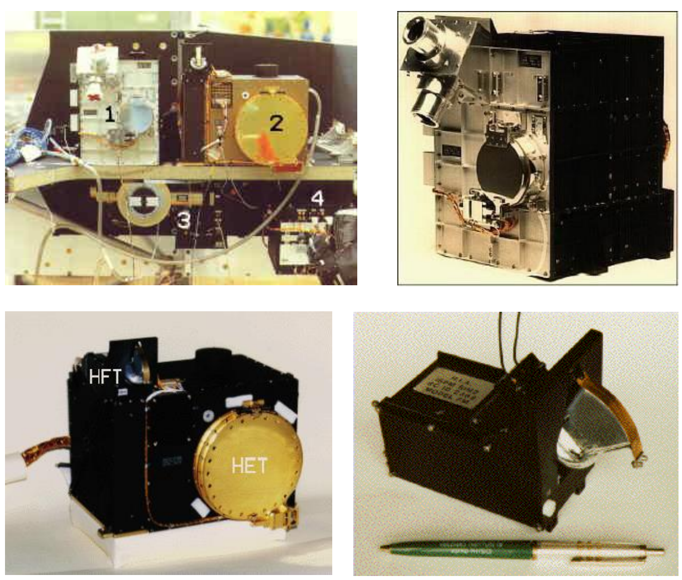

Figure 6–26: HFT Instrument Equipment.

XII. 1990s: Andrew Yau, Greg Garbe, Thermal Plasma Analyzer for Nozomi

In the 1990s, Dr. Andrew Yau and Dr. Greg Garbe were professors in the Department of Physics and Astronomy at the University of Calgary, and were co-Principal Investigators on the Thermal Plasma Analyzer (TPA) experiment, which was funded by the Canadian Space Agency. The TPA instrument was a Canadian contribution to the Japanese Mars orbiter mission, Nozomi (previously known as Planet-B). TPA's purpose was to measure thermal-energy ions in the topside ionosphere of Mars, and suprathermal ions and electrons in the Martian magnetosphere and magnetotail, while mounted on a boom on the exterior of Nozomi. Broadly speaking, it was intended to make measurements that would help researchers understand the mechanisms that have led to Mars' atmosphere "leaking away" into interplanetary space [28].

The Nozomi spacecraft was led by Japanese space science agency, ISAS, and the University of Tokyo. It was launched on July 3, 1998. Unfortunately, due to several failures of on-board systems, Nozomi failed to enter Mars' orbit; after several years of maneuvers in orbit around the Sun, the mission was terminated.

TPA is very notable for being the first-ever project funded by the Canadian government that was dedicated to planetary exploration (HFT being principally a Solar science instrument, only incidentally used for making Jupiter observations). While spacecraft-level issues kept TPA from achieving its planetary exploration goals, the fact of it being funded by CSA was a harbinger of a tide that was beginning to change in Canada's space program.

Figure 6–27: Andrew Yau and the Thermal Plasma Analyzer instrument.

XIII. 1990s: Andrew Yau, Greg Garbe, Thermal Plasma Analyzer for Nozomi

Since the 1980s, we at the Canadian Space Society had advocated that Canada begin to participate in planetary exploration projects. This included making representations to those running Canada's government space program; since its formation in 1990, the department responsible for that has been the Canadian Space Agency (CSA). Section VIII.2 describes the CSS's first foray into lobbying CSA on this topic. This was followed by a CSS submission to a CSA-held "Long Term Space Plan 2 conference" that was held December 11–12, 1991, on the topic of "A Goal for the Canadian Space Program," the goal we recommended being "To explore the solar system, and to develop it for human use." My recollection is that there were no others at that CSA planning event who were advocating for Canadian planetary exploration.

Disappointingly, the "Long Term Space Plan 2" that came out of this process (three years later, after a change in government), titled "The Canadian Space Program: A New Horizon" (downloadable from [29]), made no mention of planetary exploration. Over the next few years, CSS members had numerous conversations and engagements with people in the CSA, to try to understand why that was. (As President of the CSS at the time, as well as being an engineer working actively in Canada's space program, I had frequent access to people at CSA through this period, several of them near the top of that organization.) The answer was that "the CSA did not have a mandate to carry out planetary exploration"; the CSA's official Objectives at the time were to continue with on-going programs, contribute to economic growth and prosperity, advance knowledge, and various other mainly bureaucratic goals. In particular, we were told that "CSA does not have a Program Line for planetary exploration." Funding was divided up amongst existing Program Lines, including the Space Station program, Radarsat and others; without have a Program Line as a "home," new initiatives were very difficult to start.

We asked how one goes about getting a new Program Line created; the answer was to wait until the next Long Term Space Plan process, and try again, in the meantime continuing to press our point whenever we could. The next such opportunity came in 1996, when the "Long Term Space Plan 3" process began to be organized. By this point, CSS had gained the interest of the CSA executive who was leading the LTSP-3 planning process, Dr. Karl Doetsch [30], who was CSA's V.P. Programs. He decided to invite numerous "outsiders" into the LTSP-3 process, giving people from across the Canadian space sector opportunities to create and argue for new program proposals. In my capacity as CSS President, he invited me to become a member of one of the several working groups tasked with generating program proposals, the "Space Technology Working Group," as part of what was termed a "Space Vision process."

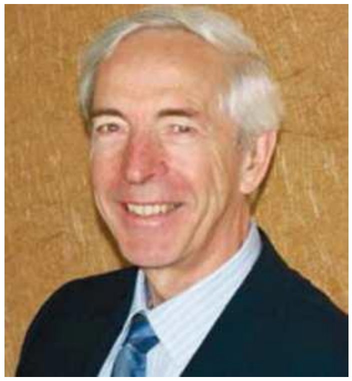


Figure 6–28: Karl Doetsch and Chris Sallaberger.

Once again, as we had done to generate inputs to CSA's Moon/Mars Working Group in 1991, the CSS convened a workshop activity, in which several dozen CSS members participated in several working meetings over the course of 1996–1997, conceiving and prioritizing concepts for numerous possible new CSA programs. I attended many meetings of the STWG and injected these CSS-generated ideas. Several such ideas were deemed worth initial consideration by that WG:

- A Moon/Mars Program, focusing on planetary exploration
- A Space Power Program, focusing on solar power satellites
- An Advanced Propulsion program, focusing on solar sails
- A Life Support Systems Program, aimed at supporting future human planetary exploration
- A Space Technology Microsatellite program

Of these, the Moon/Mars proposal was selected for advancement, under the title "Planetary Exploration Technology Program" [31]. Up to that point in the process (in mid-1997), program proposals were advocated for by those people outside the CSA who had authored them. For each proposal that advanced past this stage, a CSA staff member was assigned to work with the external proposer, to work together to fill out the proposal's details, and get it into a shape where it could be evaluated by CSA senior management. The CSA person whom Dr. Doetsch assigned to work with me on polishing the Planetary Exploration Technology Program proposal was Dr. Christian Sallaberger, who at that point was a Manager in CSA's Space Exploration and Science group (who had obtained his

PhD from UTIAS at the same time as me, in 1992). After several months of working together on that, the LTSP-3 process reached a stage where all live proposals were moved into a fully internal process; from that point onward, Chris was responsible for this proposal, as its internal champion.

On July 19, 1999, the CSA released the results of the LTSP-3 planning process, in a document titled "National Paper: The Canadian Space Program" (downloadable from [32]). It included specific mention of "planetary robotics missions" and "the growing interest in planetary exploration," and announced the start of a new Space Exploration Program, to be contained within CSA's Space Science Branch, described thusly: "The Space Exploration program will enable our scientific community and industry to participate in and contribute to the international effort aimed at understanding our solar system in relation to the origin of life and evolution of our environment. Activities to be supported include Canada's participation in international missions to other planets."

Finally, the CSA had a Program Line in place, into which Planetary Exploration projects could be proposed! A new era of Canadian government sanctioned and funded planetary exploration had finally begun.

XIV. 1996: MOST, Exoplanets

The 1999 CSA Space Exploration Program marks a watershed, between the era in which Canadian planetary explorers had to seek financial support from abroad (most often by leaving Canada), and the present era in which our government will support some planetary exploration activities within Canada. In this chapter, I do not intend to describe Canadian planetary exploration activities since then (of which there have been several notable missions, with a growing number in development).

However, there is one more project worthy of mention, which has one foot on each side of that watershed—the Microvariability and Oscillations of STars (MOST) microsatellite mission. MOST was first conceived in 1996, by Polish Canadian astronomer Slavek Rucinski and me, in response to a call by the CSA's Space Science Branch for microsatellite space science missions. At the time I was working at Dynacon (a small Toronto-area space engineering company, spun off by Peter Hughes from his Spacecraft Dynamics and Control research group at UTIAS). I had approached Slavek in his role as Chairman of the joint CSA/Canadian Astronomical Society space astronomy committee, at a CSA "Small Payloads Program" (SPP) community briefing in February 1996, to solicit interest among Canadian space astronomers in solar sailing technology (which I was then attempting to develop into a business area for Dynacon, following the

CSSP project described in Section VIII.1, which Dynacon had supported), for planetary exploration purposes—which he had to decline, since (as explained in Section VIII.2) the CSA at that point was not open to funding planetary exploration work, and Space Astronomy was defined in Canada to be limited to stars outside the solar system. But while we thus couldn't work on solar sail missions together, Slavek pitched to me his idea for a small space telescope mission in Earth orbit to carry out asteroseismology science; I rationalized working on that with him as being a step towards learning how to develop small, low-cost spacecraft, which could be a step towards later solar sail missions. We proceeded to work together to develop a proposal to submit into CSA's SPP Announcement of Opportunity for microsatellite missions, later that year. Of the twelve proposals received b CSA, our MOST proposal was one of four selected for Phase A studies.

After completion of that study, Slavek passed the Principal Investigator torch for MOST to Dr. Jaymie M. Matthews (OC) (born 1958 in Chatham, Ontario) [33], an astronomy professor at the University of British Columbia in Vancouver (Slavek remained as a member of the MOST Science Team). Jaymie's role was to lead the MOST Science Team, and to develop its instrument payload. My role was as overall system architect, leading the engineering team that designed the mission and satellite; Dynacon was the mission prime contractor. Our Phase BCD proposal won a competition against the three other proposed missions, and MOST (also known as Canada's "Humble Space Telescope") went on to be launched on June 30, 2003, spending the next sixteen years making astronomical observations from space, greatly exceeding our initial performance and lifetime expectations (while at a cost ten times lower than any previous Canadian satellite).

Figure 6–29: Jaymie Matthews with MOST.

The principal science proposed for MOST was asteroseismology [34], making very precise measurements of the fluctuations of the brightness of targets stars over extended (many weeks) durations. These data could then be used to detect seismic-like oscillations of those stars, and from that their internal structure and development history could be inferred. In addition to that, there was an another, planetary-exploration science objective—to search for evidence of planets around other stars, *i.e.*, exoplanets.

Section IX describes how Gordon Walker and Bruce Campbell at UBC pioneered ground-based astronomical techniques for detecting exoplanets, using the radial velocity technique, which looks for shifts in emission lines from stars due to doppler shift caused by periodic motion in the line-of-sight direction. One of the MOST science team members, Dr. Dimitar Sasselov of the Harvard-Smithsonian Center for Astrophysics, led another major investigation using MOST, looking for signs of photometric detections of transits to search for exoplanets around MOST's targets stars. (Coincidentally, when Dimitar was doing his PhD at the University of Toronto in the 1980s, he participated in the Canadian Solar Sail Project described in Section VIII.1) At the time Sara Seager (born July 21, 1971 in Toronto, Ontario) was a PhD student of Dimitar's at Harvard (having obtained her BSc degree from the University of Toronto), researching the atmospheres of the so-called "hot Jupiter" planets that were being detected using the radial velocity method around other stars. As members of the MOST Science Team, Dimitar and Sara used MOST to search for extra-solar planets in the photometric light-curves of MOST's target stars, looking for dips in brightness when a planet passes in front of a star, and/or an increase in brightness due to starlight reflected from the target star when a planet comes close to passing behind the star.

Figure 6–30: Dimitar Sasselov and Sara Seager.

This technique has succeeded in making detections using MOST, of planets around other stars. For example, transits were detected by a "Super-Earth," the innermost planet "e" orbiting the star 55 Cancri, using fifteen days of MOST photometry data from that star [35], taken in Feb. 2011. And in [36], the MOST science team reported their progress on attempting to measure light reflected from an exoplanet, setting an upper limit on the albedo of "hot Jupiters" around the stars HD 209458 and HD 189733.

Sara is now the Class of 1941 Professor of Planetary Science, Professor of Physics, and Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology. She is involved with a number of space-based exoplanet searches (for which MOST paved the way), including NASA's past Kepler mission, as the Deputy Science Director for the MIT-led NASA mission TESS, as the PI for the on-orbit JPL/MIT CubeSat ASTERIA, and as a lead for Starshade Rendezvous Mission (a space-based mission concept under technology development for direct imaging discovery and characterization of Earth analogs). While those mission are much more capable than the small, "humble" MOST space telescope was, she and the rest of the MOST science team pioneered the space-based exoplanet detection techniques used by those later missions.

While MOST was not funded out of CSA's new Space Exploration Program (described in Section XIII), it has the distinction of being the first space mission funded by CSA which had specific planetary exploration objectives, and which succeeded in accomplishing those objectives. It can be seen as being either the last planetary exploration mission carried out by Canadians before the 1999 Space Exploration Program watershed, or the first such mission carried out after that.

While Dynacon was closed a few years after MOST was launched, one portion of the MOST engineering team has survived and thrived—the Space Flight Laboratory (SFL) at UTIAS (under its founding Director Dr. Robert E. Zee), which we set up to develop much of the MOST satellite bus and its ground stations, has gone on to become one of the world's leading developers of low-cost, high-capability nanosatellite and microsatellite missions. Rob Zee, Henry Spencer and I continue to lead a Microsatellite Systems Engineering course at SFL, which we started in support of MOST; the design projects from that course have included numerous preliminary designs for microsat-class planetary exploration missions. We continue to promote the idea of future Canadian-led low-cost planetary exploration missions, developed using the "Microspace" technology used in SFL's past and current missions, which we brought to Canada to enable the MOST mission, which in turn can trace its roots back to the earlier CSS Canadian Solar Sail Project.

Acknowledgments

I gratefully acknowledge the friendship and collegiality offered to me by Owen Maynard, Bryan Erb, Phil Lapp, and Barry French, and many others described here, along with the stories that they shared with me about the space projects they worked on. It has been an honor and a great pleasure, spending time with and learning from these great Canadian pioneers of planetary exploration.

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