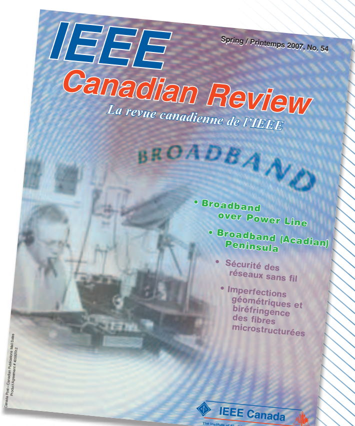
Canada's first foray into space -Alouette 1

Alouette I, the first Canadian-built satellite had more than a few sceptics to convince when initial plans for it were discussed at the Pentagon in 1958. Expected by some to function for less than 2 hours, it endured until 1972, having transmitted 10 years of comprehensive and detailed data about Earth's ionosphere and upper atmosphere. Despite unanticipated design challenges requiring novel approaches the satellite was ready for launch on schedule with much cooperation between project engineers and the Defense department. The recognition for needed expertise in satellite communication was the impetus for the development of a strong domestic space industry. Canada went on to develop Alouette II and two observatory satellites, Isis I and II launched in 1969 and 1971. The Canadian Space Agency launched MOST, a micro satellite in 2003 followed by SCISAT for ozone exploration in the same year.

"One of the ten most outstanding achievements in Canadian engineering in the past 100 years" (Centennial Engineering Board of Canada, 1987)



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by Colin A. Franklin

The Alouette Satellite Program

An International Milestone in Canadian Science and Engineering

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Abstract

With the launching of Canada's first satellite Alouette 1 from Vandenberg Air Force base, California on 29 September, 1962 Canada became the third nation in the world, after the Soviet Union and the United States, to design, build and control a satellite. The Topside Sounder Alouette 1 was an immense scientific and technological success. It was designated by the Centennial Engineering Board of Canada in 1987 as one of the ten most outstanding achievements in Canadian engineering in the past 100 years and in 2007 was designated an "event of national historic significance" by the government of Canada. It was also designated an IEEE Milestone in Electrical Engineering and Computing. This paper describes the little known origins of the program in the Department of National Defence, how the satellite was designed and its significance for the future of Canada in space. Rather than a detailed technical presentation it is more of a personal perspective from someone who was there from the beginning.

Sommaire

Avec le lancement du premier satellite canadien Alouette 1 depuis la base aérienne de Vandenberg (Californie) le 29 Septembre 1962, le Canada devient la troisième nation au monde après l'Union Soviétique et les États-Unis à concevoir, construire et opérer un satellite. La sonde en contre-haut Alouette 1 a été un immense succès scientifique et technologique. Elle a été désignée par le Comité du centenaire du génie canadien en 1987 comme une des plus remarquables réalisations du génie canadien des derniers 100 ans, et en 2007 comme un « événement d'importance historique nationale » par le Gouvernement du Canada. Elle a aussi été reconnue comme un Jalon du IEEE en génie électrique et informatique. Cet article décrit les origines peu connues du programme au ministère de la défense nationale, comment le satellite a été conçu et son importance pour le futur du Canada dans l'espace. Plutôt qu'une présentation technique détaillée, il s'agit plutôt de la perspective personnelle de quelqu'un qui y était depuis le début.

The Defence Research Telecommunications Establishment (DRTE), Ottawa is where the Alouette program was conceived and where the first two satellites were largely designed and built. It was one of a number of establishments of the Defence Research Board (DRB) which reported to the Minister of Defence. DRTE had its origins in ionosphere sounding activities carried out by the Canadian Armed Forces and NRC during WW II. Before the satellite era, radio propagation via the ionosphere was the main method of long distance communications, other than via landlines and underwater cables. Subsequently DRTE became a leader in the field of ionosphere research and by the late 1950s had become one of the foremost research establishments on the continent, with Radio Physics, Communications, and Electronics laboratories that were on a par with any in the world. In 1969 DRTE was transferred to the newly created Department of Communications and renamed the Communications Research Centre (CRC). CRC is now an agency of Industry Canada and is the government of Canada's primary laboratory for R&D in advanced space and terrestrial communications.

With the launching of Sputnik in October 1957 it was realized at DRTE and elsewhere that a satellite-borne radar would provide a very powerful means of exploring the ionosphere from above (topside sounding), and that this could have important implications for long distance radio communications. The origin of the idea, is not clear but it was Dr. Eldon Warren who picked up the concept and put forward the daring proposal that DRTE should build a swept frequency topside sounder.

In July 1958, Lloyd Berkner, Chairman of the Space Science Board of the National Academy of Sciences of the United States announced that space and facilities in satellites would soon be available and called for suggestions for experiments on the upper atmosphere. This produced an immediate response from Peter Forsyth at the University of Saskatchewan for a rudimentary single frequency sounder - which was later expanded to four frequencies. At a meeting in October 1958, called by H.G. Booker of Cornell University to discuss ionosphere experiments in satellites, a number of groups in the USA and two from Canada – DRTE and the University of Saskatchewan - indicated their interest in topside sounding.


Eldon Warren


Jim Scott

This meeting resulted in Jim Scott, the Chief Superintendent of DRTE submitting a proposal to build a topside sounder satellite, firstly to ARPA at the Pentagon in Washington on 13 November 1958 and then to the newly created NASA on 31 December 1958. Not a simple sounder operating on a few frequencies, but a 0.5-12 MHz swept-frequency one that duplicated in a satellite the functions of ionosphere sounders then used from the ground (see Fig. 1). In the meantime, and on the assumption that the proposal would be accepted, work began on the satellite project at DRTE in January 1959. Sputnik and the cold war produced a sense of urgency.

NASA officials listened to the Canadian proposal with more than a little scepticism. They were convinced that the power and antenna problems involved, and the sheer technical complexity of installing the equivalent of a bottom side sounder in a satellite was far too difficult to do at that time. International science was a definite plus for the fledgling NASA, however, so they agreed to invite DRTE to join their Topside Sounder Working Group, to launch the Canadian experiment. They sent the proposal along to the Central Radio Propagation Laboratory (CRPL) at Boulder, Colorado, to examine it for scientific merit and engineering feasibility. The CRPL agreed with the NASA view that the proposal was too ambitious, so their report recommended a fixed-frequency experiment as a first-generation Topside Sounder, and that DRTE "be encouraged to develop its swept-frequency system as a second-generation experiment."

A remarkable feature of the proposal was the absence of a serious feasibility study – apart from some basic calculations by Eldon Warren. For example no one knew how to design the sounder antennas or what the size, weight, and power consumption of the instrumentation might be.

There was no MOU and instead the agreement was formalized in an exchange of letters between the DRB Chairman (Zimmerman) and the Administrator of NASA in August 1959. It was to be a cooperative undertaking between Canada and the U.S. with each country paying its own costs in the project. The principal Canadian objectives of the program are listed at the top of the next page.

The Canadian contribution was to consist of the following: develop an ionospheric sounder for installation in a satellite to be provided by NASA; construct three models, one for installation in a satellite, one spare and one prototype; provide telemetry and recording equipment for at least one year at each of four stations, Resolute Bay, Churchill, Ottawa and St John's; exchange copies of all ionograms with cooperating agencies. The United States agreed to provide the launch vehicle, launch facilities, and a worldwide network of ground stations. The U.K. joined the program later and provided four telemetry stations. As the project progressed three additional experiments were included - to measure cosmic noise, very low frequency (VLF) radio emissions and energetic charged particles. The last experiment was contributed by NRC.

By late 1959 however it became clear that the sounder system was too complex to be designed independently of the satellite. This meant that DRTE would now have to provide three satellites (two flight models and a prototype). This news was reportedly not well received at DRB HQ and ultimately led to a major diversion of finances and manpower from other programs in DRTE plus a subsidy from DRB itself.

The rest is history; the CRPL/NASA fixed frequency satellite (S-48) suffered delays, the Canadian satellite (S-27) kept more or less on schedule; S-48 suffered more delays; S-27 was launched on 29 September 1962, to become Alouette 1, the first satellite to be designed and built by a nation other than the United States or the Soviet Union. S-48 was eventually launched in August 1964. NASA later admitted publicly that they and CRPL were so convinced that S-27 could not possibly function for more than an hour or two, if at all, that they had made no plans to use data from it. In fact Alouette 1, constructed at a time when most satellites had a useful lifespan of a few months, continued to function and provided a wealth of data for ten years before it was turned off from the ground.

2.0 Design Challenges

Text books on space technology and the in-orbit radiation environment were non-existent and the open literature and internal NASA reports were sparse. The young Canadian engineering team had no prior experience in the design of space systems and hardware but was highly skilled in the emerging area of solid state electronics. It also had the great advantage of being in day-to-day contact with scientists in the Radio Physics and Communications Laboratories in DRTE. The decision by NASA to provide a relatively large launch vehicle, a Thor Agena-B, was a great help and eliminated weight as a serious constraint in the design of the satellite. Finally there was the excellent support received from the emerging Canadian space industry and the close working relationships and trust that developed with our NASA, CRPL and AIL (Airborne Instrument Laboratories) colleagues - AIL built the U.S. topside sounder. Indeed, once the technical work started we dealt with our US colleagues as if we were all part of one big family.

Little of the technology developed for ground-based sounders was directly applicable. Aside from the use of vacuum tube systems with their associated reliability problems and weight, size and power consumption, these sounders typically used large antennas and high power transmitters. Initially it was thought that these problems might best be solved using a swept-frequency CW radar instead of a more conventional pulse system, and a good deal of time was lost on this approach [1]. The development of a vacuum tube transmitter was then undertaken – but abandoned when a parallel development showed the required performance could be obtained using transistors [2].

There were strenuous debates on the subject of transmitter power. Caution said to keep it low for reasons of cost, reliability and power consumption. The bolder approach eventually prevailed and a transmitter power ten times greater than the calculated minimum needed was finally chosen. This was a milestone decision since it greatly eased the antenna design and the mass production of high quality ionograms.

There were more stormy debates, this time on cosmic noise. Two attempts were made to measure cosmic noise using Javelin rockets launched from Wallops Island in 1959. They failed. In 1960 a 3.8 MHz cosmic noise receiver was designed and flown on a U.S. navy TRANSIT navigation satellite, providing the first measurements of cosmic noise to be made above the ionosphere [3].

PRINCIPAL PROGRAM OBJECTIVES

- Provide a basis for improvements in shortwave radio communications, particularly at higher latitudes, through a better understanding of the physics of the ionosphere
- Acquire a better understanding of the properties of the ionosphere for the scattering and deflection of radar beams
- Develop a Canadian capability in space technology

One of the most difficult problems was the design of the sounder antenna system which had to cover a 0.5-12 MHz frequency range. This eventually consisted of two antennas in a crossed dipole configuration - 150ft tip-to-tip for the lower half of the frequency range and 75 ft tip-to-tip for the upper half of the frequency range [4]. Fig.2 shows the satellite with antennas extended during tests at de Havilland.

After examining a range of possibilities, all of which seemed impractical, a solution to the problem was found in a visit by DRTE engineers to NRC. A design by George Klein for an extendible antenna was suggested as a possible approach. A 20ft antenna had been designed and built by Klein at NRC in 1951, as a solution to a UK requirement for an antenna for a radio beacon to be dropped by military aircraft.

It looked promising and was forwarded to de Havilland (later Spar Aerospace) for evaluation and possible development. Klein's key idea was to preform a thin flat strip of spring steel into a cylindrical tube with an overlapping seam, and heat treat it. It is then stored in flat form on a spool. On extension the steel strip curls into its pre-

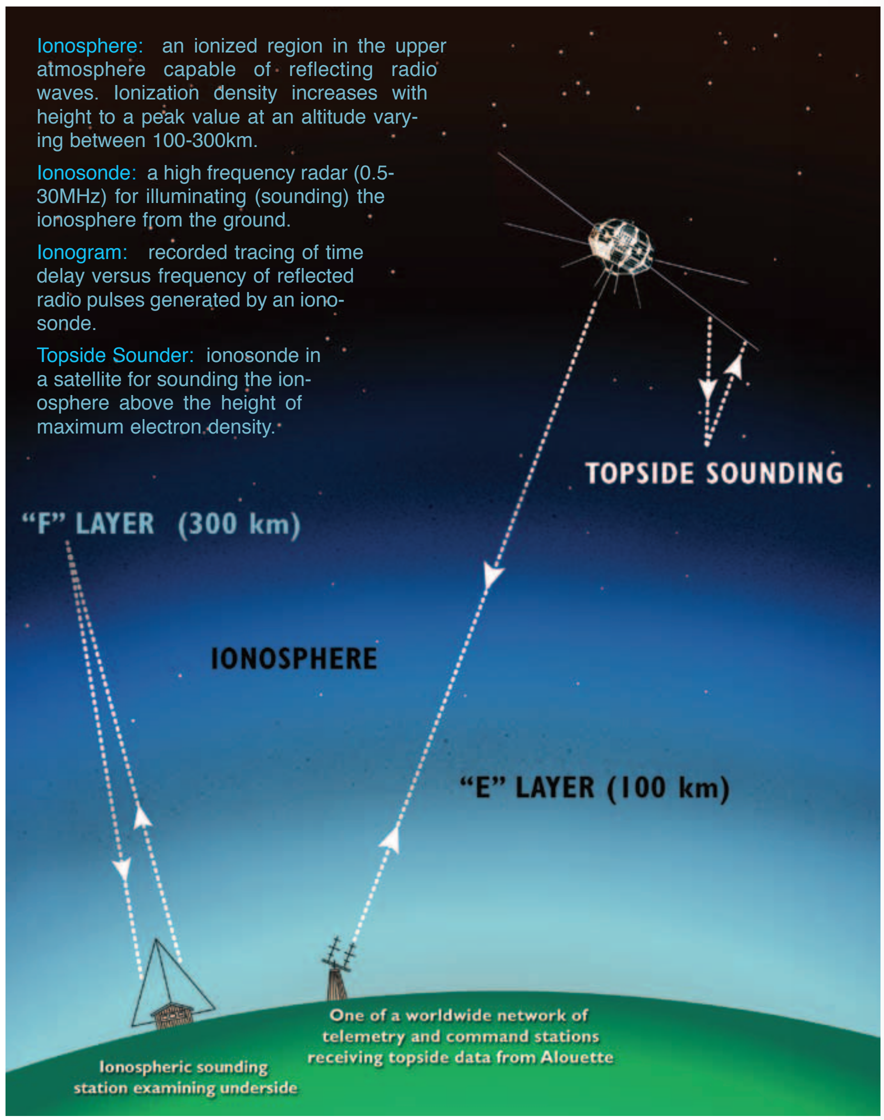

Figure 1: Bottom and Topside Sounding

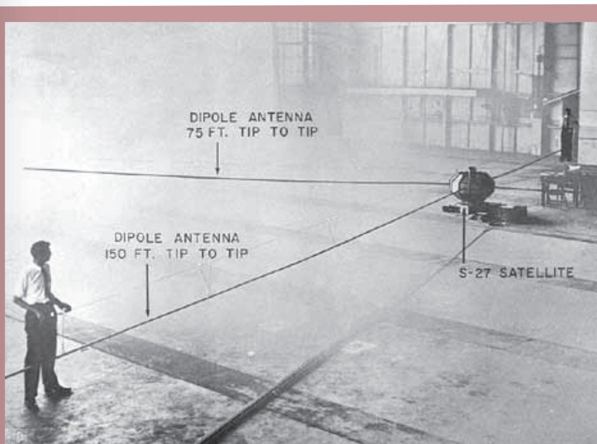

Figure 2: Satellite with Antennas Extended

formed shape to form a tube with considerable bending strength. A major devel-opment effort was required by de Havilland to convert the basic idea into an antenna for space use. (See across this page an Alouette STEM antenna module, serial no. 001). Mechanisms based on the concept subsequently became known as STEM devices or storable tubular extendible members and have been used on many domestic and international space missions. A test flight on a Javelin rocket from Wallops Island was carried out to test the extension of a pair of STEMs in space. It was a partial success; one STEM did not fully extend.

The VLF experiment was added almost too late in the program. The DRTE scientist responsible for its inclusion was Dr. Jack Belrose. It consisted of a 400 Hz – 10 kHz receiver connected to a sounder antenna - at a small risk to the main experiment. Designed and developed in six weeks, it was said to be the most cost effective experiment on the satellite and was a good example of how quickly decisions could be made and implemented on the program.

The design of the telemetry system was unexpectedly difficult. The sounder antennas generated multiple nulls in the radiation pattern of the telemetry antenna. Because the satellite was spinning, these nulls would have produced regular drop-outs in telemetry – which in turn would have hampered data analysis and severely reduced the value of the ionograms. The effect of the nulls was largely eliminated through a novel design of the telemetry and command antenna system in the satellite, and by diversity reception and combining on the ground [5].

Nine months before launch we had no telemetry transmitter to send the ionosphere data to the ground. This was due to the supplier, a major U.S. aerospace company, finding the specifications too difficult to meet. When John Stewart at RCA Victor (in Montreal, now EMS Technologies) heard of our dilemma over breakfast at a Solid State Circuits conference in Philadelphia, he proposed that his team could do it. He was told to go ahead, forget about costs and contractual details, and get us an engineering model within two months. He succeeded, the subsequent flight models operated flawlessly, and the design became the standard for subsequent Canadian and U.S. ionosphere sounder satellites [6].

3.0 Design and Testing

The approach taken on reliability was novel and controversial. Little reliance was placed on statistical reliability calculations. Instead we insisted on a thorough understanding of semiconductor devices and circuit operation and worked closely with manufacturers to ensure that only semiconductors with median parameter values were procured. Circuits capable of operating under much greater than expected temperature and power supply variations were developed to counter expected and unexpected modes of degradation and failure. The consequences of radiation damage to semiconductor components were minimized by designing for far larger variations in transistor parameters than was the accepted practice at the time. This was an early example of what is now known as Robust Design. At the time critics said we would end up damaging components and degrading reliability. Extreme temperature and voltage tests revealed time and again design weaknesses which were often easy to fix, and this was done even when the equipment had passed all its tests. To eliminate single point failures, there were spares for all transmitters and receivers and extensive redundancy in the power subsystem - including spare batteries. A great deal of effort was put into the design of the power subsystem including the design of dc-dc converters, suppression of transients and radio frequency interference, overload protection and dynamic load line analysis. To avoid seriously draining the batteries the satellite automatically switched off ten minutes after being turned on by a ground station. Finally we sent two flight spacecraft and two payload test teams to the launch site and ran a competition to decide which one to launch.

Similarly, on the mechanical side the structure and electronics units were designed for significantly higher than expected vibration levels. Also, deployable items were designed to be tested under 1g conditions on the ground, although critics claimed this was overdesign. Shortly before launch, to the alarm of the design team, the vibration levels previously specified by NASA for the launch vehicle were revised to much higher levels. New vibration tests on the spacecraft were required and were passed with no problems.

The power supply was designed for what appeared at the time to be a very pessimistic figure of 40% degradation for solar cell charging currents, after one year in orbit. This paid off as it allowed Alouette, unlike several U.S. satellites, to survive an unanticipated artificial radiation belt created in July 1962 by a hydrogen bomb test at high altitude over Johnston Atoll (South Pacific.)

With the assistance of the Defence Research Chemical Laboratories, Ottawa (now DRDC) a major effort was made to improve the reliability of commercially available Ni Cd batteries. This resulted in some important differences between the Alouette and ISIS batteries and those used in U.S. spacecraft. The resulting batteries functioned for ten years in Alouette 1 and 2 and twenty years in ISIS 1 and 2 and were superior to those used in any other space program of the period.

The electrical and mechanical design and most of the environmental testing was done in Canada. The Canadian Armament Research and Development Establishment, Valcartier provided the thermal-vacuum test facilities.

The De Havilland Special Products Division in Toronto, later to become Spar Aerospace Ltd, in addition to providing the STEM antennas, manufactured the satellite structure, and performed spin and centrifuge testing [7]. Sinclair Radio in Toronto designed the telemetry, command and beacon antenna subsystem in the spacecraft and were a major contributor in the design of the sounder antenna subsystem. Satellite vibration testing, dynamic balancing and solar simulation in vacuum was done at the NASA Goddard Space Flight Center. Detailed information on the design, construction and testing of Alouette 1 are given in [8]. Three views of the satellite are shown in Figs. 3, 4 and 5. John Chapman, Program Coordinator and Deputy Chief Superintendent of DRTE, is shown in Fig.3. Keith Brown, Satellite Section Head at DRTE and leader of the engineering team, is shown in Fig. 4.

4.0 The Launch Campaign

The two flight spacecraft and their test teams, numbering about thirty engineers and technicians, were flown to Vandenberg Air Force Base California by the RCAF in separate aircrafts. The prototype spacecraft was also brought along to verify any last minute changes on the flight spacecraft and rehearse mating with the launch vehicle. Pre-flight preparations took approximately six weeks. The Thor Agena-B was on a test flight. Alouette was underweight at 320 lbs and the vehicle had to be ballasted for launch.

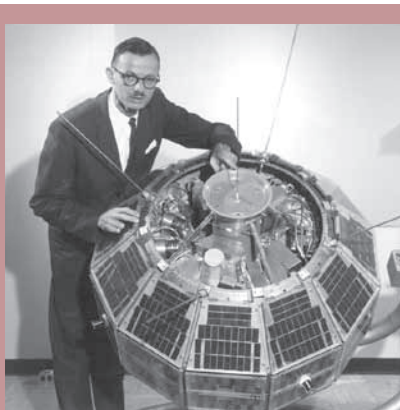

Figure 3: John Chapman with Backup Satellite – Oct. 1962

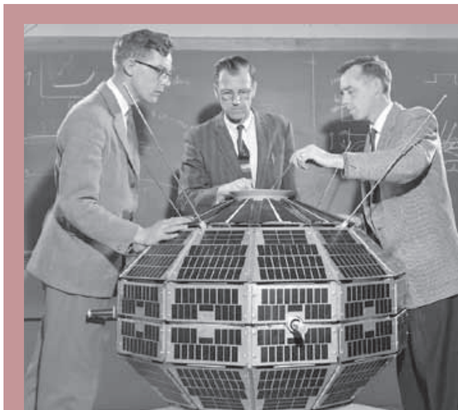

Figure 4: Alouette 1 and, from left to right, Colin Franklin, Keith Brown and John Barry

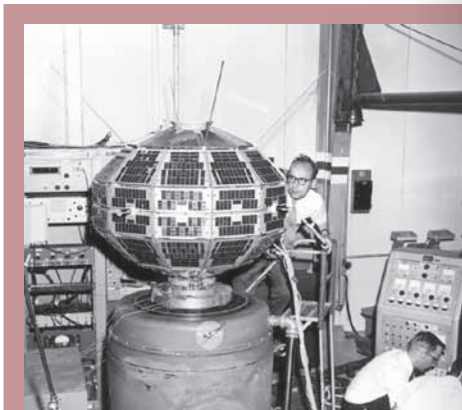

Figure 5: Alouette Vibration Testing, Goddard Space Flight Center

There were a number of launch delays due to Southern Pacific Railroad fruit trains which had the right of way and always arrived without warning, passing within 75 m of the launch pad. Furthermore, every time a launch was scheduled the 43 inhabitants of the nearby village of Surf had to be evacuated.

At launch there were two DRTE engineers at the NASA Fairbanks, Alaska ground station to confirm antenna extension and overall status of the satellite. A NASA ground station in Johannesburg and a ship in the Indian Ocean were to receive vehicle and satellite telemetry. Satellite telemetry was turned on at launch and kept on until injection into a near perfect 1000 km circular orbit at an inclination of 80.5 degrees to the equator. Fairbanks confirmed antenna extension and normal operation of the satellite and this was soon followed amidst much jubilation by the reception of the first ionograms at DRTE in Ottawa.

5.0 Program Achievements

Within a few weeks of the launch of Alouette 1, it was clear that the satellite would provide the comprehensive and detailed data on ionosphere structure that was its primary mission. Alouette 1 ionograms taken one day, six years and ten years after launch are shown in Figs. 6 and 7 on the following page.

This posed the question of whether there should be an ongoing satellite program and, if so, what form it should take. Most of the skills and expertise responsible for the success of the satellite were in a government establishment, and not in industry. If Canada was to reap the full benefits of space technology it needed a strong domestic space industry. John Chapman took the lead in negotiating with NASA a follow-up program of scientific satellites, and took action to ensure that an increasing proportion of the design and construction work would be carried out in Canadian industry. This led to the International Satellites for Ionosphere Studies (ISIS) programme in which Canada and the U.S. shared the major costs for the construction and launching of four more satellites; three Canadian and one U.S. The U.K. and seven other countries actively participated through the provision of telemetry facilities and scientific analysis effort. The three Canadian satellites were Alouette 2 - a refurbished Alouette 1 flight spare spacecraft launched in 1965 along with a U.S. probe satellite, and two observatory satellites ISIS 1 and 2 launched in 1969 and 1971 respectively. The two observatory satellites were heavier and more complex than the two Alouettes, and were prime contracted and built in Canadian industry. They carried tape recorders, probe and particle experiments from the U.S. and the U.K., and in the case of ISIS 2, two optical experiments. The principal experiment in each was still the ionosphere sounder which was essentially an upgraded version of the Alouette 1 system plus a fixed frequency sounder.

A further Canadian satellite in the series ISIS C was to study the higher regions of the ionosphere and magnetosphere out to 20 earth radii with 375 metre crossed dipoles. Planning was terminated on this satellite, to the great regret of the scientists and engineers involved, when the Canadian space program was redirected towards applications. It was necessary to wait 32 years for the next Canadian scientific satellite – the Canadian Space Agency (CSA) micro satellite MOST launched in 2003. This was followed also in 2003 with the much larger CSA ozone explorer SCISAT. Both satellites have been highly successful, are still fully operational, and are a further example of Canadian excellence in space science and engineering.

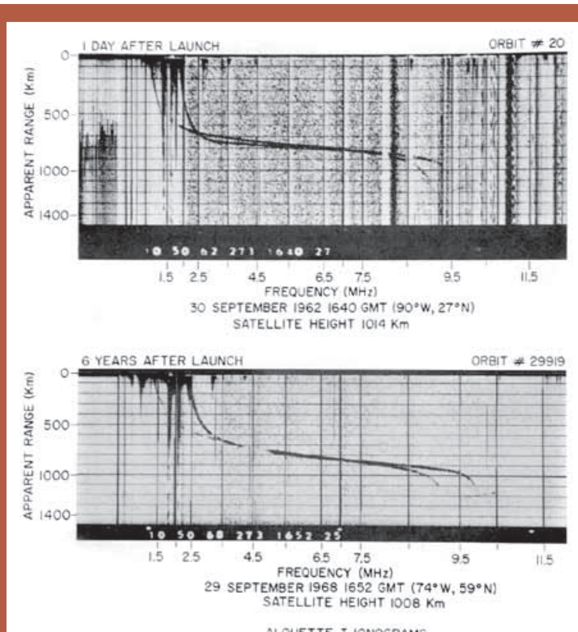

Figure 6: Ionograms – 1 Day and 6 Years After Launch

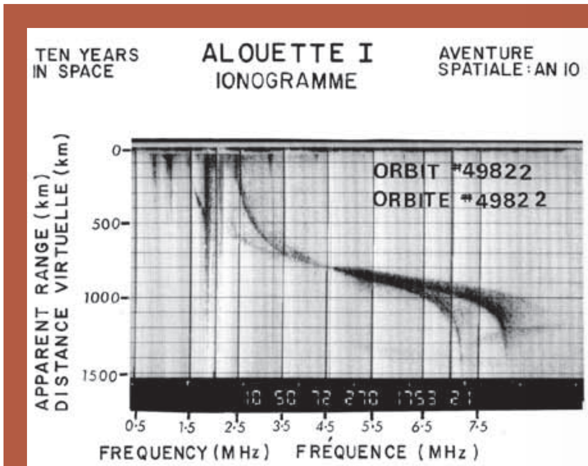

Figure 7:Ionogram – 10 Years After Launch

6. Conclusion

For ten years Alouette 1 provided scientific data that greatly extended our knowledge of the ionosphere and the earth's upper atmosphere. The success of this project led to the creation of Telesat and the Canadian space industry and its expansion into Communications, Remote Sensing, Robotics for the NASA Shuttle and Space Station, and Satellite Aided Search and Rescue. The fact that Alouette 1 performed so well and beyond all expectations gave Canada an international reputation for excellence in satellite design and engineering.

Acknowledgements

The author wishes to thank Louise Casavant and John Brebner of CRC for their assistance in preparing the figures and illustrations. Thanks are also due to Graham Booth and Friends of CRC for many background discussions on the Alouette 1 program and to Dr. LeRoy Nelms for his help on its early history. This paper is based on a presentation by the author at the IEEE International Milestone of Electrical Engineering Ceremony at CRC in 1993.

CANADIAN SCIENTIFIC SATELLITES

Alouette 1
1962 – 1972

Alouette 2
1965 – 1975

ISIS 1
1969 – 1990
loaned to Japan
1984-89

ISIS 2
1971 – 1990
loaned to Japan
1984-89

ISIS C
1969
magnetosphere sounder
(cancelled)

MOST
2003
micro satellite space telescope

SCISAT
2003
ozone layer explorer

Satellite Performance: Alouette — ISIS Program

- Alouette-ISIS program was an immense scientific and technological success with more than 1200 papers and scientific reports published.
- Alouette 1 satellite designated by the Engineering Centennial Board of Canada in 1987 as one of the 10 most outstanding achievements in the history of Canadian engineering in the past 100 years.
- Alouette 1 satellite programme designated an "event of national historic significance" by the government of Canada in 2007.
- Alouette-ISIS program designated an IEEE International Milestone of Electrical Engineering, at a ceremony at CRC, Ottawa, May 1993.
- Proc. IEEE, *Topside Sounding & the Ionosphere* Special Issue, June 1969.
- Alouette 1 and 2 operated for 10 years before being turned off. The sounders and VLF receivers in ISIS 1 and ISIS 2 operated for 20 years. Gradual deterioration of batteries ended the operation of the satellites.

Background Photo: Launch of Alouette 1 on September 29, 1962 atop a Thor-Agena rocket

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N.Ed.: This paper was also presented as the "McNaughton Lecture" on May 6, 2008, at the 21st Canadian Conference on Electrical and Computer Engineering. This followed the IEEE Canada Awards ceremony where the author received the IEEE Canada McNaughton Gold Medal in recognition of "outstanding contributions as a pioneer of the Canadian space program and a semiconductor circuit innovator".

About the Author

Colin A. Franklin graduated M.Sc in Physics from Auckland University, New Zealand and Ph.D in Electrical Engineering from Imperial College, London. He was Chief Electrical Engineer for Canada's first satellite Alouette, Chief Engineer for the follow-on ISIS satellite program. He was subsequently Project Manager for the Department of Communications (DOC) Hermes Communications Technology Satellite, and Director General of Space Programs at DOC. He is a Member of the Order of Canada (CM), Fellow of the Royal Society of Canada, Fellow of the City and Guilds Institute of London and Senior member of the IEEE. His awards include the IEEE Canada McNaughton Gold Medal, the Julien C. Smith Medal from the Engineering Institute of Canada, the John H. Chapman Award of Excellence from the Canadian Space Agency, and the Alouette Medal from the Canadian Aeronautics and Space Institute.