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ALOUETTE I

This is the story of an experiment in science, which opened the door through which Canada moved into the space age. Alouette was an achievement by a group of Canadian scientists and engineers, scientists who designed the experiments, engineers who designed the equipment. After ten years in orbit, Alouette continues on her daily tasks, measuring, reporting, and moving on in her ordered way, a tribute to her designers and builders, most of whom keep faith with Alouette and continue to listen to her daily messages from the Communications Research Centre of the Department of Communications on the outskirts of Ottawa. This brief story, written by the people involved, is a tribute to them all.

Late on the evening of September 28, 1962, with a bonechilling breeze blowing in from the dark Pacific, a Thor-Agena rocket, belching brilliant orange and white flame, lifted off its launching pad in Southern California, pushing Canada's first artificial earth satellite into orbit.

Named Alouette, after the high-flying songbird, she was the first scientific satellite designed and built entirely by a nation other than the United States or the Soviet Union.

Her aims? Provide scientists with a better understanding of the physical processes that exist in the upper atmosphere.

The day Alouette was launched an ionospheric disturbance started--one of the many that plague long-distance radio communication. The first data Alouette sent back to ground stations not only confirmed this disturbance, but also gave scientists hints about previously unknown phenomena associated with it.

The large volume of data that has come from the satellite since has provided scientists with comprehensive information about a region of the upper atmosphere that was relatively unknown before.

Even as Alouette whirled through her first orbits she brought praise from officials of the United States National Aeronautics and Space Administration (NASA).

"The Alouette is as complex as any satellite launched by the United States," said John E. Jackson of NASA. "Canada has rapidly caught up with us in satellite technology."

Designed for a useful life in space of at least one year, Alouette (now known as Alouette I to distinguish it from Canada's second satellite, Alouette II) is still operating, a record that has not been equalled by any other satellite of comparable complexity. Its degradation could be, and was, accurately predicted before launch.

Alouette I was designed and constructed by the Canadian Defence Research Telecommunications Establishment (DRTE) of the Defence Research Board (DRB), Ottawa*. She is a Canadian contribution to a joint program with the United States to investigate the ionosphere. NASA provided technical assistance, launching vehicles, launching and tracking facilities as well as some testing facilities during construction.

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* Now Communications Research Centre, Department of Communications.

The satellite has gained prestige for Canada in the international scientific and technological community. But the three million dollars it took to design and build her weren't spent for prestige reasons. Canadian scientists wanted to learn more about the upper atmosphere.

There are a number of reasons for wanting to gain such knowledge. One of the first practical benefits of a better understanding of the ionosphere could be more reliable radio communications.

Canada occupies a unique position geographically. The north magnetic Pole is located about a thousand miles north of Winnipeg and much of her northern territory lies within or north of the auroral zone. With many people spread thinly throughout this vast, forbidding area, radio is the only logical and practical means of communication. Aircraft flying in this area also need reliable radio transmission for navigation and communications.

Whenever the ionosphere becomes disturbed long-range high-frequency radio communication becomes difficult, if not impossible. The polar ionosphere especially is subject to disturbances. Because that has serious implications, the Defence Research Board has been studying the ionosphere for years.

The idea that there might be a region at the outer fringe of our atmosphere capable of conducting electrical currents was first suggested by Balfour Stewart in 1882. But, apparently, little more was done about the theory until 1901 when the Italian inventor, Guglielmo Marconi received a Morse signal in Newfoundland from a transmitter 1800 miles away in England. This sparked great interest in the subject because, until then, scientists had assumed that radio waves travelled through the air in almost straight lines, bending only slightly along the curvature of the earth for short distances before moving off into space or being absorbed in the upper atmosphere.

The following year, 1902, Arthur Kennelly in the United States and Oliver Heaviside in England independently suggested theories to show why such long-distance communication was possible. Both men, like Stewart twenty years earlier, reasoned that there must be a conducting layer in the upper atmosphere capable of deflecting radio waves back to the earth's surface. Their ideas started a long series of theoretical and experimental investigations. By 1926 it had been shown there were at least two layers in the ionosphere capable of reflecting radio waves and that the ionosphere consisted of ions and free electrons.

It was suspected there were other constituents. Sir Robert Watson-Watt, of radar fame, is credited with introducing the name ionosphere.

(An ion is an atom with one or more extra electrons attached, making it a negative ion--or with electrons missing, making it a positive ion.)

While these earlier investigations were primarily concerned with finding out why and how radio waves are reflected, present-day scientists are puzzling over the question why, in many cases, they are not reflected. For it soon became evident that the ionosphere is anything but a dependable aid to long-range communication.

Canadian scientists are particularly interested in the auroral ionosphere which exhibits disturbed conditions that are more pronounced and occur more often than anywhere else. In addition, the disturbances are frequently unpredictable.

Perhaps the worst ionospheric disturbance from the standpoint of communications, is the "polar blackout". During such occurences, the ionosphere absorbs almost all high-frequency radio waves, making it difficult to communicate between ground stations, except by the use of very low frequencies and sophisticated techniques not normally available to commercial users.

Rocket flights with instruments, and other experiments have shown that these polar blackouts stem from an abnormal increase in the ionization caused by solar particles. The effect on communications is a complete cessation of radio sky-wave transmission at high frequencies.

Some ionospheric disturbances cause sudden loss of communications, producing abrupt and simultaneous radio fadeout throughout the daylight hemisphere. They may last from about ten minutes to an hour. Polar blackouts, however, although more gradual in their beginning and recovery, last for substantially longer periods--sometimes continuously during daylight hours, for several consecutive days.

The "ionospheric storm" is another type of disturbance intensified in the auroral zones. It is characterized by a general instability of ionospheric conditions, a decrease in the maximum density of ionization and an increase in absorption of radio waves. Fewer frequency channels than normal can be used for communications during these periods and those few are subject to rapid fluctuations in signal intensity.

An ionospheric storm is usually accompanied by a magnetic storm or a period of unusual fluctuation in terrestrial magnetic intensity.

One thing that has long been obvious is that the sun has a lot to do with the ionosphere's behaviour. Variations occur with transition from day to night and from night to day.

Disturbances are also associated with activity of the sun such as sunspots.

For a long time it was a popular misconception that "empty space" around the earth's atmosphere was a vacuum. Scientists, of course, knew this to be untrue, but only in recent years have they been able to explore this part of earth's environment. They have found that a continuous stream of solar particles---electrons and protons--is blowing past the earth's atmosphere and reacting with it.

A number of theories exist trying to explain what is happening, but none is universally accepted yet. Each theory, built up on the basis of known facts, is used as a starting point to suggest experiments that might be performed. New data might or might not fit theory, in which case the theory will be strenghthened or have to be altered.

One theory is that the stream of particles blowing past earth originates in the sun's corona. The corona, which is visible in photographs taken during an eclipse, consists of a very tenuous ionized gas of protons (hydrogen nuclei) and electrons above the sun's gaseous surface.

At the bottom of the corona, according to theory, this ionized gas moves outward very slowly---a few hundred metres a second. But as it moves away, it is replaced by more gas rising from below. The coronal gas accelerates and in about five days it has travelled a million kilometres (about 630,000 miles) away from the sun. Measurements on satellites and space probes show the particles are travelling at about 400 kilometres (260 miles) per second as they pass earth. This stream is called the solar wind.

This ionized wind, consisting of hydrogen nuclei (protons), helium (alpha particles) and about 50 free electrons per cubic centimetre, has a magnetic field and sometimes comes in "gusts". It is particularly turbulent during sun-spot activity.

When the charged particles in this solar wind strike the magnetic field (magnetosphere) surrounding the earth, a shock wave is created and the solar wind divides to flow around the magnetically protected cavity containing the earth.

Although the earth's magnetic field protects the earth's atmosphere from being hit directly by most of the solar particles, some do get into the upper atmosphere. Just how is still a matter of scientific speculation and investigation. One theory is that the particles go past the earth, then flow in from the wake of the magnetosphere along magnetic lines of force. This could explain how particles concentrate at higher latitudes to cause disturbances such as the aurora.

There is enough evidence to suggest a strong correlation between solar activity and ionospheric behaviour. Alouette is helping to confirm this evidence in a much more effective manner than was possible previously with ground-based measuring equipment.

Scientists have studied the ionosphere for many years by sending radio waves up from ground stations and receiving, at near-by or remote stations, the waves reflected by the ionosphere. By comparing transmitted and reflected signals they have been able to deduce many facts about the ionosphere.

Ionization does not increase uniformly with altitude. At some elevations there are pronounced increases in electron and ion density and these are referred to as layers. These change with time of day, location relative to the geomagnetic poles, sun-spot activity and other factors.

The lowest layer of concentration, the D layer, occurs during daylight hours at a height of about 60-90 kilometres (35-55 miles). The electron content is relatively low and, until recently, the layer was thought to be caused by photo ionization of some atmospheric constituent, such as nitric oxide, by solar radiation capable of penetrating to that level. Recent rocket experiments, however, indicate the reactions in the D region are much more complex.

Frequencies in the broadcast band are among those affected by the D layer. Reception of distant stations is usually much better at night, sometimes causing interference with signals from local stations.

In the next layer of concentration, the E layer electron density during daylight varies extensively with the amount of solar radiation. As darkness approaches, electrons recombine rapidly with positive ions, reducing the ionization density to a value much lower than during daylight. Radio waves in the broadcast band are among those reflected by the E layer.

At a height of about 200-300 kilometres (130-190 miles) lies the maximum-density F layer. During daytime in the summer months it divides into two layers, F1 and F2. Both are assumed to be caused by ionization of atomic oxygen or nitrogen through the action of short-wavelength ultraviolet radiation from the sun.

Studying the ionosphere beyond the F2 maximum has been more difficult than studying below it. If the frequency of sounding signals is increased above a critical frequency for F2 there will be little, or no echo return. But for many years scientists were anxious to investigate above F2. It is the side closest to the source of ionizing radiation and they realized that new information might lead to a better understanding of how ionization is affected by sun-spot cycles, the earth's magnetic field and other natural conditions. This, in turn, could lead to benefits such as more reliable long-range communications.

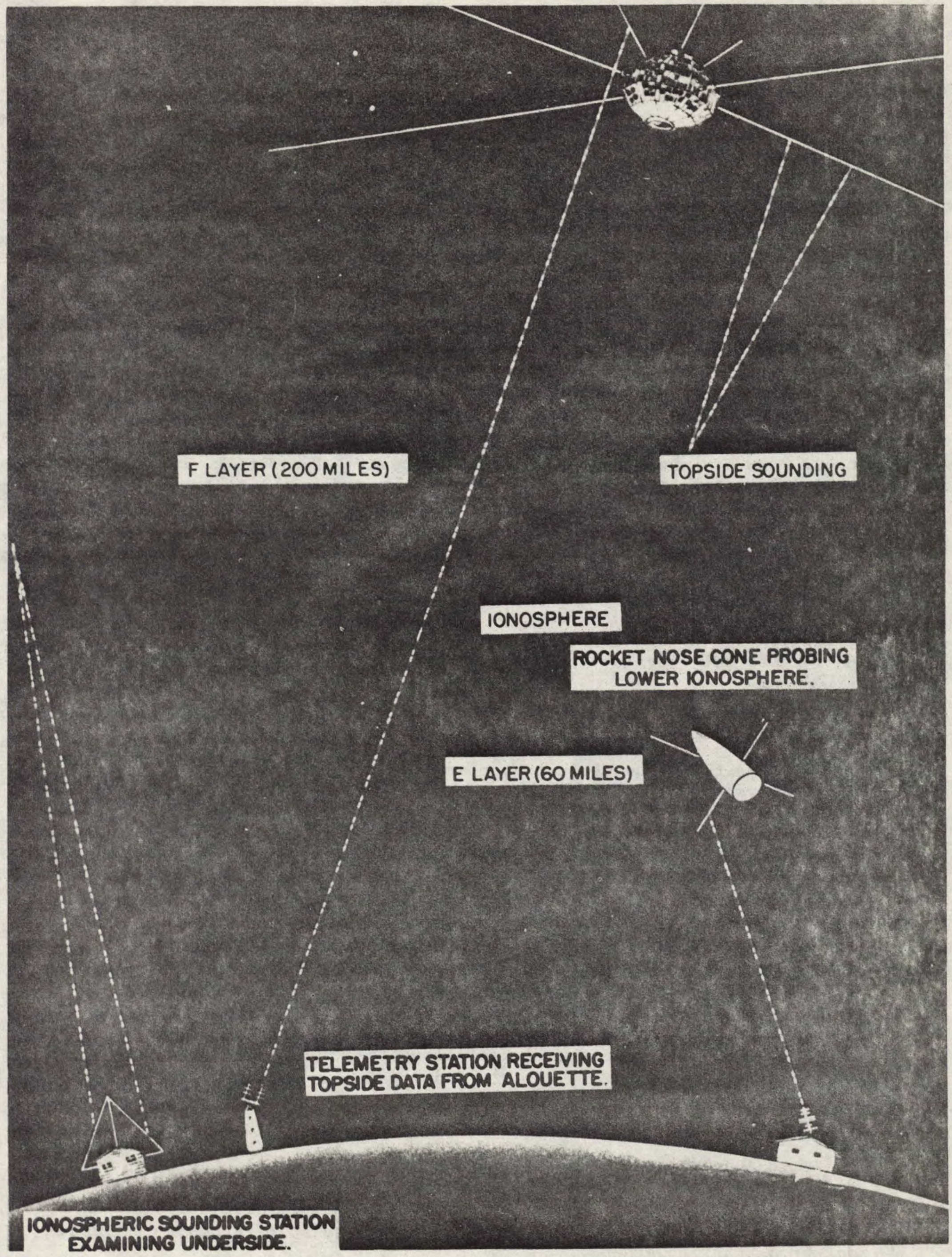
To extend their investigations above F2, scientists began sending instruments to high altitudes as soon as suitable rockets became available. But this has limitations of short flight times, restriction to a few launching sites and relatively high cost. Despite these drawbacks, much valuable research has been done and is continuing to be done with rockets.

A new, powerful way of studying the region above F2 became feasible with the successful development of earth satellites and facilities to launch them. For the first time it became possible to sound the ionosphere from above synoptically.

Information obtained from a satellite such as Alouette I is unique in that each individual sounding taken is a measure of some of the parameters of the ionospheric medium over a wide range of depths below the satellite (700 kilometres for Alouette I) and soundings are taken at about one-degree intervals of latitude along the satellite's path. This provides a wealth of information on the spatial variations of the high environment of the earth, which is not available from any other experiment.

Initiative has been a key factor in Canada's satellite program right from the beginning. Prior to a conference in November 1958, the U.S. National Academy of Sciences (NAS) issued invitations to interested groups to submit proposals for topside ionospheric sounders (satellites containing equipment similar to the ionosondes mentioned earlier). A number of proposals were submitted from Canada and the United States, including one from DRTE.

Scientists and engineers at DRTE reasoned that their proposal would meet with greater favour if it incorporated advanced ideas and engineering. In effect, it was a "second generation" design that would use a sounder capable of sweeping through a range of frequencies. None of the other proposals incorporated this advanced capability.



"A limited degree of "topside" sounding has been possible with rockets, but it wasn't until the advent of earth satellites and the facilities to launch them that it became possible to obtain extensive information about the upper side of the ionosphere."

As it turned out, all the proposals submitted through NAS came to a dead end. But during this period, DRB's liaison officer in Washington discovered that the newly-formed National Aeronautics and Space Administration (NASA) had been organized with terms of reference for foreign programs in space and might be willing to consider a proposal such as DRTE had just submitted to NAS.

Having already worked out a careful plan for their previous proposal, DRTE was able to approach NASA quickly with a definite plan. As a result, agreement was reached very soon between NASA and DRTE for a topside sounding program.

The general terms of the original agreement were that Canada would design and build the satellite; NASA would contribute technical know-how where necessary, certain testing facilities, launch vehicles, launching and tracking facilities, and eight telemetry stations for acquisition of data from the satellite.

DRB, which spent about $3 million on the Alouette I program, handed responsibility for its part of the work to DRTE.

Alouette I is considered relatively large for a scientific satellite by North American standards. She weighs 320 pounds; her near-spherical body is 42 inches in diameter and 32 inches high.

She circles the earth in a near-circular, near-polar orbit at an average altitude of 1000 kilometres (600 miles) and completes earh orbit in 105.5 minutes.

The orbit was chosen in such a way that the satellite would take ionospheric soundings in daylight and night-time conditions as well as in twilight conditions. Sometimes the satellite would be in sunlight during the entire orbit; at other times she would be in the earth's shadow, the night side, for 40 per cent of the orbit. The orbital plane, in fact, rotates with respect to the earth-sun line in such a way that the orbit goes through a cycle, from full sun to 60 per cent sun to full sun again. The cycle takes three months.

As the earth rotates, each of Alouette's subsequent orbits appear to shift westward by about 25 degrees. In little more than 12 hours, she has appeared above the horizon of every ocean and every continent of the world.

In about a dozen places scattered around the world this periodical appearance is watched with interest. For they are the locations of the global network of tracking stations that tell Alouette what to do and when to do it. Then they collect the fruits of Alouette's labors, data from the ionosphere.

As the satellite rises above the horizon, a tracking station turns on its telemetry transmitter and receiver to establish contact. Sometimes it does this as soon as the satellite comes into the line of sight, still about 3,500 kilometres (2,200 miles) away. Usually, however, stations start to communicate when the satellite has come within about 2200 kilometres (1400 miles), some 15 degrees above the horizon.

As a ground station's steerable antenna follows the satellite traversing the sky, the station sends a specially coded command message over its very-high-frequency (VHF) command transmitter, consisting of combinations of seven audio tones. Such commands may tell the satellite to turn its sounder on, or report on the state of its batteries, or perform one of its other experiments. Once the satellite is turned on to take ionospheric soundings, it sends the results back to the ground station over its telemetry transmitter as they are obtained. Similarly, it may measure cosmic radio noise, very-low-frequency signals, or the presence of energetic particles.

But, whereas the satellite has to be told when to start work, she doesn't have to be told when to stop. She does this automatically after a clock on board has counted off ten minutes. And she speeds away down over the horizon to her next assignment.

That assignment and every other one she gets is carefully planned by scientists in Ottawa. Each week an operating schedule for Alouette I is sent to all tracking stations in the world-wide network. They are told where the satellite will be at any given time--orbits are known to a very high degree of accuracy--and which of her experiments she is to carry out on a particular pass. They are also given details of the state of the electronic apparatus aboard.

When Canadian scientists and engineers started thinking about Alouette I, or S-27 as she was first called, they wanted one role for the satellite--to measure the state of the ionosphere directly below the satellite as it orbited around the earth. The initial proposal to NASA talked only about this one experiment. As the project progressed, the designers added three complementary experiments. These represented certain refinements of the task proposed for the spacecraft, but did not represent any significant change in the original plan.

Firstly, by appropriate design of the sounder receiver it became possible to measure cosmic noise. Secondly, incorporating a very-low-frequency receiver made it possible to "listen" to radio noise in the frequency range of 1 to 10 kilohertz. Finally, the National Research Council proposed an experiment to measure primary cosmic ray particles, such as electrons, protons and alpha particles, outside the denser portions of the earth's atmosphere. Subsequently, NRC designed and built the equipment for this experiment.

The scientific objectives these experiments represented were considered very ambitious and resulted in a complex system.

In effect, what Canadian engineers were told is this: build a miniature electronic laboratory you can blast into the earth's upper atmosphere on top of a rocket and which will then do four different kinds of sophisticated scientific measurements in an environment full of almost unknown hazards; build it to work at least a year and you won't get much time to think about it, either.

It was obvious that major efforts would have to be made to prevent a catastrophic failure that would disable all experiments. It was also obvious this would result in a complex system, demanding extreme reliability.

Throughout, Alouette engineers followed one important principle, which can be stated like this: If you are not sure it will work reliably--change it. And that is exactly what they did, determined to leave as little as possible to chance. It meant frequently retesting, up to a few days before launch time, which even meant replacing parts in the spacecraft after it had been flight tested.

There is little doubt that the "play-it-safe" approach--Alouette's designers called it conservative design--saved the spacecraft from an untimely end in many ways. It is not to say that Alouette I was not a highly advanced piece of machinery when it was built. Incorporated in the satellite were many components representing what engineers call "state-of-the-art" technology.

Actually, Alouette went into orbit with a "first" in spacecraft design--the longest antenna ever flown on any space vehicle at that time. It was so successful it has been used on many U.S. spacecraft since. The design made possible an antenna measuring 150 feet, tip to tip, consisting of two elements extending from the spacecraft. A second pair of dipoles, measuring 75 feet in total, was placed at right angles to the first.

The length of these antennas was dictated by the requirements for the ionopheric sounder experiment. The problem was: how to get such a structure into orbit? Obviously, it is impossible to launch a satellite with rods of this length extending from the sides. Even at rest they would collapse under their own weight, let alone survive the acceleration and air friction of a rocket ride.

The answer was an invention by an engineer of the Canadian National Research Council that had lain practically dormant for 20 years. It allowed the satellite to be launched with the entire antenna system tucked away inside, deploying after the satellite had been placed in orbit.

The principle is similar to that of a common steel tape measure, which consists of a slightly concave spring-steel tape wound on a spool inside a small housing. When pulled out, the tape is semi-rigid. In the spacecraft antenna application the strip is made of prestressed, specially heat-treated steel, about 0.004 inch thick and four inches wide. This strip is wound flat on a spool inside the spacecraft. For extension it is pushed through a circular orifice and emerges in tubular form with overlapping edges. The result is a semi-rigid, continuous tube, slightly less than one inch in diameter.

The development work on this device was done by a Canadian company, which co-operated with DRTE in its application as a satellite antenna. The original concept of the device was as a tank antenna, cranked out by hand. To design a fully automatic system that had to survive extreme conditions and on which depended much of the success of the spacecraft's mission, took a lot of work, both on behalf of government engineers and their counterparts in industry.

The extension mechanism used for Alouette was simple in principle, but had to be made highly reliable. Just after the spacecraft separated from the rocket, a microswitch activated an electric motor coupled to the spool on which the antenna unit was wound. The tube was cranked out to its full length at a rate of about two inches per second.

This particular design had two enormous advantages: it was light--a unit with 75 feet of tube material coiled up inside weighs no more than 10 pounds; and it did not take much space inside the spacecraft. The units are also quite strong, which was of considerable importance during extension, when the satellite was spinning at 122 revolutions per minute. The extension under those conditions means changing the spinning body's moment of inertia, with a considerable amount of force acting on the extending members.

Testing this system on the ground was a difficult proposition. Because of gravitational force, which is absent in orbit, the individual tubes had to be supported by an elaborate system of cables and trolleys over which the tubes could run during extension trials.

It is not surprising that the engineers kept their fingers crossed when Alouette was launched. Arrangements had been made to station a tracking ship in the Indian Ocean to monitor antenna extension, but at the critical moment there were equipment and operator troubles aboard, and the Canadians were kept in suspense until a report came in from the tracking station at Johannesburg, South Africa, that the antennas had started to extend. Full extension was verified later.

Alouette's power plant is partly located on the outer skin. It consists of 6,480 solar cells, tiny silicon chips (about $\frac{1}{2}$ x 1 inch) that convert the sun's rays into electrical energy. They charge the batteries located inside the satellite. The solar cells are distributed over almost the entire outer surface.

To provide adequate charging currents regardless of the orientation of the satellite with respect to the sun, about the same number of cells must be illuminated. That is why Alouette was made as nearly spherical as possible. The surface area, and therefore Alouette's size, was also determined by the power requirements of the electronic payload. To accommodate the necessary number of cells, an outside surface area of 2,000 square inches was needed. Of this total area, only about one quarter is illuminated, on the sun side, so that the number of solar cells actually charging the batteries is only about 1,620.

Alouette's near-spherical shape was also desirable from another point of view, namely that of temperature control. Most electronic components are sensitive to changes in temperature; their operating characteristics can vary considerably with wide temperature excursions. Solar cells, for instance, are more efficient when cool. For every degree rise in temperature they can lose $\frac{1}{2}$ per cent of their charging efficiency. This meant the solar cells would have to be adequately exposed to sunlight to do their work, but not so much as to overheat them.

The problem was partly solved by the fact Alouette was designed to have a slight spin--about two revolutions per minute--to keep her stabilized. This, at the same time, avoided the danger of "hot spots" on the outer skin due to overexposure of any side to direct sunlight. Temperatures could be conveniently averaged around the outer shell.

Another means of keeping the skin temperatures under control was provided by covering the cells with paperthin chips of glass, acting as thermal insulators but letting light through. They could also protect the solar cells from sandblasting by micrometeorites and harmful forms of radiation. These cover glasses have a special non-reflective and spectrally selective coating, which passes ultraviolet light, used for the conversion to electricity, and filters out infrared rays, responsible for the heating effect.

The glass covers, which are attached to the solar cells with an epoxy-based adhesive, together with the satellite's spin were designed to keep the cells within a temperature range of -20°C to +50°C. Actually, solarcell temperature went up as high as 75°C at times. This was much too wide a range of temperatures for the inside payload. Most electronic components are normally made for an average temperature close to room temperature. It was therefore desirable to isolate the inner payload from the outside.

The glass covers, the solar cells and the aluminum skin formed part of the isolating function. In addition, the inner surface of the shell was laced with aluminum mylar, interleafed with unbonded glass paper (known as a kropschot blanket). Temperature readings taken automatically inside the satellite and telemetered back to earth indicated that the payload temperatures stayed close to those intended--between 4 and 30°C.

Canadian engineers put a great amount of effort into the satellite's thermal design because temperature has an effect on almost every component. The manner in which temperature control was carried out is called passive control, as opposed to active control. The latter makes use of automatically activated vanes, blinds and thermal switches regulating the amount of heat conducted between the outer shell and the inner payload. While active control is more effective--it can keep the temperature of even the outer shell to within 40°C--Alouette's designers rejected it because of doubtful reliability. Instead, the satellite's overall design was such that greater temperature variations could be tolerated.

Temperature considerations were so important that they largely determined the selection of a suitable launch time for Alouette I. The launch sequence went like this: After lift-off and a vertical ascent, a roll, followed by a pitch-down and yaw brought the Thor-Agena carrying the satellite into the desired trajectory. The vehicle continued until the required velocity had been reached. At that point the Thor motor cut off and the vehicle coasted for half a minute. Then, small explosive charges separated the Agena and the satellite from the Thor. The Agena motor fired, and during the $2\frac{1}{2}$ minutes it was burning, the shroud protecting the spacecraft was ejected. After the first Agena engine cut-off the vehicle and spacecraft were in an elliptical trajectory that was to transfer them to the final orbit altitude. A second Agena burn, sustained for three or four seconds, put the vehicle in its final orbit. After the second engine cut-off the spacecraft was given a spin of about 122 revolutions per minute and was separated from the Agena by a spring mechanism, just about one hour after lift-off.

Alouette's designers preferred most of this action during the first hour to take place in the dark. It was realized that during the 48 minutes of coasting, after the first Agena cut-off, the spacecraft would be fully exposed, but would not yet be spinning, which meant solar heat could not be equalized around the shell. For this reason the time of launch was chosen such that the satellite would be in the earth's shadow during its ascent.

Some heating up of the solar cells during ascent could not be avoided. When the shroud was ejected the vehicle was only at an altitude of about 180 kilometres (100 miles). At this altitude the vehicle with the spacecraft in front, travelled at about 27,000 feet per second, which was enough for some aerodynamic heating, even though the atmosphere at that altitude is quite rare. The engineers went to great pains to try and calculate the amount of heating that would result. Because little was known about the actual density and composition of the atmosphere at that altitude, they could only come up with an estimate. It appeared that the spacecraft's forward-facing solar panel could reach a temperature of about 70°C due to aerodynamic heating. They never ascertained whether or not this actually happened, for the spacecraft at that stage was out of range of any telemetry station and skin temperatures could not be monitored.

What also helped to determine launch time was the fact that the scientists wanted to get as many soundings as possible on the first few orbits, just in case something went drastically wrong with the electronic equipment at an early stage. This meant they would need all available power. In turn, this required adequate illumination of the solar cells to keep the batteries charged. At the same time, the engineers did not want to risk exposing the spacecraft to too much sun at the very beginning, at least not until they could be absolutely sure their passive temperature control system was working. It was decided to launch the satellite at such a time that it would get some shade to begin with, about 30 per cent on the first few orbits, and progressively more sun on subsequent orbits.

The chosen launch "window" (period during which launch is possible with regard to the desired objectives) was between 11:30 p.m. and 1:30 a.m. Pacific Daylight Time during the night of September 28 to 29.

Temperature was only one of the main problems that faced the mechanical engineers. Generally speaking, they had to provide a package that would survive the stresses of launch and the inhospitability of space, and that would protect the electronic payload. Each of these considerations had its effects on the final construction.

Despite the most careful design techniques, there still remained a strong element of trial and error. The realization of this was a major factor in the way Alouette's builders approached their task.

For instance, when the first model of the flight structure was put through vibration tests, it vibrated too much at certain frequencies. The structure had to be stiffened further by braces.

Building materials believed to be relatively unaffected by radiation included micarta, polyurethane epoxy, teflon, aluminized mylar, unbonded glass fibre paper, epoxy-based FeO paint and polyurethane-based TiO_2 paint. Some of these were fairly sophisticated materials. Also included was a very unsophisticated one: commercial brown wrapping paper.

To cope with the near vacuum conditions of space, materials with high partial pressures that sublime easily had to be avoided. As a result, Alouette's structure is entirely of aluminum, with steel and stainless-steel fasteners. Grease and oil were used only in the sealed ball bearings of the antenna extension mechanisms; they had to operate only once--to deploy the antennas--and what happened to them afterwards wasn't too important.

It was believed the near vacuum might actually do more good than harm to the aluminum used for Alouette. Aluminum surfaces are normally covered with a thin layer of oxide that forms because of the metal's exposure to air. These oxides have a wedging action in the tiny cracks between surface grains, which causes highly concentrated surface stressing. In a high vacuum, the oxides evaporate. As a result, the fatigue strength of aluminum in a space environment probably improves with time, the engineers believed.

The spacecraft's electronic system was built in separate units, which were potted with polyurethane foam in aluminum boxes. This provided rigidity and damping of vibration.

The locations of the boxes inside the spacecraft were established largely by a trial-and-error method. This was found to be the most practical way to find compromises between such considerations as ease of access, balance and electronic interference.

The end result wasn't viewed by the engineers as the optimum in packaging and weight efficiency, but ease in removal and replacement of parts, for testing purposes, was an important criterion in their packaging design. They did make full use of the space available, which had been determined by the outside surface area needed for the solar cells rather than by the space required for the electronic boxes inside.

From the packaging point of view, extensive miniaturization of the electronic content wasn't necessary. Miniaturization was desirable, however, from an electronic point of view. Microelectronic components generally have the advantage of high reliability and low power consumption. The electronic systems were fully transistorized, for instance, making use of the superior reliability and efficiency of semiconductor devices over tubes. To find suitable transistors wasn't easy. Alouette's sounder transmitter had to deliver fairly strong pulses of radiowaves. At the time the system was completed, this was judged to be the maximum power available from a transmitter using transistors of proven reliability. Engineering calculations provided little margin for absorption effects in the ionosphere. The alternative, the use of vacuum tubes, would have provided more power, but would have also meant greater power consumption, greater weight and more space. The choice was made in favour of the more reliable and efficient semiconductor transmitter on the grounds that ionospheric absorption could affect soundings only under the worst conditions. Actually, some rocket tests indicated that the semiconductor device would provide an adequate margin for adverse conditions. Still, the engineers had to shop around quite a bit for transistors that would do the job reliably; the choice wasn't very wide--they had arrived pretty close to the frontiers of power transistor technology at the time.

The complexity of Alouette's electronic systems is partly due to the desire to avoid failures. Considerable redundancy in electronic components was built in--spare parts could take over from others in case of failure. The complexity also showed up in the construction of the electronic systems; the necessity to build individual circuits into separate boxes provided engineers with the challenge of reliable interconnection.

But Alouette I was complex to begin with, merely because of the nature of her task. The most complex system of all was the ionospheric sounder. What it does is switch on and off alternately its transmitter and receiver in very rapid succession to respectively send and receive short pulses of radio waves. Each transmission is sustained for only 0.0001 second. Another 0.0001 second after the transmitter shuts off, the receiver switches on and waits for the pulse to travel into the ionosphere, be reflected and return. The receiver operates slightly less than 0.016 second each time. After it has shut off the transmitter switches on again. The entire process is repeated 62 times a second. The receiving interval is long enough for a pulse to travel more than 2,500 kilometres (1,600 miles). While the reflecting surface is always within this limit, signals may, in fact, not take the direct-line route and travel considerably further. At the other extreme, the sounder can't detect any reflecting layers closer than 35 kilometres (22 miles).

The frequency of the transmitted pulse of radio waves goes up from 0.5 to 12 megahertz. The transmittor and receiver "sweep" through this range in about 12 seconds every 18 seconds.

Some fairly sophisticated circuitry had to be incorporated in the electronic equipment to perform this function; it had to be able to "keep time" accurately and process its output in such a way that it could be radioed to earth.

The other experiments required significantly less complicated equipment. The cosmic noise experiment essentially measured the strength of "background" signals received by the sounder. Some of these signals occur sporadically and appear to be associated with solar activity. Besides solar noise there are continuous noise emissions from the galaxy as a whole. The very-low-frequency receiver is another relatively simple device, which measures natural radio signals of frequencies between 400 and 10,000 hertz. The particle experiment consisted of six fairly standard particle detectors, some of them Geiger counters, that measured intensities of electrons, protons, and alpha and heavier particles. The equipment for this was provided by the National Research Council.

The long sounder antennas aren't the only protrusions from the spacecraft hull. There are also four short antennas on top of the satellite, pointing at 45 degrees upward in four different directions. It is through these that the spacecraft's telemetry system operated.

The function of the telemetry system, sending back to earth the data from the experiments and "housekeeping" data, was considered so important that two separate transmitters were installed. This provided for redundancy in case of the failure of one of them, but actually both transmitters were put to work. Because of the limitations placed by international radio regulations on the amount of data that can be sent at once, one transmitter would have been barely enough. Using the two, increased the total transmission capacity by about 50 per cent. Another advantage was that lower recording-tape speeds at ground stations were possible than with just one transmitter in operation. This carried some weight in view of the large cost involved in keeping 13 ground stations supplied with recording tape.

One of these transmitters was produced only a few months before launch. Originally it had appeared that it wouldn't be difficult to buy such a device--several manufacturers offered them for sale. However, it soon became evident that, in the way DRTE put it, "advertising had outstripped engineering". Those on the market just weren't good enough. A Canadian manufacturer, contacted at the last moment, put on a crash program and came up with a transmitter that surpassed even the claims advertised earlier by competitors--and just in time.

Besides the experimental data, the telemetry transmitters were to handle what is known as housekeeping data, information on the state of affairs in the satellite, such as battery voltage, solar charging currents and temperatures.

These data had to be selected somehow in the spacecraft, before they could be transmitted. DRTE developed a special electronic device called a commutator, which takes quick samples all over the satellite. With this commutator it was possible for Alouette to take her own temperature in 11 different locations, check her seven batteries, measure voltages in at least eight locations and perform several other measurements, a total of 29, all within two seconds. Engineers on the ground need all this information to be able to pin-point trouble spots and to be able to tell the satellite what to do.

This command capability was particularly important. In principle, it was made necessary by the fact that at least twice as much power was required to operate all experiments than could be supplied by the solar cells during a 60-per-cent sun orbit. Therefore it had to be possible to switch experiments on and off remotely, to prevent excessive power drains. Alouette's operators also wanted to be able to switch on spare equipment if necessary and have the option of operating the satellite with any or all of the experiments on or off.

All this was made possible by the command system designed for the satellite. Command messages were coded in the form of a sequence of tones, to be received by a special command receiver aboard the satellite. It was designed to sort out the 40 different commands that were possible, such as turning on and off various experiments, switching batteries or activating spare units.

While the failure of a command signal to turn on a certain function could have had serious consequences, the failure to turn off something was considered as much, or even more of a hazard--it could have resulted in serious power drains. To prevent this, an automatic turn-off circuit was incorporated, which disconnects all power supplies ten minutes after they have been turned on.

Special circuitry was also built into the command receiver to prevent any stray signals, that had nothing to do with Alouette, from affecting the satellite.

The command receiver was one of the two systems in the satellite designed for continuous operation. The other was a low-power transmitter sending a continuous signal by means of a small antenna on top of the spacecraft to provide a tracking beacon. Both of these required a very reliable power supply--Alouette had to keep her ears open at all times to be able to receive commands, and without her tracking beacon she might have become lost. This was particularly critical just after launch, when the orbit had not been computed yet and ground stations needed a signal from the satellite to aim their antennas. The command system and the tracking beacon were connected to the same power source as the rest of the satellite's systems--six rechargeable nickel-cadmium batteries--but they were given the privilege to automatically always select the battery with the highest voltage.

The satellite's other electrical systems were to be connected to the power supply by command. This was arranged in such a way that they could draw power from any one of four batteries, which would each be fed by an array of solar cells independently of each other. Two other batteries were put in as spares that could be switched in by command to take over from any of the others. A seventh battery was intended exclusively for the antenna extension system, which also required very high reliability. This battery was allowed to run down after it had done its job.

The primary limiting factor in the operation of the satellite was expected to be the gradual decay of the charging currents from the solar cells, which, after the first five years, turned out to have proceeded pretty well as anticipated. Most of this degradation was expected to occur, and did occur, within the first few months. After that, the solar cells continued to lose their efficiency, but the rate of decay became progressively slower and after a few years had become so small it no longer had any appreciable short-term effects. It was concluded that the solar cells could continue to operate for a long time and would probably outlive other components.

Solar-cell degradation is caused by radiation. An unforeseen factor that affected the solar-cell operation was the creation of an artificial radiation belt by the Starfish Event, a U.S. hydrogen-bomb test above the Pacific in July 1962. It caused a drop in Alouette's charging currents that was close to the most pessimistic predictions. What saved the satellite was the fact that the designers had been extremely conservative when allowing for initial current drops.

For a while, an unforeseen quirk in Alouette's behaviour looked as if it would end her useful life soon after her fifth birthday. The rate of slow-down of the satellite's spin was much higher than had been predicted. Prior to separation from the booster, the satellite was spun up and actually separated doing 120 revolutions per minute. Extension of the antennas slowed it down to 1.4 revolutions per minute, which was lower than the intended spin rate of about two revolutions per minute. From what was known at the time about the mechanisms that would affect the satellite's spin rate, it was calculated that the spin half life would be six years. In other words, after six years the satellite would be spinning at half the initial rate--0.7 revolutions per minute. As it turned out, the satellite was already down to this after about a year and a half. It is believed that after five years Alouette had stopped spinning, but some data indicated it was oscillating, much like a torsion pendulum. Loss of one telemetry channel due to malfunction of a transistor has prevented read-out of the attitude sensor, so Canadian scientists can't tell directly.

At first it was believed this oscillating motion would eventually stop and the satellite would be caught in what is known as "gravity capture". This would have meant that the longest sounder antenna would point earthward, which, in turn, would have resulted in the loss of many sounding data. Later it became evident that the oscillating motion was sustained, instead of decaying.

The loss of spin resulted in a major study at DRTE of the behaviour of non-rigid bodies in orbit. Scientists and engineers suspected that the long antennas were the culprits. They reasoned that probably the antennas, instead of extending straight out, were bending as a result of being heated up on the sun side. They studied the complicated implications this behaviour would have for the satellite's motion in space and came up with a theory that fitted the observations of the satellite's behaviour. They concluded that the satellite's oscillating motion was sustained by the same mechanism that at first slowed down the spinning motion.

When Alouette was designed it was realized that a catastrophic failure could occur at any time, as a result of a sizable meteorite smashing through the hull, for instance. The satellite's usefulness could also be seriously impaired by the burn-out of some component, which is unpredictable. Some minor failures had, in fact, occurred by the end of the fifth year, although they had no appreciable effect on the spacecraft's overall usefulness. It included failure of a transistor due, it was believed, to radiation damage. One of the particle detectors gave up after one year, but this was due to the fact it was designed to operate for one year and was expected to be "used up" within that period.

Even had the satellite stopped operating after one year, scientists feel they would have had more than their money's worth. The analysis and interpretation of the Alouette data, they said, led to "major advances in our knowledge of upper atmospheric ionization". Substantial progress was made in understanding the physical processes that affect the behaviour of the atmosphere.

Almost nothing was known about the high atmosphere above about 300 kilometres (about 200 miles) when Alouette I was launched. It became evident soon after launch that even the greatly oversimplified assumptions common previously about the physics of the region were largely incorrect.

The discovery of a very-low-frequency band of radio noise that occurs at particular times over much of the earth has revealed a lot about the composition and temperature of the upper atmosphere. Some of the records dramatically demonstrate how high-frequency radio waves are "guided" by the earth's magnetic field. Radio waves may follow the magnetic field lines for as much as 10,000 kilometres (6,000 miles), making as many as four "trips" between the northern and southern hemispheres before they return to earth.

Alouette was the first to detect certain well-defined "ledges" of ionization above the magnetic equator. These appear to be aligned along the magnetic field, forming a "dome" above the equator. Patches of dense ionization have been discovered in the polar regions and at the equator. A strange "trough"-- a deficiency in ionization--exists about 250 kilometres (150 miles) upward at latitudes near Ottawa. The location of this trough, like many other phenomena in the ionosphere, appears to depend on events taking place on the sun. Alouette measured bursts of electromagnetic energy originating on the sun; no effect of the solar corona had been measured that close to the source before.

The continuous operation of Alouette I since 1962 has provided a set of data that cover, with the same measuring instruments, more than half a solar cycle (through the minimum and nearly to the maximum of solar activity). This has, for the first time, allowed studies of the long-term variations in the ionized high atmosphere as the sun becomes more active. Also, the existence of a large quantity of data, extending well into a complete solar cycle, allows confirmation and more complete understanding of some of the discoveries made by Alouette I and other satellites launched later.

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