The Alouette II satellite was built by the Defence Research Telecommunications Establishment, Canada, and launched on 29 November, 1965 by the National Aeronautics and Space Administration of the U.S.A. as part of an international satellite programme for the study of the high atmosphere. The orbital parameters are:

- apogee: 2982 kilometers
- perigee: 502 kilometers
- inclination: 79.8° prograde
- period: 121.4 minutes
- spin: 2.25 revolutions per minute.

For the first orbit perigee occurred at 27° south latitude and the latitude of perigee moved south 1.89° per day. The satellite currently operates on command for about 6 hours per day, collecting data from one or more of the following five experiments:
1. A topside sounder, which measures the distribution of electrons in the topside ionosphere as a function of distance from the satellite.

2. A background radio noise experiment, which measures the noise environment from about 0.2 to 14 Mc/s.

3. A very-low frequency (VLF) experiment, which measures radio frequency emissions from 50 to 30,000 cycles per second.

4. An energetic particle experiment, which measures the flux of electrons with energies above 40 Kev, 250 Kev and 3.9 Mev, the flux of protons with energies above 500 Kev, above 100 Mev and in the range 1 to 8 Mev, and which measures proton spectra in the range 100 to 600 Mev.

5. An electrostatic probe experiment, which measures electron number density and temperature at two locations near the satellite surface.

A sister satellite, Explorer XXXI, was launched by the same vehicle and is in nearly the same orbit as Alouette II. On 29 January, 1966 the two satellites were 540 kilometers apart and were separating at a rate of 8 to 9 kilometers per day. Explorer XXXI contains ion and electron probes, and an electrostatic probe identical to the electrostatic probes on Alouette II.
The purpose of the dual launch is to permit nearly simultaneous comparisons between the data obtained by the sounder, VLF and electrostatic probe experiments in Alouette II and the probes in Explorer XXXI, and to provide ion and electron temperature and ion composition data at the height of the satellite for use with the sounder data. Since the distribution of electrons between the peak of the F layer of the ionosphere (the height of the peak of the F layer ranges from about 200 to 500 kilometers) and the satellite can be determined from the sounder records, use of this data in conjunction with the data measured at the satellite by the probes is expected to provide a great deal of information about the entire region above the peak of the F layer. In addition, comparisons can be made with data obtained from the Alouette I satellite (Warren 1962; Warren 1963; Belrose and Barrington 1965, DRTF report, 1966) launched on September 29, 1962, into a 1000 kilometer circular polar orbit, which is still providing 1 to 2 hours of topside sounder, VLF, background radio noise and energetic particle data per day.

The Topside Sounding Experiment:

The topside sounder in Alouette II provides an average pulse power of about 300 watts into the aerials at a pulse repetition rate of 30 per second and pulse width of
100 μsec. The sounder sweeps from 0.2 to 14.0 Mc/s, once every 30 seconds. It is normally on for periods of 13 minutes. The aerials used for the sounder are two dipoles, of length 240 feet and 75 feet tip to tip.

A topside sounder ionogram, taken when the satellite was at a height of 900 kilometers, is shown in Fig. 1. This record was obtained when the satellite was at a height of approximately 900 kilometers, near Bermuda. The axes of the ionograms are apparent range (time delay) in kilometers and frequency in Mc/s. The pulse repetition rate of 30 pulses per second provides 4800 kilometers of apparent range between sounder transmitter pulses. When the telemetry tapes are processed into ionograms, a height interval of 2000 kilometers with 100 kilometer apparent range markers, or of 4500 kilometers with 200 kilometer markers is usually used. To provide rapid identification, the markers at multiples of 1000 kilometers are made double the width of the other markers. The frequency sweep rate changes sharply at 2.0 Mc/s. This rate is about 0.15 Mc/s/sec below 2.0 Mc/s and 1.0 Mc/s/sec above 2.0 Mc/s. The slow sweep rate below 2.0 Mc/s enables the frequency of phenomena on the ionograms to be measured with an accuracy of ±5 Kc/s, or three times the accuracy that can be obtained with Alouette I.
The three characteristic reflection traces, the S-wave 0-wave and L-wave are identified on the record. The plasma resonance spikes (Lockwood 1963 Culvert and see 1963) that occur at the plasma frequency, $f_p$, at the upper hybrid frequency, $f_{uh}$ ($f_{uh}^2 = f_p^2 + f_r^2$), and at the fundamental and harmonics of the gyrofrequency, $f_g$ and $nf_g$, are also identified.

An ionogram taken when the satellite was near apogee is shown in Fig. 2. At apogee the reflection traces usually show great retardation and there is often more than one path of propagation by which the L-wave may return to the satellite. Electron densities of $10^3$ to $10^4$ electrons per cubic centimeter are common near apogee, but very low electron densities (less than 200 electrons per cubic centimeter) are occasionally encountered at high latitudes.

An ionogram taken when the satellite was near perigee is shown in Fig. 3. For these conditions, the electron density at the satellite is relatively large, and the reflection traces are strong. On this record, both earth echoes and echoes from the top of a sporadic E layer are present. The spikes occurring at harmonics of the electron gyrofrequency (Lockwood 1965) are also identified.

**The Very Low Frequency Experiment**

The very low frequency experiment is occasionally operated simultaneously with the topside sounder and shares the same broad-band telemetry channel. This mode of operation produces mutual interference between the two experiments, but for certain studies the potential advantages of the
combined experiment outweigh the disadvantages of the interference (Barrington et al. 1965). So far little of the simultaneous data have been analysed. On several passes per week, at various latitudes, the VLF experiment is operated alone. On one such pass recorded over Australia the event shown in Fig. 4 was observed. Here a normal fractional hop whistler, i.e., the dispersed electromagnetic impulse that has propagated upwards from a lightning discharge to the satellite, is shown. A proton whistler (Gurnett, et al. 1965) and the first helium whistler (Barrington, Belrose and Mather, 1966) that has ever been detected are also identified. The dispersion of the fractional hop whistler can be used to determine the total electron content along the whistler path. The frequency at which the proton trace separates from the fractional hop whistler (the cross-over frequency) determines the relative abundance of protons at the satellite height, while the dispersion in the tail of the trace can be used to derive number density of protons at this height. The dispersion of the helium whistler can be used to find the number density of helium at the satellite, and the helium cross-over frequency in a function only of the relative abundances of the various ion constituents. Thus assuming that the ionosphere at the satellite height is composed solely of electrons, protons, helium ions and oxygen ions a signal such as that shown in Fig. 4 contains information from which the electron density at the satellite height as well as the relative and absolute abundances of the ion constituents (Barrington, Belrose and Mather, 1966) can be deduced. In addition, sufficient information is available
to provide a check on the accuracy of the theory and measurements used in deriving the data.

The extended high frequency coverage of the Alouette II VLF receiver has permitted the detection of signals from several ground based VLF transmitters. In Fig. 5 the signals from one such transmitter may be seen at frequencies of 17.6 and 18.2 Kc/s. Considerable information on the propagation of VLF waves within the ionosphere can be obtained from studying the regions in which such signals are observed. Also shown in this figure is noise with a sharp lower cut-off frequency that has been triggered by a whistler. It has been suggested (Erice and Smith 1964) that the lower cut-off frequency of such noise is the lower hybrid resonance of the plasma at the satellite height, and the facts to date seem to support this hypothesis (Dzarrington, Delrose and Nelms, 1965). For the orbit of Alouette II the lower hybrid resonance frequency lies between a few hundred cycles and 20 Kc/s, and the resonance frequency will be within the pass band of the Alouette II VLF receiver, whenever noise such as that shown in the figure occurs. Since this resonance frequency is related to the local electron density and the ion composition, this phenomena provides yet another source of information on the constitution of the ionosphere.

The Background Radio Noise Experiment:

The AGC voltage from the swept-frequency sounder receiver is monitored all the time that the topside sounder
is operating. These data provide a measure of the background radio noise level at the satellite as a function of frequency within the sweep range of about 0.2 to 14 Mc/s. Essentially this experiment is very similar to one carried in the Alouette I satellite (Hartz, 1964a, 1964b, and 1964c), save that in the present equipment the sweep range has been extended with the result that data can be obtained at significantly lower frequencies.

In general a portion of the record near the upper end of the sweep range contains interfering transmissions that propagate up from the ground above the frequency for which the ionosphere is a shield. Similarly, there is evidence that a portion of the low end of the frequency range, below the electron gyrofrequency also is contaminated by ground transmissions. Between these two limits, however, it is possible to identify at least the following main types of noise and to get detailed quantitative data on them:

(1) galactic noise, which exceeds the receiver noise level at frequencies greater than about 0.8 Mc/s,

(2) noise emissions that appear to be generated within ionosphere: these occur in the frequency range between the electron gyrofrequency, \( f_H \), and the upper hybrid frequency, \( f_T \), and

(3) solar noise emissions, which appear sporadically above the galactic noise level and which extend down in frequency to a lower limit of about 0.6 Mc/s: to date a number of Type III bursts have been identified in the records but other

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types of solar noise have not yet been found at these same low frequencies.

The Energetic Particle Experiment:

The purpose of the energetic particle experiment can be stated in general terms as follows: (1) to provide data which will aid in the understanding of the mechanisms responsible for the production and control of outer Van Allen radiation zone particles, and of auroral particles, (2) to study the related problem of entry into the earth's magnetic field of solar and cosmic ray particles, and (3) to study the general distortions which occur in the earth's magnetic field as a result of its interaction with the solar wind.

The experiment, which is an improved version of one flown in Alouette I, consists of seven different counters capable of detecting electrons with energies above 40 Kev, 250 Kev and 3.9 Mev and protons above 500 Kev, in the range 1 to 8 Mev and above 100 Mev and of measuring proton spectra in the range 100 to 500 Mev. Most of the detectors are directional, that is they measure intensities in a small range of angles about a given direction which is determined with respect to the direction of the earth's magnetic field by magnetometers on board the satellite. At the time of writing all detectors are operating normally.

The experiment is capable of a time resolution of about 1/8 of a second although in most of the analysis counting rates averaged in 1 second and 4 second intervals will be used. Automatic data processing equipment forms an important part of the experiment since more than $10^6$ data
points per month are obtained and it is necessary to plot all of these in the initial part of the analysis. The data from the telemetry tapes are first transferred to digital magnetic tape and the processing is done on an IBM 360 computer. The computer output is then plotted off-line on a EAI 3500 Data plotter.

One type of measurement which could not be made with Alouette I but which can be made with the present experiment is electron pitch angle distributions. One directional detector looks out at right angles to the satellite spin axis and, for most satellite orientations, this detector sweeps out an appreciable range of angles with respect to the magnetic field direction during a half spin period (about 13.5 sec). Fig. 6 shows two examples of electron pitch angle distributions obtained in the outer radiation zone at an L value of about 6. A study of the shape of such distributions, particularly in the loss cone, may yield information about the mechanisms responsible for precipitation of electrons into the atmosphere.

The Electrostatic Probe Experiment:

A pair of thin cylindrical electrostatic probes (Brace, Spencer and Dalgarno, 1965; Spencer et al., 1965; Brace and Reddy, 1965) are employed on the Alouette II satellite for investigating the following:

1. the nature of the plasma in the immediate vicinity of the spacecraft,
2. the potential of the satellite relative to the plasma, and the nature of its variations,
3. the nature of the ion and electron wake which forms behind the satellite as its leading surfaces
sweep out the ambient particles in its path.

The two probes are used independently and sequentially. A repeating sawtooth voltage is applied to the probe which is in use, and the resulting current which flows to the probe from the plasma is detected and transmitted to recording stations on the earth (Fig. 7). The amplitude and curvature of these volt-ampere characteristics permit the electron concentration and temperature along the orbital path to be derived at about one second intervals.

Four linear ranges of current detection sensitivity permit the electron concentration to be measured when in the range of $10^2$ to $10^6$/cc. The electron temperature can be resolved in the range of approximately 200 to 20,000°K. Fine structure in the electron concentration along the satellite path can be detected if its dimensions exceed approximately one hundred meters.

Measurements of the satellite potential are particularly important in a satellite having an extremely long antenna in which large voltages are induced by their high velocity through the geomagnetic field. The satellite's potential can be resolved when it lies between -10 volts and +2 volts. This is done by noting the voltage which must be applied to drive the probe to the plasma potential. The gross nature of the ion and electron wake can be derived by observing the roll modulation of ion and electron currents as the probes pass behind the satellite.
References:

Figure Captions:

Figure 1: An Alouette II topside sounder ionogram recorded when the satellite was near Bermuda, at an altitude of 900 kilometers. The various reflection traces are identified.

The Z-wave plasma frequency at the satellite, \( f_Z \), occurs at \( X = 1 + Y \)

The 0-wave plasma frequency at the satellite, \( f_N \), occurs at \( X = 1 \)

The X-wave plasma frequency at the satellite, \( f_X \), occurs at \( X = 1 - Y \)

The plasma spikes observed at the satellite occur at the following frequencies:

\( f_H \), the electron gyrofrequency, occurs at \( Y = 1 \)

\( f_N \), the plasma frequency, occurs at \( X = 1 \)

\( f_T \), the upper hybrid frequency, occurs at \( X = 1 - Y^2 \)

\( n f_H \), the multiples of the electron gyrofrequency, occur at \( Y = \frac{1}{2}, \frac{1}{3}, \ldots, \frac{1}{n}, \ldots \)

Figure 2: An Alouette II topside sounder ionogram recorded when the satellite was near Bermuda, at an altitude of 2802 kilometers.

Figure 3: An Alouette II topside sounder ionogram recorded when the satellite was near Santiago, Chile, at an altitude of 535 kilometers.

Figure 4: A VLF spectrogram, showing a proton and helium whistler. The lower part of the figure is the actual spectrogram obtained from a sono-graph spectrum analyser. The upper part of the figure illustrates the idealized form of these whistlers.

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Figure 5: A "Rayspan" spectrogram, showing signals from VLF transmitters at 17.6 and 18.2 Kc/s. Also illustrated is a band of lower hybrid resonance noise at about 5 Kc/s, that has been triggered by the whistler echo of the fractional-hop whistler appearing at 3.5 seconds.

Figure 6: Pitch angle distributions obtained during two passes on day 336 (Dec. 2, 1965). In one spin period each pitch angle is sampled twice and the open and closed circles each refer to a half period.

Figure 7: A repeating sawtooth voltage ($V_a$) is applied to each cylindrical electrostatic probe and the current to each collector is measured by a multi-range current detector (I). Only one of the probes is shown here.