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THE ISIS SATELLITES

by

C.D. Florida

DRTE TECHNICAL NOTE NO. 619

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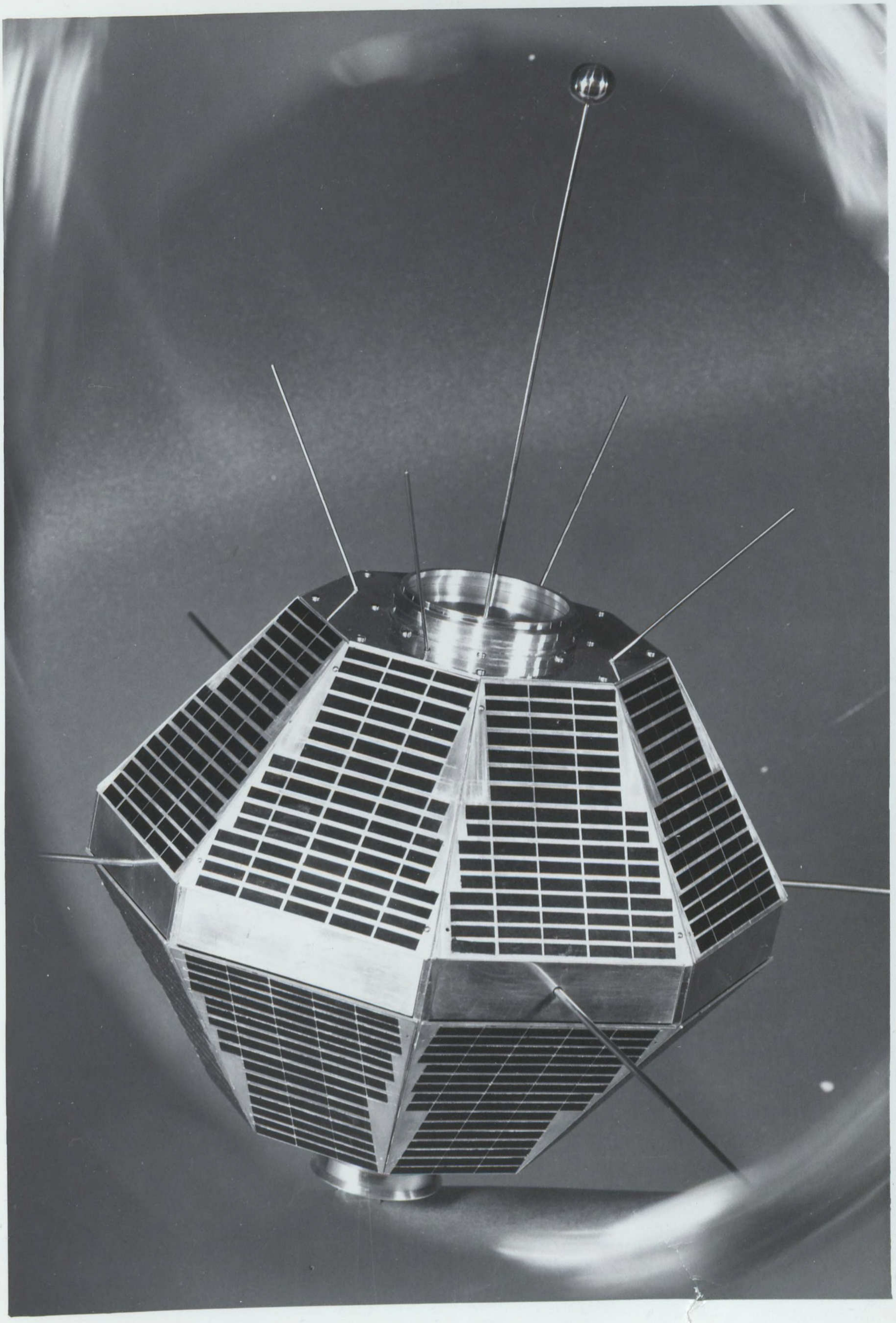

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THE ISIS SATELLITES

BY

C.D. FLORIDA

A series of ionospheric satellites is being designed to follow the highly successful Alouette I. The report describes this series, and points out the differences in both experiments and instrumentation between each of the satellites and the reasons for them.

1. INTRODUCTION

Alouette I was launched from California on September 29, 1962. It was the first satellite to be designed and constructed in Canada and was launched by a U.S. vehicle as part of a joint space programme between the U.S.A's National Aeronautics and Space Administration (NASA) and Canada's Defence Research Board (DRB).

Shortly afterwards a new joint programme was arranged between the U.S.A. and Canada in which Canada would be responsible for the design and construction of further ionospheric satellites. These satellites, named, Alouette II, ISIS-A, ISIS-B, and ISIS-C, would be launched at intervals to cover the present solar cycle. When approving the programme, the Canadian Government stipulated that industry should be used to the fullest possible extent in order that skills developed within DRB should be imparted to industry so that by the end of the programme, a Canadian industrial space capability shall have been built up. Programme management was delegated to DRTE (now CRC).

At the time the agreement was reached Alouette I had been operating for about six months. Although none of its redundant units had been needed, few people expected it to survive for much longer. In order to save time, therefore, it was decided that the first satellite in the new series would use the spare flight model of Alouette I, modified slightly to overcome known deficiencies in Alouette I and also to operate in a higher orbit. This next satellite is known as Alouette II.

The purpose of this report is to describe the satellites that have been launched or are being developed, and to point out the differences between them in both experiments and instrumentation and the reasons for these differences.

It is planned to revise the report from time to time as significant stages, e.g., launchings, are reached.

2. ALOUETTE I

In order to understand the differences between Alouette I and Alouette II it is first necessary to review the experiments and facilities available in Alouette I.

2.1 ALOUETTE I EXPERIMENTS

The experiments are listed in Table 1.

TABLE 1 - ALOUETTE I EXPERIMENTS

Ionospheric Sounder	
Frequency coverage	1 MHz to 12 MHz
Transmitter power	100 watts
Transmitter pulse width	100 μsec
Pulse repetition frequency	66 Hz
Frequency sweep rate	1 MHz/s
VLF	
Receiver, untuned	400 Hz to 10 KHz
Cosmic Noise	
From AGC of Ionospheric Sounder	
Energetic Particle	
Protons	0.5 to 700 MeV
Electrons	40 KeV to 3.9 MeV
Alpha	5 MeV to 2.8 BeV

The ionospheric sounder is used to measure electron density as a function of height. A radio wave transmitted toward the ionosphere, either from below or from above, will suffer total reflection when the electron density has a value given by

$$Ne = \frac{f^2}{80.5}$$

By varying the frequency of the radio wave a plot can be obtained of echo delay versus frequency. Such a plot is termed an ionogram and a typical one is shown in Fig. 1. Using the relation between electron density and frequency, the plot can be transformed into one relating echo delay and electron density. Finally, by taking into account retardation processes, information regarding altitude versus electron density can be obtained.

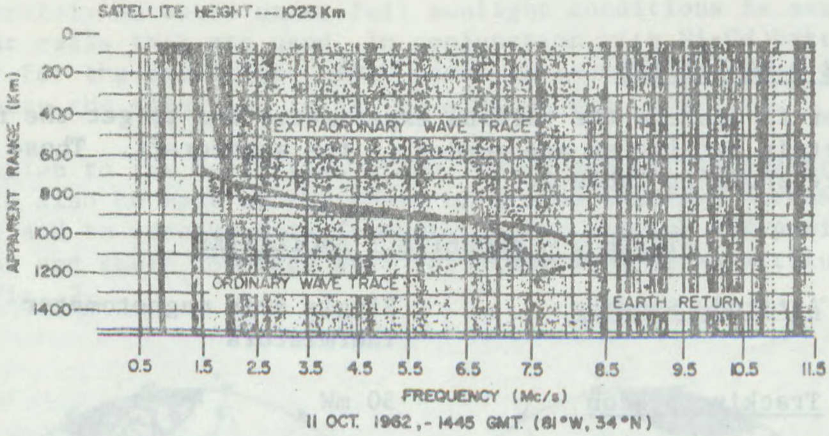


Fig. 1. A typical ionogram

Several things can be illustrated by the ionogram shown. First, the trace extends from about 1.5 MHz to about 7.5 MHz. The lower limit is set by the plasma frequency; any frequency below this will not be propagated. It was from a consideration of the electron density to be expected during the anticipated lifetime of Alouette I at the satellite height of 1000 km that the lower frequency limit of the sounder of 1 MHz was determined. The upper frequency limit is set by the maximum electron density that exists in the ionosphere. When the frequency exceeds the critical value corresponding to this maximum electron density (the foF2), the wave passes through the ionosphere without reflection. The upper frequency limit of 12 MHz was decided upon after considering the maximum electron density to be expected during the satellite lifetime. Secondly, spikes exist at the satellite height at low frequencies. The spikes are due to plasma and gyro-frequency resonances triggered by the sounder transmitter. Thirdly, at frequencies above foF2 not only are earth returns visible but also interference is noticed. These three things will be referred to again later during a discussion of changes between Alouette I and Alouette II.

The ionospheric sounder used in Alouette I is similar to the ground sounders (ionosondes) that have been used for many years. The 100 watt, 100 μsec, pulse transmitter used was calculated to give a signal/noise ratio of 10 when used with a receiver of 30 KHz bandwidth. The pulse repetition frequency is the highest that can be used for the expected ranges of the ionosphere when retardation effects are considered, while the sweep rate of 1 MHz/s permits the sounder frequency to change by about one-half the receiver bandwidth between successive transmitter pulses.

The VLF experiment is carried to investigate "whistler" propagation. The untuned receiver has a gain of 85 db and a very tight AGC loop that gives a high degree of amplitude compression with a wide dynamic range.

Since the ionosphere acts as a screen at frequencies below the critical the receiver works against a background of cosmic noise and this is measured by monitoring the AGC voltage from the sounder receiver.

The Energetic Particle experiment carried in Alouette I was supplied by the National Research Council. Six particle counters are used to record the number of particles within the energy ranges shown in the table.

2.2 ALOUETTE I FACILITIES

In order to operate the various experiments and to get the results back to earth, certain facilities are needed in the spacecraft. Those provided for Alouette I are shown in Table 2.

TABLE 2 - ALOUETTE I FACILITIES

Attitude Sensing	Single axis magnetometer Thermistors
Tracking Beacon	50 mW
Telemetry	2W FM 100 KHz bandwidth 1/4W PAM/FM/PM 50 KHz bandwidth 4 subcarriers
Command	24 basic commands
Antennae	Sounder: crossed dipoles 150 ft. and 75 ft. Telemetry and Command: turnstile whips Tracking Beacon: 1/4 wave whip
Power	6480 p-on-p type Solar cells: Ni-Cd batteries

Alouette is spin-stabilized with the spin axis (at time of launch) normal to the plane of the ecliptic. Information regarding its attitude is obtained from the magnetometer and from several thermistors located in the spacecraft. The tracking beacon, as its name denotes, is used by tracking stations to acquire the satellite and so to determine its present orbit in order to predict future orbits.

The data link between the satellite and the ground stations is formed with two telemetry transmitters. Sounder information together with frame and line synchronization and frequency marker pulses, or VLF information, is transmitted on a 2W FM transmitter in the 136 MHz band. Whether the sounder or VLF experiment is selected is decided by ground command. The other transmitter, also in the 136 MHz band, uses 4 subcarriers to transmit cosmic noise, energetic particle, attitude sensing, and housekeeping information.

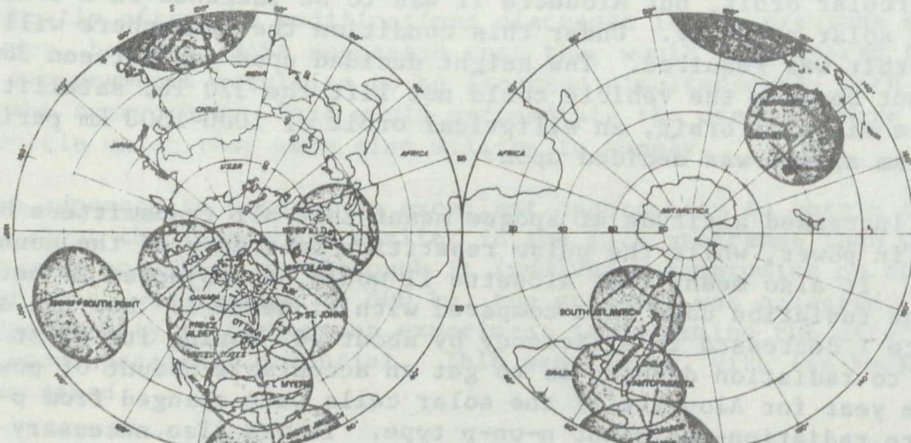
The command system for Alouette I has a total of 24 basic commands. It uses a command gate to prevent spurious operation and an automatic turn-off system which switches the satellite off after ten minutes from the time of switch-on. The command channel is in the 123 MHz band.

It is the antenna system which makes Alouette different from other satellites. The sounder, operating down to 1 MHz, requires long antennae.

A dipole 150 ft. long is used for the band 1 MHz to 5 MHz, while one of 75 ft. length is used from 5 MHz upwards. The rest of the antenna complement is more conventional: a turnstile is used for both telemetry at 136 MHz and for command at 123 MHz, and a 1/4 wave whip for the tracking beacon.

Approximately 18 watts under full sunlight conditions is available from the 6580 solar cells that are used, in conjunction with Ni-Cd batteries, to provide power for the satellite. This power is reduced by about one-third during orbits where the satellite is in the minimum sun condition.

In addition to the facilities shown, which are all satellite borne, mention should also be made of the chain of ground stations necessary to command the satellite and to receive data from it. A map showing the positions of these stations and their coverage area for satellites at an altitude of 1000 km is shown in Fig. 2.



15° ELEVATION

Fig. 2. Location and coverage of Alouette telemetry stations

2.3 ALOUETTE I OPERATIONAL BEHAVIOUR

At the time of writing 6-1/2 years after launch, Alouette I is still functioning very nearly perfectly. Four imperfections have been observed, as follows:

a) The silicon detector in the energetic particle experiment failed after its predicted lifetime in the space radiation environment of one year.

b) During conditions of low percentage sunlight five channels of housekeeping information are lost. Four of these channels are available from another source.

c) The batteries are aging. Operations of about 1-1/2 hours per day are still possible.

d) The spin rate of the satellite decayed much faster than was originally predicted.

3. ALOUETTE II

It was mentioned earlier that in order to get the next satellite launched as soon as possible it was decided to use the spare flight model of Alouette I for Alouette II, with as few modifications as possible. This section will attempt to describe the modifications that were considered necessary.

The major changes were caused by a change in the orbit requirements. Alouette I was launched just prior to a period of sunspot minimum and is in a 1000 km circular orbit, but Alouette II was to be launched in a condition of increasing solar activity. Under this condition the ionosphere will rise, so a higher orbit was required. The height decided upon was between 2000 and 3000 km, but because the vehicle could not lift the 320 lb. satellite to this height in a circular orbit, an elliptical orbit of 1000-1500 km perigee and 2000-3000 km apogee was decided upon.

The increased altitude at apogee meant that all transmitters had to be increased in power, while the pulse repetition frequency of the sounder had to be halved. It also meant that Alouette II would be subjected to between 3 and 4 times the radiation dose rate compared with Alouette I. Now the solar cells of Alouette I decreased in efficiency by about 40% during its first year in orbit due to radiation damage, so to get an acceptable amount of power at the end of one year for Alouette II the solar cells were changed from p-on-p type to the more radiation-resistant n-on-p type. It was also necessary to consider each semiconductor component in the spacecraft from the point of view of radiation damage.

Another modification,besides the orbit change, that was considered necessary was to improve considerably the sounder data quality when the sounder is operating over highly populated areas. Fig. 1 shows, as previously mentioned, some interference present above the critical frequency. This can be sufficiently strong that cross-modulation products at the receiver IF frequency of 19 MHz can obliterate all the data. A re-design of the receiver was therefore necessary.

Because Alouette II was launched in a period of increasing solar activity, the maximum electron density in the ionosphere will be higher than for Alouette I. The highest frequency of the sounder should therefore also be raised. On the other hand, as the apogee of the orbit is higher, the local electron density and the local magnetic field should be lower than experienced by Alouette I. As it is the local electron density and the local magnetic field that determine the frequency of the plasma and gyro spikes that are visible in Fig. 1, it is clear that the sounder lower frequency should be reduced. A decision to reduce the lower frequency limit involves increasing the length of one of the sounder antennae.

As well as the modifications so far described, which were deemed necessary, there were others that were highly desirable if time permitted them to be incorporated. One was to alter the sweep rate so that $\frac{\Delta f}{f}$ would be more nearly constant over the sounder frequency sweep. Another was to increase the bandwidth of the VLF receiver. The final one was to provide better attitude sensing.

In total these changes proved to be quite comprehensive, and every electronic unit in the payload had to be re-designed.

3.1 A DIRECT MEASUREMENTS SATELLITE

The aim of the ISIS programme is to launch satellites equipped with sufficient instrumentation that all ionospheric parameters can be measured simultaneously. Alouette I falls short of this ideal as no instrumentation is carried for such parameters as ion mass, ion temperature, and electron temperature. Shortly after the modifications discussed in the previous section were decided upon, however, NASA suggested that they would be prepared to instrument a direct measurements satellite to be launched simultaneously with Alouette II and into the same orbit. This would necessitate the use of a more powerful launch vehicle which they were also willing to supply.

This appeared to present an excellent opportunity to obtain further information about the ionosphere earlier in the ISIS programme than would otherwise have been possible, so although it involved a compromise on the orbit, the perigee of which was reduced to 500 km, the proposal was accepted. It also gave an opportunity to perform an experiment to determine the effect of long antennae upon spacecraft potential. This experiment, with its background, will now be described.

3.2 SPACECRAFT POTENTIAL

It is well known that a conductor moving in a magnetic field will have a potential induced in it. This effect is also noticed on metallic spacecraft, the potential being proportional to $(\overline{V} \times \overline{B})L$ where $\overline{V}$ is the spacecraft velocity, $\overline{B}$ is the earth's magnetic field strength at the spacecraft, and L is a spacecraft dimension. It has already been pointed out that Alouette is distinguished from other satellites by its long antennae and that these have been increased for Alouette II. Consequently, Alouette II should have a large potential induced in its antennae: calculations show that it may reach 25 volts. This induced potential will cause a current to be drawn from the plasma. Because, however, the mobility of electrons is so high compared with that of ions, the area of the antenna needed for electron collection will be small; hence one end of the antenna will be clamped at space potential while the other end may reach -25 volts. The spacecraft body would thus be at a fairly high negative potential. The consequence of this is that electrons in the vicinity of the spacecraft would be repelled and ions attracted. Instrumentation placed on the satellite body to measure local electron and ion concentrations and temperatures would therefore not view an undisturbed plasma.

One way of ameliorating this condition is to couple the antennae capacitively, at the same time insulating the roots of the antennae for a distance approximately equal to the radius of the plasma sheath, as the disturbed plasma is called. When this is done the sheath should appear somewhat as shown in Fig. 3. The antennae on Alouette II are coupled in this manner and insulated guards one metre long are attached to each root.

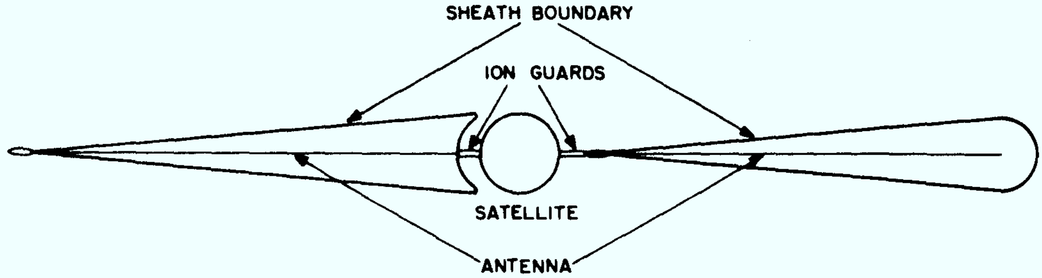


Fig. 3. Sheath structure expected around capacitively coupled antennae equipped with ion guards.

To perform the experiment two Langmuir probes are carried, one on the direct measurements satellite and the other on Alouette II. Since the Langmuir probe can measure the spacecraft potential, a comparison of the results from the two probes enables any effects due to the long antennae on Alouette II to be seen.

3.3 ALOUETTE II EXPERIMENTS

The final specifications for the Alouette II experiments are shown in Table 3.

TABLE 3 - ALOUETTE II EXPERIMENTS

Ionospheric Sounder	
Frequency coverage	0.2 MHz to 13.5 MHz
Transmitter power	300 watts
Transmitter pulse width	100 μsec
Pulse repetition frequency	33 Hz
Frequency sweep rate	0.15 MHz/s between 0.2 and 2 MHz 1 MHz/s between 2 and 13.5 MHz
VLF	
Untuned receiver	50 Hz to 30 KHz
Cosmic Noise	
From AGC of sounder receiver	

Energetic Particles

Protons	0.5 to 700 MeV
Electrons	40 KeV to 3.9 MeV
Alpha	5 MeV to 2.8 BeV

Langmuir Probe

Electron density	10^3 to 10^6 e/cc
Electron temperature	400 to 5000°K

It will be noted that, compared with Alouette I, the sounder receiver bandwidth has been extended at both ends of the range, the sounder transmitter power has been increased, the pulse repetition frequency decreased, and the frequency sweep rate modified. The VLF receiver has also been given an extended bandwidth. Not shown in the table is the much greater immunity to interference provided in the re-designed receiver.

3.4 ALOUETTE II FACILITIES

Table 4 presents a list of the facilities provided in Alouette II. Comparison with Table 2 shows that attitude sensing is more comprehensive, that the sounder long antenna has increased from 150 to 240 ft., and that all transmitter powers have been increased. Two subcarriers have been added to the wide-band telemetry transmitter: one is used optionally on command to transmit either the ionogram frequency markers or housekeeping data; the other transmits Langmuir probe data.

TABLE 4 - ALOUETTE II FACILITIES

Attitude Sensing	3 axis magnetometer Thermistors Solar aspect sensor
Tracking Beacon	100 mW
Telemetry	4W FM 100 KHz bandwidth 2 subcarriers
	2W PAM/FM/PM 50 KHz bandwidth 4 subcarriers
Command	24 basic commands
Antennae	Sounder: crossed dipoles 240 ft. and 75 ft. Telemetry and Command: turnstile whips Telemetry beacon: 1/4 wave whip
Power	6480 n-on-p Solar cells: Ni-Cd batteries

3.5 ALOUETTE II OPERATIONAL BEHAVIOUR

Together with the direct measurements satellite referred to in paragraph 3.1 which is now known as Explorer XXXI, Alouette II was launched from the Western Test Range, California, at 04:48:47 G.M.T. on November 29, 1965. The orbit achieved was almost perfect; the achieved parameters are compared with the nominal ones in Table 5.

TABLE 5 - ALOUETTE II ORBIT

	Nominal	Achieved
Perigee	500 km	501.84 km
Apogee	3000 km	2982.25 km
Inclination	80^o	79.82^o

In addition it was asked that Alouette II and Explorer XXXI should remain in the same orbit, separated along the orbit path by less than 1000 km for one month. Fifteen days after launch the separation was 83 km and was increasing at a rate of 9 km/day.

All experiments and facilities are working as planned. Results indicate that the capacitive antenna coupling combined with the ion guards has been successful in reducing considerably the effect of the plasma sheath. The bandwidth extension of the VLF experiment has yielded new information; while the re-designed sounder system suffers less interference than did Alouette I.

About two years after launch the Langmuir probe data showed that the plasma sheath effect had become noticeable. The most probable explanation is that one of the condensers used to couple the antenna poles has failed in the short-circuit mode. At the time of writing (3-1/4 years after launch) this is the only known fault.

4. ISIS-I

The next satellite in the series is named ISIS-I and it presented the first opportunity to instrument a single satellite to measure most, if not all, of the important ionospheric parameters at the same time and the same place. It carries a total of ten experiments, which are shown in Table 6. It will be seen that the specification of the ionospheric sounder is little changed from Alouette II: the frequency coverage was extended again and for the same reasons; that is, the satellite was launched into a higher orbit later in the solar epoch. Similarly, the transmitter power was raised.

The fixed frequency sounder is a new experiment in the ISIS series. (Because this experiment is also an ionospheric sounder, the first experiment has been re-named the swept frequency sounder.) It is, however, similar to that borne by Explorer XX. Its purpose is to study irregularities in the horizontal plane: to do this it is better to observe a single frequency. Essentially the difference is that the ISIS-I swept frequency sounder samples at the same frequency at intervals of about 200 km, whereas the fixed frequency sounder samples at intervals of about 0.27 km.

The VLF experiment has added to it a swept frequency transmitter whose purpose is to stimulate resonances among ions similar to those previously reported with electrons at higher frequencies.

TABLE 6 - ISIS-I EXPERIMENTS

Swept Frequency Sounder	
Frequency coverage	0.1 MHz to 20 MHz
Transmitter power	400 watts
Pulse width	100 μsec
Pulse repetition frequency	33 Hz
Frequency sweep rate	Varying from 0.15 MHz/s to 2 MHz/s over band
Fixed Frequency Sounder	6 frequencies: 0.25, 0.48, 1.0, 1.95, 4.0, and 9.303 MHz
Mixed Mode Sounder	Fixed transmitter frequency at 0.85 MHz Swept receiver
VLF	Receiver: Untuned 50 Hz to 30 KHz Transmitter: Logarithmic sweep 500-0-9500 Hz
Cosmic Noise	From AGC of sounder receiver
Energetic Particle	Protons: 100 KeV to 60 MeV Electrons: 3 KeV to 2 MeV
Langmuir Probe (2)	Electron density 10^3 to 10^6 e/cc Electron temperature 400 to 5000°K
Ion Mass Spectrometer (2)	Atomic mass range 1 to 20
Ion Probe	Ion density 10 to 6 x 10^6 Ion temperature 700 to 4000°K
Soft Particle Spectrometer	Electrons and positive ions: 10 eV to 10 KeV
Beacon	137 MHz

A change will be noted in the energetic particle experiment. Many of the phenomena of the ionosphere appear to depend on low energy electrons, so the lower limit of detection of electrons was reduced from 40 KeV to 3 KeV. Together with the soft particle spectrometer, electrons from 10 eV to 2 MeV are measured. The soft particle spectrometer also measures the flux of positive ions from 10 eV to 10 KeV.

More information regarding the ion density and temperature will be gained from the ion probe experiment while ion masses will be determined by the Ion Mass Spectrometer. Two instruments are fitted for this experiment in order to enable measurements to be taken along the satellite velocity vector at all latitudes.

Two instruments are also used for the Langmuir probe experiment, whose range is the same as for Alouette II. One of the Langmuir probes and also the ion probe are mounted on 3-foot booms.

The beacon, at 137 MHz, together with the 136 MHz tracking beacon (Table 7) will measure scintillations particularly in the auroral zone.

It is only to be expected that the large number of experiments needs increased facilities in the satellite. These are discussed in the next section.

4.1 ISIS-I FACILITIES

A list of the facilities provided for ISIS-I is given in Table 7.

TABLE 7 - ISIS-I FACILITIES

Attitude Sensing	3 axis magnetometer Thermistors Solar aspect sensor
Attitude Control	Spin maintenance and spin axis attitude control by magnetic torquing
Tracking Beacon	100 mW
Telemetry	4W FM 100 KHz bandwidth 2W PCM/PM 50 KHz bandwidth 4W 400 MHz 500 KHz bandwidth, for fast playback of tape recorder, or direct transmission of sounder or VLF experiment
Command	216 possible commands Programmer: 5 commands can be stored together with their times of execution. These commands may be selected from a group of 10 Clock
Date Storage	Tape recorder 3000-ft. tape. Record/Playback speed ratio 1:4 4 tracks used as: 1) PCM at 2500 bits/in 2) Sounder up to 10 KHz 3) VLF up to 20 KHz 4) Reference tone and clock

Antennae	Sounder: crossed dipoles 240 and 61.5 ft. Telemetry (136 MHz) and command: turnstile whips Tracking beacon and 137 MHz beacon: quadraloop 400 MHz telemetry: annular slot
Power	11,000 n-on-p type Solar cells: Ni-Cd batteries

The most significant difference in the facilities provided between ISIS-I and its predecessors in the series is in the provision of on-board data storage. At the time of the initial design of Alouette I this was considered impracticable; as Alouette II uses the same spaceframe as Alouette I, there would have been no room for data storage, quite apart from the lack of time for the necessary development work. In spite of the large number of ground stations (Fig. 2), however, there are large areas around the world from which data are unavailable, so it was decided that to fill in these areas data storage would be provided in ISIS-I. The tape recorder used is capable of storing information from all experiments simultaneously.

Data storage necessitated other changes in the facilities required. The experiments and the tape recorder must be able to be switched on when the spacecraft is out of range of any ground station. Consequently a programmer was provided which is capable of storing 5 commands as well as the times at which each command is to be implemented. Each command may be selected from a list of 10 of the more common commands. A clock is provided so that the tape recorder may be switched on at the desired time and the actual time at which data are recorded is also recorded. The clock is able to be reset.

Provision of the programmer and clock has complicated the command system and in addition, to control all the experiments, a large number of commands is required. A total of 216 commands is available.

The telemetry requirement has also been altered as a result of data storage. If the number of data links remained the same as in the Alouette satellites, data would be gathered from one area of the world at the expense of data at the station where the recorded information would be received. To avoid this an extra link is provided. Also, in order to receive all the information stored in the tape recorder during one pass this data link must be wide-band. A 400 MHz link with a bandwidth of 500 KHz is therefore provided.

This link will also be used to transmit the sounder or VLF data in the event of trouble with the wide-band 136 MHz link, the transmitters of which are already duplicated in the spacecraft.

Another change will be noticed in the telemetry system. Previously the data from experiments other than the sounder or VLF, and also housekeeping data have been transmitted in continuous form, by use of frequency multiplexing. In ISIS-I these data are time multiplexed, using pulse code modulation: this change should make automatic data reduction simpler at the ground data centres.

While the instrumentation for attitude sensing is similar to that on Alouette II, on ISIS-I attitude control is incorporated also. Alouette I has shown marked changes in the attitude of its spin axis, and also a rapid decay in its spin rate. The spin axis attitude changes can be explained by a combination of gravity gradient effects on the long antennae and the magnetic moment of the spacecraft and the excessive spin rate decay by thermal bending of the antennae causing the spacecraft's centre of pressure to be displaced from its centre of gravity; solar radiation pressure is then able to exert a decelerating torque. Hence, on ISIS-I, spin rate will be controlled by magnetic torquing to within the limits of 1 and 3 rpm, while spin axis attitude is also capable of being modified.

To meet the requirements of the extra transmitters, more antennae are required. These are listed in Table 7. The quadraloop antenna is mounted around the mid-section of the spacecraft, while the annular slot is cut in the section which is the top of the spacecraft at time of launch.

Not only extra experiments, but also extra facilities, need increased supplies. The 11,000 solar cells will be capable of providing 5 hours per day of full spacecraft operation under minimum sun conditions after one year in orbit, providing, of course, that the radiation environment does not change.

A sketch of ISIS-I is shown in Fig. 4.

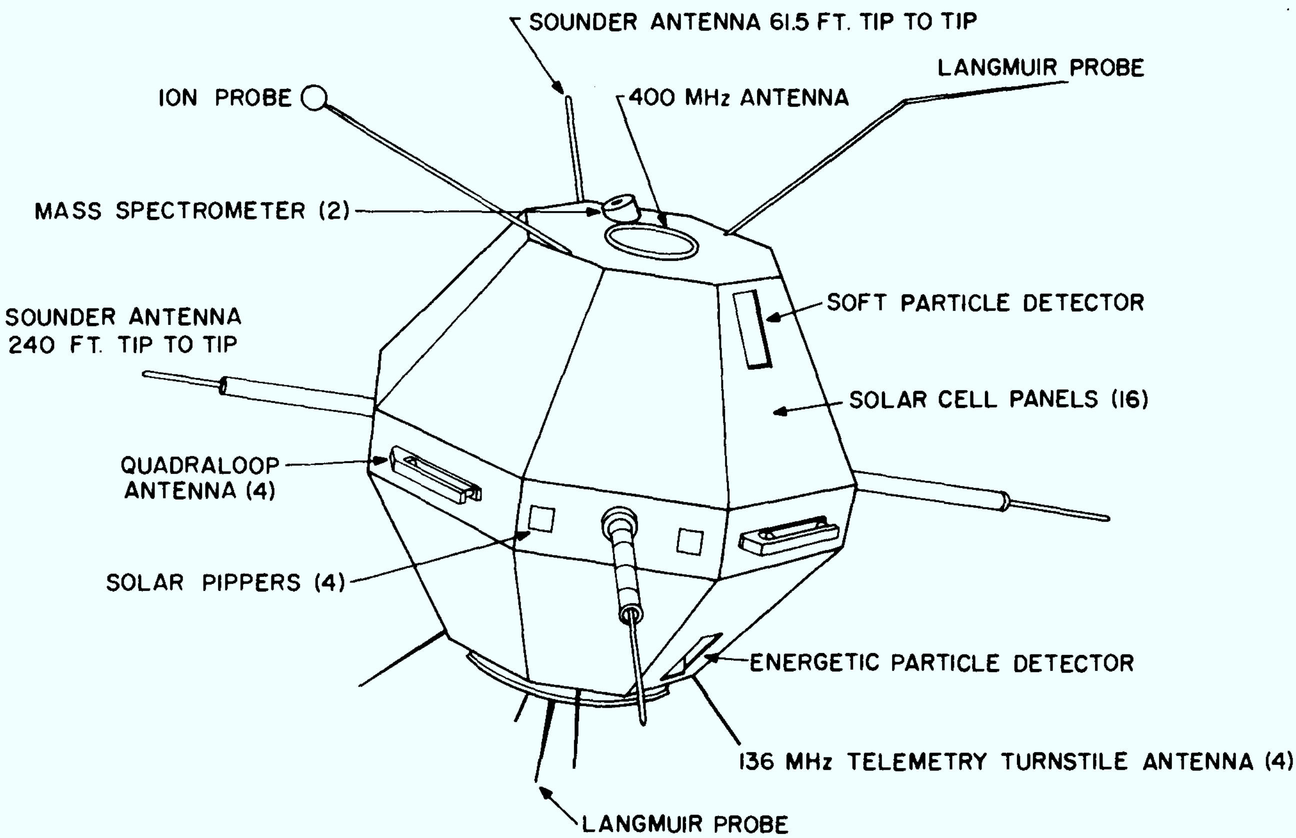


Fig. 4. Antenna and experimental layout of ISIS-I

4.2 LAUNCH AND EARLY RESULTS OF ISIS-I

ISIS-I was launched from the Western Test Range, California, at 06:46:15 GMT on January 30, 1969. As with the Alouette satellites, the launch was near perfect, as Table 8 shows.

TABLE 8 - ISIS-I ORBIT

	Nominal	Achieved
Perigee	565 km	574 km
Apogee	3500 km	3522 km
Inclination	88.5^{o}	88.4^{o}

Because of the complexity of ISIS-I, the mission requirement that simultaneity of experiment operation be possible, and the time taken to reduce and analyse sufficient experimental data, the testing phase of this satellite is lengthy. At the time of writing (one month after launch) it has not been completed, but it is possible to say that all satellite systems are operating nominally, and all experiments are acquiring good data with the exception of the IMS experiment which gave good data when first switched on but then degraded. Of particular interest are the tape recorded results from previously inaccessible locations; e.g., Antarctica, and the results from the mixed mode operation of the sounder system. This latter experiment was a late modification to the system.

5. ISIS-B

The mission for ISIS-B has been defined and the experiments selected. The mission will be that of a monitoring satellite to perform the measurements, with supporting experiments, near the peak of the solar cycle that were so well performed by Alouette I at the minimum. Because these measurements will take place at a time of high solar activity, when the height of the ionospheric peak rises, the circular orbit will be as near to 1700 km as the vehicle can achieve, instead of the 1000 km used for Alouette I. Inclination will be 75^{o} prograde.

5.1 ISIS-B EXPERIMENTS

The experiments for ISIS-B are listed in Table 9.

TABLE 9 - ISIS-B EXPERIMENTS

i) Swept Frequency Sounder
ii) Fixed Frequency Sounder
iii) VLF
iv) Cosmic Noise
v) Energetic Particle
vi) Langmuir Probe (2)
vii) Soft Particle Spectrometer
viii) Beacon
ix) Ion Mass Spectrometer
x) Ion Probe
xi) Oxygen Red Line Photometer
xii) Scanning Photometer

It will be seen that the first ten experiments are similar to those in ISIS-I. Indeed, it is expected that the first eight will be practically identical, while the two ion measuring experiments, although different from those in ISIS-I, will have the same purpose.

Two new experiments will be carried, both to observe optical phenomena. The oxygen red line photometer will study the atomic oxygen emission at 6300 Å, while the scanning photometer will observe an atomic oxygen emission at 5577 Å and one due to ionized molecular nitrogen at 3914 Å and the ratio between them.

5.2 ISIS-B FACILITIES

The facilities provided for ISIS-B will be similar to those on ISIS-I. The inclusion of the two optical experiments has caused some modifications to the structure, but in the main this will be similar to that of ISIS-I. The different ion measuring experiments, because of package configuration, have forced the quadraloop antenna for the VHF beacons to be abandoned; the VHF antenna, and also an altered UHV antenna, will be mounted at the top of the spacecraft. The ion probe, also, does not need to be boom mounted; since the second Langmuir probe can also be body-mounted no booms will be used on ISIS-B

Launch of ISIS-B is scheduled for late 1970.

6. ISIS-C

The experimental complement of ISIS-C has not yet been defined. It is highly probable that the mission will be of an exploratory nature to seek information regarding the high ionosphere out to the magnetospheric boundary.

7. ENGINEERING SUPPORT

As well as the design of the spacecraft, the ISIS programme includes support services in the form of two telemetry stations and a data processing centre. These will be described briefly.

7.1 RESOLUTE BAY TELEMETRY STATION

Situated on Cornwallis Island, NWT, at 74.7°N, 94.9°W, Resolute Bay is in an ideal position for reception of telemetry from near-polar orbiting satellites. It has a dual reception capability for the 136 MHz telemetry band and command capability for the 123 and 148 MHz allocations.

7.2 OTTAWA TELEMETRY STATION

Although this station does in fact gather a considerable quantity of data, its primary function is that of a control station. For ISIS-I a 400 MHz reception capability is needed and to this end a 60 ft. dish antenna has been installed, complete with the necessary electronic and mechanical hardware for punched paper tape drive. This dish was fitted with 136 MHz dipoles in order to give Ottawa a dual telemetry capability for use in the early operational life of Alouette II and Explorer XXXI. The 136 MHz system was modified in order to give a monopulse capability to the dish so that ISIS-I can be followed automatically using the 136 MHz telemetry transmissions to ensure reception of the 400 MHz transmissions.

7.3 DATA PROCESSING CENTRE

While Alouette I was the only Canadian satellite, the DRTE Data Processing Centre processed all the telemetry tapes from some 14 telemetry stations located as shown in Fig. 2. In this time 15,000 reels of magnetic tape were processed (2400 ft. per reel), some 10^6 ionograms being produced. With the advent of Alouette II an arrangement was reached with Goddard Space Flight Center, the Institute for Telecommunication Sciences and Aeronomy*, and with the Radio Research Station† for a division of the work on Alouette II among the four agencies. Accordingly CRC (formerly DRTE) is now responsible for processing Alouette II ionograms from six stations only: College, Alaska; Resolute Bay, NWT; Ottawa; Tromso, Norway; Ouagadougou, Upper Volta Republic, and Kashima, Japan, but is also responsible for quality control of all telemetry tapes, for copying all VLF, solar noise, housekeeping, and energetic particle date, and for copying Langmuir probe data. All Alouette I results are still processed at CRC.

For ISIS-I the CRC Data Processing Centre has the same responsibilities for VLF, housekeeping, and quality control as for Alouette II, and for the processing of all ionograms. The PCM data, from which all other experimental results

*Now ESSA/RL
†Now RSRS

come, is processed on a production basis by the Goddard Space Flight Center, but CRC has a capability in this area for special requests and "quick look" information.

8. CONCLUSIONS

The report has outlined the differences between Alouette I and some of its successors. It is not possible at present to do more as the programme is not complete. Instead, in this concluding section, some thoughts will be offered concerning the direction in which satellite instrumentation is likely to develop.

In the field of digital computation it took 100 years for the ideas of Babbage to bear fruit with the first stored-programmer digital computer. A number of computers then appeared, each offering modest improvements over its predecessor. After ten years of vacuum-tube computers, the first solid-state computer was developed. The greatly improved reliability of the solid-state computer immediately made possible great increases in the complexity of computers, and the present day very fast, very complex, very large in memory capacity, but very reliable machine was born.

Scientific satellite instrumentation, similarly, has so far been fairly rudimentary, with limited command capability, not much in the way of memory, and little on-board data processing. This is only natural: it is not economic to spend a lot of time and money on the development of a complex satellite instrumentation system if failure is going to result at an early stage. Launch vehicles have, however, improved greatly in reliability, so that there is now a high probability of a satellite being placed in a desirable orbit. Some satellites, also, have demonstrated that reliability is achievable. Notable among these, of course, is Alouette I, which after 6-1/2 years in orbit still continues to send back 1-1/2 hours of useful data each day. Experience such as this will surely influence future designs so that one may look forward to the scientific satellite of the future being a very flexible instrument, capable of obeying many involved commands, sorting and processing large volumes of data, and presenting the results to the experimenter in the way best suited to his requirements. It is hoped that the satellites described in this report will contribute, albeit modestly, towards these ends.

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