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KIRTLAND AIR FORCE BASE, NEW MEXICO

AFSWC BLUE SCOUT JUNIOR PROGRAM FOR 1962

by

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PROGRAM FOR 1962

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ABSTRACT

The Air Force space physics program is designed to determine certain properties of the region above the earth's atmosphere that have important military implications. The Blue Scout Junior Program for 1962 is intended to investigate the nature of turbulence at altitudes up to 100,000 km. This note describes the instrumentation which is needed to study the turbulent region and the responses expected from these instruments. The relationship between this program, the entire AFSWC high altitude program, and NASA's high altitude program is also discussed.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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I. Introduction

It has been established that charged particles are streaming from the sun even during relatively quiet solar periods, and that this solar corpuscular radiation can significantly alter the earth's magnetic field. In particular, a boundary region is formed which surrounds the earth and contains the earth's magnetic field. The boundary region extends downward toward the earth's surface as far as the solar corpuscular radiation penetrates. Interactions in the boundary region certainly influence the earth's magnetic field below this region, but it is the boundary region itself that is of greatest interest to the Air Force.

In this introduction, the present status of experimental measurements and the conclusions which have been drawn from this evidence will be reviewed. Then some Air Force problems which are closely related to space physics, and the specific measurements of importance to these problems will be discussed.

The following sections will describe some problems of the boundary region in more detail, outline the portion of NASA's program which involves the boundary region, and propose a course that AFSWC can take in solving some specific problems that are of primary importance to the Air Force.

1. Solar Corpuscular Radiation

The existence of solar corpuscular radiation near the earth was postulated as a means of explaining the correlation between solar activity and magnetic storms on the earth[1]. Somewhat later, an analysis of type I comet tails indicated that particles were emitted from the sun even during relatively quiet times. Biermann's[2] analysis of comet tails concluded that during undisturbed periods in years of high solar activity, the plasma from the sun has a density of about 100 particles $\cdot$ cm^{-3} and a streaming velocity of about 500 km $\cdot$ sec^{-1} (1 kev) near the earth. Recently, several Soviet rockets[3] have carried gridded ion traps which were sensitive to protons with energies greater than 15 ev. Lunik I detected fluxes of about 2×10^8 particles $\cdot$ cm^{-2} $\cdot$ sec^{-1} with energies greater than 15 ev during a quiet day in a year with moderate solar activity. This is consistent with a density of 100 particles $\cdot$ cm^3 and a velocity of 20 km $\cdot$ sec^{-1} or a density of 4 particles $\cdot$ cm^{-3} and a velocity of 500 km $\cdot$ sec^{-1}. The fluxes reported showed large fluctuations over periods of several minutes. If these fluctuations are real, they would not be consistent with the simple picture of a steady solar wind due to hydrodynamic expansion or evaporation of the solar corona. However, it is not clear whether these fluctuations are due to variations in the corpuscular radiation intensity or to the motion of the cosmic rocket. The real purpose of these measurements was to distinguish between two proposed models for the distribution of particles in interplanetary space. The first possibility was that solar corpuscular radiation does stream continuously from the sun; the second was that interplanetary space is filled with a stationary plasma through which the earth moves. Due to the motion of Lunik I, protons in a stationary plasma would have had an energy of about 5 ev relative to the detectors, so this experiment confirms the conclusion that a streaming solar corpuscular radiation is present even during quiet days.

Finally, Explorer X[4], which reached an altitude of 230,000 km, carried a plasma probe. The largest positive ion fluxes detected were in the energy range of 250 to 800 ev and varied from 8×10^6 to 8×10^8 particles $\cdot$ cm^{-2} $\cdot$ sec^{-1}. If the mean energy were 500 ev, this would correspond to a velocity of 300 km $\cdot$ sec^{-1} and densities of 0.3 to 30 particles $\cdot$ cm^{-3}. These particles were observed to arrive at the earth from the direction of the sun. Since Explorer X was on the night side of the earth when these measurements were made (satellite-earth-sun angle of 140^o), it is uncertain whether these large fluctuations were due to variations in the intensity of solar corpuscular radiation or to turbulence due to the presence of the earth. The conclusion that can be drawn from all these measurements is that a plasma is streaming from the sun during undisturbed periods. It is not clear whether this plasma forms a steady solar wind or whether there are large fluctuations in the density of particles at the earth's orbit.

2. Form of the Boundary Region

The exact problem of the interaction between a streaming solar plasma and the earth's magnetic field has never been solved, but various one and two dimensional approximations to the real problem have been solved exactly[5,6], and three dimensional solutions have been approximated[7]. These treatments conclude that if there were a steady solar wind and if no turbulence existed in the interaction with the earth's magnetic field, then a thin ($\sim<$ 100 km) current sheath would be formed around the earth extending to 5 to 15 earth radii on the day side of the earth and to perhaps 10 to 100 earth radii on the night side. It has also been shown that this interface is unstable to small perturbations at least in some regions[6,8], and possibly over the entire surface. The absence of a thin current sheath has also been shown experimentally, though there is some evidence for the presence of a very thick (several earth radii) diamagnetic boundary region separating the earth's magnetic field from the interplanetary field[9].

3. Hydromagnetic Waves

Above about 10 earth radii, large (100 γ or 10^{-3} gauss) fluctuations in the magnetic field intensity with periods of a few seconds have been observed[10]. These are presumably due to the presence of hydromagnetic waves which are produced in the turbulent boundary region and which propagate downward toward the earth's surface. Hydromagnetic waves with periods of several minutes involving large scale oscillations of much of the earth's outer magnetic field have been observed at the ground[11], so there appear to be oscillations ranging in extent from an ion cyclotron radius to several earth radii.

4. Air Force Interests

Vela-Hotel is a project to define a method for detecting clandestine nuclear explosions in space. It appears necessary to locate detectors above the earth's trapped radiation belts, so the extent of these belts must be determined on the night side of the earth as well as on the day side where most measurements have been made. The background radiation from the sun must be accurately measured over long periods of time so that the sensitivity limits which should be placed on the detectors can be determined. On the night side of the earth, hydromagnetic waves could form shock fronts which may result in high frequency particle fluctuations. Since these fluctuations may limit the allowable sensitivity, hydromagnetic wave formation and propagation must be investigated.

It is necessary to investigate the amount of radioactive debris which will eventually return to the earth if a nuclear weapon were detonated beyond the boundary region. This amount will depend on the nature and the extent of turbulence in the boundary region.

Studies of turbulence in the boundary region may also provide valuable tests of theories important to nuclear weapon phenomenology.

II. Problems

1. Solar Corpuscular Radiation

In this section we will review the questions which must be answered before the structure of the boundary region can be determined. First, the nature of solar corpuscular radiation and of the interplanetary magnetic field beyond the influence of the earth must be determined. This must include a determination of fluctuations in the particle flux, the energy spectrum, and the magnetic field vector during quiet periods, during disturbed periods after solar flares, and correlations between particle flux, energy, and magnetic field fluctuations. The temperature of the solar plasma is important in the study of turbulence and in explanations of the structure of the earth's magnetic field above the night side of the earth. The temperature (or the mean particle energy as seen from the streaming plasma, in the event that there is not an energy equilibrium) of greatest importance is that of the protons. It is possible that the proton temperature is different along and perpendicular to field lines that exist in interplanetary space. The electron temperature will probably be much more clearly defined and easier to measure than the proton temperature, but the two temperatures need not be the same.

2. Form and Structure of the Boundary Region

Another problem is the determination of the shape and structure of the boundary. This would include a determination of the spectrum and amplitude of the turbulence as a function of altitude and of the polar angle and azimuthal angle with respect to the earth's magnetic axis. At present it is not certain whether turbulence exists at all points in the boundary region or whether some portions are stable. It is quite likely that at least the frequency spectrum and scale of the turbulence will be a function of position on the boundary. The most obvious regions of interest in the boundary are:

1) directly toward the incoming plasma

2) directly away from the incoming plasma

3) toward the neutral points at which the total magnetic field drops to zero (probably slightly to the sun side of the earth's magnetic axis).

4) perpendicular to both the earth's magnetic axis and the velocity vector of the incoming plasma.

If large scale turbulence exists, it is possible that intrusions of solar wind particles can form clouds which will move in the earth's field for a period of time before either breaking up completely or being expelled. These intrusions could take place at a single point in the boundary region, throughout the region, or intrusions may be entirely absent.

3. Hydromagnetic Waves

Hydromagnetic waves have been detected in the boundary region. The type of waves present, or in particular the dispersion relations, should be measured experimentally. The attenuation of these waves is also important to many physical problems such as the acceleration and loss of trapped particles and atmospheric heating. Attenuation measurements are most significant below the boundary region and would require determination of the spectrum of hydromagnetic waves in the large background field of the earth. Typical hydromagnetic wave amplitudes are less than 100 γ so an accuracy of about 1 γ would be required to adequately describe the waves. This measurement need not be accurate to 1 γ in the total field intensity, but only in the variation in field intensity.

The presence of hydromagnetic waves implies the presence of turbulence at some point in the interface region. To study the mechanism of formation of hydromagnetic waves would require the simultaneous measurement of hydromagnetic waves and of turbulence. These measurements would include the dependence of hydromagnetic wave frequency and amplitude on the size of the turbulent structure and the energy spectrum of particles involved in the turbulence.

4. Acceleration Mechanisms

Another question to be answered is whether particle acceleration mechanisms are in operation. Acceleration is possible in the region where solar corpuscular radiation is deflected, i.e., on the surface of the turbulent structure or on the surface of intrusions of solar-corpuscular radiation. It is possible that hydromagnetic waves accelerate charged particles. Finally, acceleration could take place during times of large scale magnetic disturbances which follow solar activity. A study of acceleration on the boundaries of turbulent structures would require rapid measurements of the particle energy spectrum and the vector magnetic field. Since surface thicknesses are likely to be as thin as ion cyclotron radii and intrusion velocities could approach the incoming particle velocities, it may be necessary to make measurements in time intervals shorter than ion cyclotron periods.

Acceleration by individual hydromagnetic waves may be difficult to detect since the fractional change in energy of a trapped particle due to the interaction with a single wave will probably be small. The effect may be appreciable on the night side of the earth or near neutral points where hydromagnetic shock waves could be formed. A long period correlation between hydromagnetic wave intensity and the trapped particle energy spectrum would give some measure of the effectiveness of hydromagnetic wave acceleration. Also, the simultaneous observations of hydromagnetic waves, turbulence, and the angular distribution of charged particles should provide an experimental observation of the reflection of trapped particles from moving hydromagnetic waves and from turbulent structures. A thorough investigation of acceleration during storms would require a complete investigation of the energy spectrum and mirror point distribution of trapped particles, the changes in magnetic field intensity (including hydromagnetic waves), and variations in atmospheric density during storm periods.

5. Trapping Mechanisms

Finally, there is the possibility of trapping of solar corpuscular radiation in the earth's magnetic field. Trapping for short periods could take place in the turbulent region by scattering of particles or diffusion of magnetic field lines through the turbulent structures. Particles trapped by this method would be lost in a short time by the same mechanism. Trapping for longer periods would require injection of solar corpuscular radiation deeper into the earth's magnetic field, perhaps from intrusions or clouds of solar particles at some point on the boundary. The existence of isolated clouds of moderate energy (10 ev - 1 kev) protons in the boundary region would imply such a trapping mechanism was in operation. The existence of a belt of moderate energy trapped particles with a lifetime of about a day has been predicted in order to account for variations in the magnetic field at the earth's surface during a magnetic storm[12,13]. There is some evidence from magnetic field data for the existence of a diamagnetic belt or ring current at altitudes of five to ten earth radii[14].

III. Programs Scheduled by NASA

1. Delta S-3

The most relevant experiments planned by NASA are two Delta S-3 satellites scheduled for launch in 1961 and 1962. These will have elliptic orbits with perigees of about 200 km and apogees of about 77,000 km. They are intended to study the relationships between trapped particles, solar wind particles, and magnetic fields. Satellite observations are necessary to answer questions regarding long term effects such as the change in particle densities, mirror point densities, and energy spectra of trapped particles during and after a magnetic storm. The magnetometer and plasma probe will also detect hydromagnetic waves and turbulence. The magnetometer sampling rate of three times per second will be sufficient to accurately determine the shape of hydromagnetic waves and the change in the frequency spectrum during solar disturbances, at least in the absence of a high background field. The direction of propagation and the dispersion relations will not be measured adequately. The presence of turbulence will be detected with the plasma probe, and some features of its structure can be determined from the 32 point energy spectrum which will be taken during intervals of 10 seconds or longer. The motion of turbulence will not be accurately determined. Also, the satellites will not look at all the points of interest in the boundary region.

2. Rangers

Rangers 1 and 2 will be fired in 1961 to a distance of about 2×10^6 km. These will carry magnetometers and plasma probes which should provide background information on the undisturbed solar corpuscular radiation and the interplanetary magnetic fields. This information is essential before data on turbulence can be analyzed adequately. The instruments are not designed to gather detailed information on turbulence (the plasma probe will take nine seconds to read each energy channel and two minutes to determine the entire energy spectrum). The magnetometer will provide measurements of one component of the magnetic field at 0.1 to 0.01 second intervals, then switch to other components at ten second intervals. This will detect rapid changes in the strength of the magnetic field, but will not distinguish between rapid intensity and directional changes.

3. EGO and Later Shots

Beyond 1962, NASA is planning several satellites which will carry rather elaborate experiments. The payloads are not definitely established yet, but they will measure magnetic fields including fluctuations up to frequencies of 10^4 cps. They should also be able to provide refined measurements of turbulence over their complete orbits.

IV. Proposed AFSWC Blue Scout Jr. Program

1. Required Instruments

The primary interest of the Air Force is a detailed study of the formation, growth, and breakup of turbulent structures in the boundary region. The formation and propagation of hydromagnetic waves are of secondary importance. It has been determined experimentally that significant changes in the magnetic field can take place in a one second time interval[10], so a complete study of turbulence will require a measurement of all components of the magnetic field and of the particle flux in several energy ranges at intervals of 0.1 to 0.5 second. Data are not required over the complete trajectory, and it is believed preferable to obtain rapid readings along short segments of the trajectory than to obtain readings at intervals of a few seconds all along the trajectory.

In order to obtain the desired data, the following instruments will be required:

1) A magnetometer capable of giving vector measurements with an accuracy of about one gamma in fields below 100 gammas, and with an accuracy of one percent in higher background fields. The instrument must be capable of taking readings in 0.01 second to provide acceptable angular information since the payload will probably rotate at about 3 cps.

2) One or two particle detectors capable of measuring the energy spectrum of protons and electrons from about 10 ev to several kev. These instruments should have a sampling time of about 0.01 sec, and several energy channels should be measured during each data transmission cycle. It would be preferable to have two detectors with one pointed along the spin axis of the vehicle and one perpendicular to the spin axis. These instruments could determine the directional dependence of the particle flux during each data transmission cycle. It would also be possible to operate in a second mode in which an accurate energy spectrum could be taken along the spin axis.

3) Absolute directional orientation must be supplied, possibly by a sun sensor. This could either provide marker pulses which would be transmitted along with other data, or it could be used to trigger the data sampling sequence.

2. Expected Responses

With these instruments, the following responses are expected during passage into a turbulent structure:

1) A change in the intensity and direction of the magnetic field. This could take place in a time interval from 0.1 second to a few seconds.

2) Simultaneously, particles with energies near or somewhat below that of undisturbed solar corpuscular radiation should be detected. The energy spectrum of particles should be carefully analyzed during passage through the boundary of a turbulent region, since any difference between the energy spectra within a turbulent region and on the boundary of the region would imply at least temporary particle acceleration is taking place. If such acceleration is detected, directional information on the particle flux and the magnetic field would be obtained with the proposed system, so analysis in terms of various models could be carried out.

3) Inside a turbulent structure, the fields may vary rapidly, particularly in direction. Particle fluxes could be quite directional, or they may be nearly isotropic, depending on the type of turbulence encountered and on the relative velocity between the detector and the turbulent structure.

Passage from within a turbulent structure to the outside undisturbed field would obviously reverse this sequence of events.

Hydromagnetic waves would be identified by a change in the magnetic field intensity, possibly accompanied by a slight change in direction, but no great increase in the density of protons above thermal energies. It is conceivable that hydromagnetic waves could be propagated through a turbulent structure. This would be identified by detection of a wave-like magnetic disturbance during a period in which moderate energy particles are also detected. The hydromagnetic wave should change the particle flux by compression, but should not drastically alter the energy spectrum.

3. Preferred Instrumentation

A detailed study of the motion of hydromagnetic waves and of turbulent structures would be simplified by the use of a small package ejected from the main vehicle. The small package would carry a single magnetometer sensor and perhaps a single energy-channel particle counter. This package should be located at a distance of tens or hundreds of kilometers from the main vehicle during its useful lifetime. Correlations between responses of instruments on the small package and on the main vehicle would provide information regarding the extent and motion of turbulent structures and the direction of motion and dispersion relations of hydromagnetic waves.

4. Relationship to Entire AFSWC High Altitude Program

The AFSWC high altitude program for 1961 includes three probes to study charged particles, x-rays, and gamma rays in and above the boundary region. The first flight is intended to investigate proton and electron fluxes in the low energy range. Two electrostatic analyzers will be carried, one detecting protons and electrons with energies up to 20 Kev, and the second in the energy range up to 1 Mev. This probe has a planned apogee of 75,000 N.M. The second probe will carry a magnetic spectrometer to 30,000 N.M. to measure protons in the energy range of 1 kev to 1.5 Mev. The third probe will carry two scintillators with six bias levels to detect x-rays and gamma rays from 1 kev to 30 Mev at altitudes up to 35,000 N.M.

The 1962 program has been the subject of this paper. Flights should take place in mid or late 1962, and the trajectories should have apogees of about 100,000 km. Four flights are planned to investigate the four previously mentioned areas of interest in the boundary region. The objectives are to investigate turbulence and hydromagnetic waves in the boundary region, preferably during relatively quiet solar periods. The use of the small package described under preferred instrumentation is planned.

Planning for the 1963 program is still in preliminary stages. The objectives are to study turbulence and hydromagnetic waves over a variety of solar conditions. This would require a satellite program, with two satellites being planned at present. Each satellite would carry several small packages which could be ejected on command to gather detailed information during important solar events. The instruments will be designed on the basis of experience gained in the 1962 program, and the instruments on the 1962 probes are being designed so they can be modified for eventual satellite utilization.

The AFSWC space physics program also includes a number of pods which are attached to ICBM's undergoing development tests. These pods are primarily used for low altitude measurements, but they also provide a means of testing equipment and data collecting techniques prior to use on high altitude flights. Each instrument to be used on a high altitude probe is usually flown on an ICBM pod prior to the probe flight.

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