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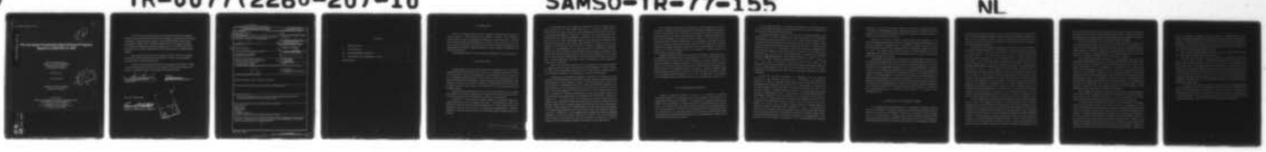

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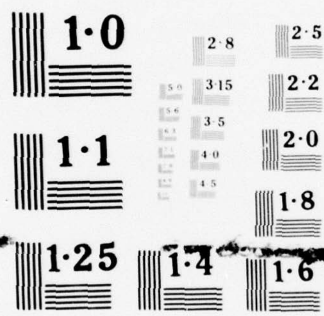

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REPORT SAMSO-TR-77-155

The Aerospace Corporation Space Sciences Program: Report to COSPAR CY 1976

Space Sciences Laboratory
The Ivan A. Getting Laboratories
The Aerospace Corporation
El Segundo, Calif. 90245

29 July 1977

Interim Report

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Prepared by
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This interim report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract F04701-76-C-0077 with the Space and Missile Systems Organization, Deputy for Advanced Space Programs, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009. It was reviewed and approved for The Aerospace Corporation by G. W. King, Vice President and General Manager, The Ivan A. Getting Laboratories. Lieutenant A. G. Fernandez, SAMSO/YAPT, was the project officer for Advanced Space Programs.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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This report reviews the results obtained by the space research program of The Aerospace Corporation. Research projects dealing with solar physics, magnetospheric physics, and aeronomy and atmospheric science are described.

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CONTENTS

I. INTRODUCTION

The Ivan A. Getting Laboratories of The Aerospace Corporation are carrying out a research program in space science which consists of satellite- and rocket-borne measurements as well as complementary analytical and theoretical work. Research efforts during the past year concentrated on studies of x-ray emission from the solar corona using data returned by the Skylab mission, analysis of data on the dynamics of the magnetosphere returned by several spacecraft as well as studies of atmospheric and ionospheric phenomena.

The subsequent sections of this report present highlights of the research program.

II. SOLAR PHYSICS

A large number of soft x-ray flare events have been observed with The Aerospace Corporation/Marshall Space Flight Center S-056 x-ray telescope that was part of the ATM complement of instruments aboard Skylab. Data analysis carried out by Vorpahl et al., of Aerospace indicated that soft x-rays emitted by a flare come primarily from an intense well-defined core surrounded by a region of fainter, more diffuse emission. Loop structures are found to constitute a fundamental characteristic of flare cores and arcades of loops are found to play a more important role in the flare phenomena than previously thought.

The data show no correlations between the size of core features and: (1) the peak x-ray intensity, as indicated by detectors on the SOLRAD satellite; (2) the rise time of the x-ray flare event, or (3) the presence of a nonthermal x-ray component.

An analysis of flare evolution indicates evidence for preliminary heating and energy release prior to the main phase of the flare. Core features are found to be remarkably stable and retain their shape throughout a flare. Most changes in the overall configuration seem to be the result of the appearance, disappearance or change in brightness of individual features, rather than the restructuring or reorientation of these features.

The observations lend some support to theories such as that of Cheng and Spicer which demand that the flare process take place in a loop of coronal plasma. Observations of limb flares, however, in which a spike develops at the top of a loop, have not been explained within this framework. Conversely, limb observations bear some resemblance to the configuration proposed by Sturrock in which field reconnection takes place at the top of a loop. Interestingly enough, the core featues are remarkable stable and almost always retain their structure well throughout the course of a flare. Most changes in the overall flare seem to be due to variation in brightness of individual features, or to the appearance of new ones, rather than to a reorientation of individual features that might be caused by gross magnetic field restructing. It should be noted, however, that the closely spaced, crossed x-ray structures constituting the most intense part of a flare would be a natural place for field line reconnection to occur over a small area. Detailed comparisons with theory await a determination of more quantitative conditions in the flare core.

Finally, the observation that the soft x-ray emitting plasma is not always confined to a single loop does not render invalid theories of flare cooling such as that of Culhane, but rather, simple modifications should be made to these theories to express the fact that the plasma is contained in multiple loops and sometimes entire arcades.

In addition to the morphological analysis of many flares which Vorpahl et al. have carried out (described above) data on several flares were obtained at very high temporal resolution and have been analyzed by Vorpahl. One such flare occurred at 1827 UT on 1973 September 5. Photographs taken at 9 s intervals allow detailed information to be obtained about the site of the energy release, as well as about the evolution of the flare itself. Observations suggest that the flare occurred in an entire arcade of loops rather than in any single loop. Sequential brightening of different x-ray features indicates that some excitation moved perpendicular to the magnetic field of the arcade at velocities of 180-280 km s^{-1}. The most intense x-ray features were located in places where the magnetic field composing the arcade had a small radius of curvature with horizontal field gradients higher than the surrounding region and where the axis of the arcade changed direction. Vorpahl suggest that the arcade geometry strongly influenced the propagation of the triggering disturbance, as well as the storage and site of the subsequent deposition of energy. A magnetosonic wave is suggested as the propagating mechanism triggering instabilities that may have existed in the preflare structure. This event demonstrates that all energy emitted during a flare need not be released immediately nor in the same location, thereby eliminating some problems encountered in many flare theories.

Solar abundances determined from the analysis of chromospheric line intensities are subject to uncertainties owing to the particular atmospheric models and the values of the atomic rate constants used. In addition, they are incomplete since the chromospheric spectrum contains no lines from the important noble gases. Published compilations of solar system abundances are frequently strongly weighted by meteoric data for the nonvolatile elements. Recent determinations of solar abundances using other techniques such as the analysis of permitted corona lines, the solar wind, and solar cosmic rays have confirmed the general abundance models derived from chromospheric and meteoric studies, but have raised questions about the abundances of specific elements, in particular neon, argon, and oxygen.

Rugge of Aerospace and Walker of Stanford have developed a relationship between the calculated emission functions (at x-ray wavelengths) for Ne X and Mg XI and used it for determining the relative solar coronal abundance of neon and magnesium. The relative abundance is calculated directly from the relative intensity of the resonance lines of Ne X (12.143A) and Mg XI (9.169A) without the need for the development of a detailed model of the thermal structure of the corona. Moderate resolution Bragg cyrstal spectrometer results form the OV1-10 satellite were used to determine a coronal neon to magnesium relative abundance of 1.47 ± 0.38. The application of this technique to a recent higher resolution rocket observation gives an abundance ratio of 0.93 ± 0.15.

III. MAGNETOSPHERIC RESEARCH

Energetic inner-zone protons ($E \geq 10$ MeV, $L \leq 2$) constitute an especially interesting component of the geomagnetically trapped radiation. Their presence in the magnetosphere has long been attributed to the beta decay of energetic albedo neutrons ejected from the atmosphere by incident cosmic rays, a process denoted by the acronym Crand. The demise of any such protons is assured by ionization loss (Coulomb drag) in the tenuous atmosphere. However, the observed population of inner-zone protons bears little resemblance to any calculated balance between these two competing processes, mainly because the spatial and spectral distribution of geomagnetically trapped protons is profoundly affected by radial diffusion.

Croley, Schulz and Blake of Aerospace have reported on a new measurement of the inner-zone proton distribution function and described a new method of extracting the optimum radial diffusion coefficient therefrom.

Omnidirectional proton intensities ($E \approx 9$-310 MeV) have been measured in seven energy channels by means of instruments on board the satellite OV1-19 (1969-25C). Unidirectional spectra representative of the time interval March-November 1969 (a period near solar maximum) have been constructed from the data by standard methods. The results enable one to construct the distribution function f(M,L) at vanishing second invariant J for $1.18 \leq L \leq 2$. The profiles of f(M,L) thus obtained are manipulated by a new variational method to yield normalization parameters for the radial diffusion coefficients $D_{LL}^{(m)}$ and $D_{LL}^{(e)}$, caused, respectively, by magnetic and electrostatic impulses of magnetospheric extent. One typically obtained $D_{LL} \sim 7 \times 10^{-9} + 1 \times 10^{10} \times (\gamma M_o/M)^2 L^{10} \, day^{-1}$ as the best two-parameter fit to $D_{LL} = D_{LL}^{(m)} + D_{LL}^{(e)}$, where $M_o = 1$ GeV/G and γ is the ratio of relativistic mass (m) to rest mass (m_o). The distribution function f(M,L) obtained from the new data described here agrees rather well with past determinations and the radial diffusion coefficient obtained by the present (variational) method agrees rather well with such coefficients determined by previous investigators.

During 1973 and 1976 operations of a transportable very low frequency transmitter at high latitudes were carried out. An experiment was performed to determine the effect of controlled phase changes of the transmitted wave on the magnetospherically propagated signal received in the conjugate region. The results have now been reported by Koons and Dazey of Aerospace and Dowden and Amon of the University of Otago. At periodic intervals the phase of the driving voltage was changed (essentially instantaneously) by 180^o. The amplitude of the 6.6-kHz signal detected in the conjugate region went to zero and recovered with a characteristic time constant of 33 ms. This is 10 times longer than the antenna current response time and is in fact comparable with characteristic electron interaction times with whistler mode waves. Between the times at which the phase reversals occured the received signal was amplitude modulated. The period of the modulation was ~ 26 ms. An upper side band was present in the spectrum while these pulsations were occurring. These characteristic times are in general agreement with theoretical predictions of bandwidths, growth rates, and particle-trapping frequencies for whistler instabilities in the magnetosphere. Data obtained ffrom the controlled transmissions and from lightning-generated whistlers propagating in the same duct were combined to determine the plasma and wave parameters at the geomagnetic equator. Of particular interest is the level at which the magnetic field of the wave saturated. During the time period for which the data were analyzed this was found to be 3.5 pT (mγ).

Energetic ($E \geq 1.6$ MeV, ≥ 3.9 MeV) trapped electron fluxes observed at the synchronous altitude during 1974 and 1975 by an experiment aboard ATS-6 carried out by Paulikas and Blake of Aerospace exhibit a modulation in intensity which is correlated with the passage of sector structure boundaries of the interplanetary magnetic field past the earth. The electron fluxes reach equilibrium intensities during the time the magnetosphere is in a given IMF sector which are highest in the fall for (+) sectors and highest in the spring for (-) sectors.

These results are interpreted in the context of the observations of Burton et al., who found that the energy flow from the solar wind into magnetosphere mimics in some ways the behavior of a half-wave rectifier familiar in electronic applications. The input of energy into the magnetosphere proceeds only if the magnetosphere sees a southward component of the interplanetary magnetic field; a northward IMF component apparently inhibits the transfer of energy into the magnetosphere. Thus, to first approximation, the dynamics of the magetosphere are a function of the orientation of the magmetosphere in solar-equatorial coordinates (the natural coordinates of the flow of the solar wind plasma). The interaction between solar wind and magnetosphere is expected and found to be strongest when the magnetosphere is immersed in a southward pointing interplanetary field. This occurs during northern hemisphere spring, when the earth is in a (-) sector of the interplanetary field, and in the fall, when the earth is in a (+) sector of the interplanetary field.

IV. AERONOMY AND ATMOSPHERIC PHYSICS

The importance of precipitating particles to thermospheric processes in auroral latitudes is well known. In contrast, the possible role that similar particles might play at middle and low latitudes is unresolved. Indeed, the very existence of such an energy source is a matter of dispute. Although several rocket and satellite instruments have provided data which bear on this question, difficulties have arisen from the apparently conflicting nature of the results which have been reported. If such particles are present in significant numbers, they will play a role as a source of (1) ionization, (2) atmospheric heating, and (3) atmospheric emissions. Such a source could be especially important at night, when solar ultraviolet radiation is absent. Furthermore, if the particle flux were variable, this source could play an important role in transient events such as sporadic E and other ionospheric disturbances.

Morse and Rice of Aerospace have presented new data from two rocket flights and examined the published evidence for the existence of a corpuscular source of ionization at E region heights. The rockets were launched from White Sands Missile Range (magnetic latitude of $\sim 43^{\circ}$) and provided measurements of energetic electrons and protons between 40 eV and 5.5 keV in the E region below 120 km. A daytime flight (solar zenith angle χ of 58°) launched during a geomagnetically disturbed period (Kp = 5-) provided measurements of a small flux of electrons which exhibits a strong altitude dependence below 500 eV but essentially none above that energy. The observed electron energy flux at 116 km is 1.8×10^{-3} erg/cm^{2}s. Morse and Rice interpret these to be photoelectrons. During the nighttime flight they observed an energy flux which was less than 10^{-5} erg/cm^{2}s. The electron flux values contrast sharply with much higher values reported by some other investigators. After reviewing data and the relevant literature, Morse and Rice conclude that (1) data obtained from one location must be carefully interpreted with regard to implications about the general ionosphere, since a real geographic variability exists; (2) since no significant fluxes of energetic particles in a geomagnetically disturbed ionsphere are observed, even in the presence of fluctuating nighttime E region ionization, the presence of such fluctuations cannot be taken as evidence of precipitating particles; and (3) many reports of corpuscular radiation contain high flux values which are not supported by observations of 391.4-nm radiation from N_2^+.

Chiu of Aerospace has constructed a phenomenological model of global ionspheric electron density by organizing samplings of monthly-averaged hourly ionospheric sounding data from some 50 stations in the epoch 1957-1970. The main purpose of such a construction is to provide a simple and easily accessible representation of the temporal, synoptic and solar activity-related variations of the electron density which is frequently required as a subsidiary input in a number of dynamical calculations of upper atmospheric interest. For such a purpose, he has have attempted to avoid smaller scale variations included in more sophisticated phenomenological models. Further, in order to satisfy the requirement of minimal computer storage, the model is purely phenomenological and does not take into account the dynamical interaction between the ionsphere and the neutral atmosphere, such as the more complete physical synoptic models. Nevertheless, the simplicity of the model has some applicational advantages in a number of dynamical calculations such as the global effect of Joule heating in the the.;nosphere, electrostatic field mapping in the atmosphere and ion drag in thermospheric modeling.

The model, describing noontime F2-layer critical frequencies to better than 2 MHz average maximum error and to better than 0.5 MHz root mean squared error, is particularly suitable for applications in space communication and ionosphere-atmosphere coupling studies. Magnetic dip angle and north-south asymmetry effects are incorporated in the model. A 'secular' variation of the ionospheric density exists in the epoch 1960-1971. In addition, a modelling of the polar ionosphere is included.

Three dimensional numerical calculations of thermospheric wind, density and temperature fields generated by solar EUV hearing and joule heating have been carried out by Straus et al. of Aerospace. These model calculations indicated that many of the global characteristics of the thermosphere are generated by EUV heating alone. However, several observed features were found to be poorly represented by the model results if only EUV heating is considered. These include the amplitude of the diurnal temperature variation and properties of the dirunal variations of the meridional wind and pressure gradient fields. An investigation of the extent to which joule heating of the thermosphere at high latitudes resolves some of these difficulties. This heating lowers the day to night temperature ratio, since it provides a heat source at night. It brings calculated meridional winds and pressure gradients into better agreement with observations, since it raises isobaric surfaces at high latitudes.

This investigation was primarily motivated by the fact that we noted significant discrepancies between temperature, density and wind fields deduced observationally and those resulting from self-consistent solutions of the mass, momentum, and energy conservation equations using the absorption of solar EUV as the sole heat source.

The general effects of high latitude heating due to the dissipation of ionospheric currents driven by electric fields on the order of 5 mV/m at mid-latitudes have been shown to be appreciable. Such heating causes a change in the global wind system because it raises the pressure at high latitudes, thereby driving the asymmetric meriodional wind observed in incoherent radar backscatter measurements. It modifies the amplitude of the diurnal variation of thermospheric temperature and density because it provides a direct nighttime heat source, whereas solar radiation provides none. In addition, it can increase the latitude at which maximum density and temperature occur, so that at least qualitative agreement with observational data in this area is attained. In addition, it ameliorates to some extent the problem of the inadequacy of solar EUV to maintain the normal thermospheric temperature, since it provides an additional heat source. However, the assumed magnitude of the high latitude heat source used in this study is not sufficient to change the requirement for significantly more solar heating than given by Hinteregger. Furthermore, an increase in high latitude heating sufficient to alleviate the EUV flux problem would affect the global circulation system to such an extent that the winds would no longer agree with observational data.

Only relatively simple temporal and spatial variations of high latitude heating have been included in the calculations described here.

Variations with local time, season and geographic or geomagnetic coordinates may, in fact, be quite important. Although detailed analyses of this aspect of the problem await further observational data, some of the effects of such variations have been touched upon. For example, high latitude heating which is stronger at night than during the day would cause a further increase in the nighttime meridional wind speed and a decrease in the amplitudes of the diurnal temperature and density variations. If more heat is deposited in the summer hemisphere than in the winter, the latitude at which the temperature and density maximize would be increased. If more heat is deposited in one geographic hemisphere than in the other, notable meridional flow across the Equator would occur even at equinox.

As a result of this analysis, it appears that both EUV and high latitude heating must be included in attempts to model global thermospheric dynamics. In addition, since high latitude heating and EUV heating have different spatial and temporal characteristics, their total effect is sensitive to the relative quantites of each deposited in the upper atmosphere. Thus, more experimental data on the variations of each is needed before a quantitative numerical model of the thermosphere can be developed.

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