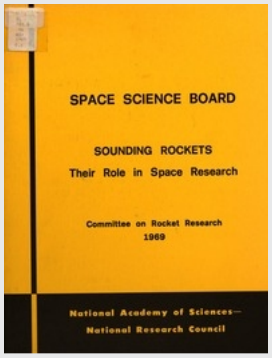

Sounding Rockets: Their Role in Space Research

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SOUNDING ROCKETS

Their Role in Space Research

Committee on Rocket Research

SPACE SCIENCE BOARD

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February 1969

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Introduction

In the Spring of 1968, the Space Science Board's Committee on Rocket Research undertook to examine the status of research using sounding rockets and to evaluate scientific progress made since the Board's last examination of the subject in 1965*. The Committee was interested in reassessing the role of rockets in a balanced space research program, the effectiveness of rocket programs for graduate education, and in isolating major scientific questions most likely to be resolved by sounding rocket techniques. Attention was given to technological and fiscal problems.

Committee members surveyed a large percentage of scientists actively engaged in rocket research in the United States and Canada. Government agencies involved in sounding rocket operations briefed the Committee on the status, plans, and fiscal outlook of their programs. This report draws heavily on material supplied by these sources. The Committee's recommendations, which appear at the end of the report, are directed toward increasing the effectiveness of rocket research within the context of a balanced space program.

Notable Scientific Results of Rocket Research

Since rockets were first equipped with scientific instruments over twenty years ago to probe the upper air and space, they have accounted for or contributed to discoveries of major scientific and practical significance. A few of these discoveries are mentioned below. A more detailed summary of rocket findings from 1965 to 1968 is included in the Appendix.

The Earth's atmosphere is completely opaque to wavelengths shorter than about 3000 A; rockets provided the first means of directly examining this portion of the spectrum. Observations of the solar ultraviolet spectrum were first notably extended beyond the limit detectable at the Earth's surface by means of a spectrograph on V-2 rocket in 1946, and one of the earliest triumphs of rocket solar astronomy was the discovery of solar x rays originating in the million-degree corona. Over the years, knowledge of the solar spectrum has steadily increased as the observable limit has been extended from approximately 2200 A in the early V-2 measurements, through the line-emission region, and into x-ray wavelenghts. By 1950 the solar spectrum had been broadly mapped and the outlines of the mechanisms by which solar ionizing radiations produce and control the ionosphere were discernable. In recent years, satellites too have monitored the various emission levels, but the principal characteristics of the emissions, so important to our understanding of the Sun and the upper atmosphere, were identified from rocket data.

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*"Rocket-Satellite Research," Chapter 7 in Space Research: Directions for the Future, Report of a Study by the Space Science Board, Woods Hole, Mass., 1965, Nat. Acad. Sci.-Nat. Res. Coun. Pub. 1403, Washington, D. C., 1966

The existence of three new branches of astronomy - ultraviolet, x-ray, and gamma-ray astronomy - is also attributable to the ability of sounding rockets to place instruments above the obscuring atmosphere. Rockets have recorded the ultraviolet spectra of stars and planets, and measurements of the hydrogen Lyman -α absorption line in the stellar spectra have permitted determination of hydrogen atom concentrations in interstellar space. Other lines have provided evidence of high-velocity mass ejection from hot supergiant stars. X-ray sources in the galaxy were discovered by rocket-borne detectors; later flights measured their spectra, variability, angular size, and location, permitting the identification of some sources with optical objects.

The main features of the structure of the Earth's atmosphere above balloon altitudes have been identified and partially mapped by rockets. Of particular note are the temperature maximum near 50 km, the temperature minimum near 80 km, and the higher temperatures at greater altitudes. Satellites have contributed a great deal of information on density variations above 200 km, but rockets have provided the basic framework for interpretation of the satellite data in terms of variations of temperature and composition. However, the picture of atmospheric structure is not complete in a geographic sense and more rocket data are needed. The geocorona, which constitutes the outermost portion of the atmosphere, was also first recognized and described on the basis of rocket data. An understanding of the relevant physics was developed with the guidance provided by the rocket data.

Sounding rocket investigations changed the concept of ionospheric layers to ionospheric regions, showing that what had been regarded as separate layers were generally just ledges on an electron-concentration distribution that increases fairly steadily up to the F_2 maximum. Almost all our knowledge of ionospheric chemistry, critically important to an understanding of upper atmospheric processes, stems from rocket soundings. Also of major significance to this understanding are the precise data obtained by rocket-borne instruments on the heights of airglow emissions; prior to the availability of sounding rockets very little could be learned on this subject.

Rocket measurements have given the most precise description available of particle fluxes in auroras. Although such data should in principle be obtainable by satellites as well, a satellite's high velocity as it passes through narrow auroral features requires an extremely high rate of data acquisition, and this factor has increased the relative contributions provided by rockets in auroral measurements.

Finally, the existence of electrical current systems in the ionosphere and the polar and equatorial electrojets was detected by rockets and the altitudes of the current systems were measured.

Major Scientific Questions Likely to be Answered by Rocket-borne Experiments

Some of the outstanding fundamental questions on the nature and processes of the atmosphere and space are more accessible to sounding rocket investigations than to other techniques. Data from satellites and from ground based observations are also important, and these also are problems that are most amenable to attack by these techniques, or by some combination of techniques It is likely that the following questions, at least, will be resolved by rocket-borne experiments or a combination of rocket results with observations from other sources.

Astronomy and Solar Physics

Far Infrared - 20 to 1000 μm:

1. Is the spectrum of cosmic background-radiation at 400 to 1000 μm like that of a 3 K blackbody?

2. Do interstellar grains emit radiation and does this radiation yield important information on their composition?

3. What is the nature of Seyfert galaxies, quasi-stellar sources, and protostars in our galaxy? Do other kinds of objects which also emit infrared radiation exist as well?

Far Ultraviolet - 900 to 3000 A:

4. What is the nature of interstellar grains?

5. What is the ultraviolet flux of hot stars? This information is needed to determine the accuracy of model atmospheres and temperature scales which will, in turn, aid in determining elemental abundances and processes of stellar evolution.

6. What are the effects of pressure broadening on the strong resonance lines, and what are the elemental abundances, in the photospheres of hot stars? These measurements can be made in the ultraviolet without the large corrections for excitation and unobserved ion states necessary in the visible.

7. What is the rate of mass loss in stars with expanding envelopes?

8. What are the abundances of elements in the interstellar medium?

9. What is the thermal and kinetic structure of the Sun's chromosphere and corona?

10. What kinds of stars have chromospheres and coronas?

X Rays - 1 to 60A

11. Does a hot intergalactic plasma exist and does it have enough mass to close the universe gravitationally?

12. What is the nature of x-ray emission lines in various sources? If the x rays originate in a hot gas surrounding a neutron star or white dwarf, such emission lines should be present in Scorpius XR-1.

13. Is there a variation with galactic latitude due to galactic neutral hydrogen in the absorption of soft x rays?

Magnetosphere, Aurora, and Airglow

1. What is the nature of auroral and magnetic substorms and what is their relation to the physics of the magnetosphere?

2. What is the nature of the ionospheric current systems, especially in the auroral ionosphere?

3. What are the processes that accelerate auroral particles?

4. What wave-particle interactions are associated with aurora and what is their role in magnetospheric dynamics?

Ionosphere

1. What is the influence on the ionosphere of motions and energy balance in the upper atmosphere?

2. Are stratospheric warmings a major influence in increases in D-region ionization?

3. What is the level and source of ionization in the nighttime E region?

4. What energy degradation processes occur associated with the absorption of solar ultraviolet radiation and what is the flux and spectrum of the resulting photoelectrons?

Aeronomy

1. What is the momentum source for the semiannual oscillation in the equatorial mesophere?

2. What is the vertical extent and general morphology of sudden stratospheric warmings and quasi-biennial oscillations (26-month periodicity)?

3. What process is responsible for the high temperature of the winter mesopause?

4. What is the origin and composition of noctilucent clouds?

5. What is the nature of wave structures in the 70-to-120 km region?

6. What is the magnitude of tidal wind and temperature variations? To what extent are they affected by ambient winds, longitude, nonlinearity, instability, viscosity, and ion drag.

7. To what extent do wave disturbances associated with tropospheric weather systems penetrate the upper atmosphere?

8. What is the nature of the turbopause? What are the characteristics of turbulent diffusion below the turbopause? What is the nature of the transition to molecular diffusion? Does it result from a sudden damping of turbulence, or from the exponential increase with altitude in molecular difussion (in inverse proportion to atmospheric density)?

9. What is the composition of the mesosphere, particularly with respect to minor but important species like NO and Na and excited states such as the $a^1 \Delta g$ state of O_2?

10. What is the distribution of ozone and other important, chemically active species in the mesosphere as function of time of day, season, and position? What is the relative importance of reactions with constituents other than oxygen allotropes?

11. What is the role of eddy diffusion in determining the atmoic oxygen content in the thermosphere?

12. What is the vertical distribution of major and minor constituents as a function of time?

13. To what extent do the troposphere waves penetrate the upper atmosphere?

14. Can planetary waves be observed in the stratosphere and mesosphere?

The Role of Sounding Rockets in Scientific Research

A number of techniques are available to study the Earth's atmosphere and space. Among them are artificial satellites and space probes, ground-based instruments employing, for example, optical, radio, and radar techniques, scientifically instrumented aircraft, balloons, and sounding rockets. Each has its role and its advantages; a well designed experimental program exploits the techniques best suited to its particular objectives.

The greatest single advantage of sounding rockets for studying the upper atmosphere is their unique ability to obtain direct, vertical profiles in the altitude range of about 40 to 200 km. There is no other means of obtaining true vertical profiles by direct measurement, although some parameters can be measured indirectly by ground-based observations such as Thomson backscatter. This region of the atmosphere is of extreme interest in atmospheric and space research. Here are the D, E, and part of the F regions of the ionosphere, characterized by complex chemical reactions in response to solar energy, the global electric current system, and the electrojets. Complicated physical processes in the magnetosphere focus energy into the auroral zone, where precipitating energetic particles, auroras, strong electric fields, electrojet currents, and enhanced ionization all give clues about the total magnetic storm and substorm process. This altitude range spans the region where mixing ceases to be the dominant process governing atmospheric composition and diffusive separation begins. Here, too, are found airglow, some aerosols, and noctilucent clouds. Most of the ultraviolet solar energy entering the atmosphere is absorbed here, and neutral particles, ions, and electrons are present simultaneously. Large changes in composition, temperature, and winds occur with height; much of what happens at higher altitudes is determined by the composition and structure in this region.

Study of this region from 40 to 200 km by means other than sounding rockets is constrained by the fact that balloons cannot attain altitudes greater than about 40 km and that satellites are not effective below about 200 km because of lifetime limitations. The advent of variable orbit satellites able to dip down to about 140 km, possible in the early 1970's, would ameliorate the situation, but they will not be capable of instantaneous vertical profiles free of latitudinal and local time variations which are so important in the study of many parameters of interest in this region of space. Ground-based instruments can, and do, probe this region by indirect means, and for some investigations are more effective than space-based instruments. For other investigations, such as detailed analyses of atmospheric composition at various altitudes and times, in situ measurements are essential. DC electric fields and D-region ionic composition, for example, are impossible to infer from any type of ground-based technique. Similarly, only rocket-based instruments can measure the local rates of optical excitation and emission in the upper atmosphere.

In addition to the unique contributions that sounding rockets make to the study of the 40-to-200 km region, they have several attributes that are used to great advantage in experimental programs. Their high velocity, which is usually large compared with the vertical transport processes occurring at altitude, combined with the short flight times (about six minutes) and speed of data gathering, make them particularly suited to the study of rapidly occurring transient phenomena or brief events such as eclipses, and measurement of physical parameters at a given moment of time. These same characteristics make them less suitable than ground-based or satellite techniques for long-term monitoring or global coverage -- except, of course, in the 40-to-200 km region where they are the only method available for in situ observations.

The logistic flexibility of sounding rockets is a substantial added benefit to experimental programs and increases the usefulness of the technique in the study of special, transient events. By choosing the appropriate rocket type, trajectory, and hardware, almost any desired velocity, altitude, and spin rate may be attained. The ability to launch a sounding rocket at a specific time and place (consistent, of course, with range locations and usage) is often indispensable to a particular scientific objective. The vehicle can be held in readiness for a long period of time and then be launched at precisely the most favorable moment. Ground-based installations are often quite difficult to move to other locations, particularly if they require large antenna systems (e.g., Thomson-scatter radar, partial reflection sounders). It is frequently more efficient to set up a temporary rocket launching facility for a special purpose. This is well illustrated by several recent eclipse expeditions and by the shipboard firings made in the 1965 NASA Mobile Launch Expedition. To compare rocket and Thomson-scatter measurements of electron density and temperature, it has been easier to take the rockets to the sounders rather than the reverse. Similarly, rockets lend themselves more easily than satellites to coordinated work with ground-based instruments. Scientists who have attempted to compare satellite results with ionosonde and Thomson-scatter data appreciate that it is difficult to find suitable times when a satellite passes overhead at a specific location, particularly if certain ionospheric conditions are desired. It is not nearly so difficult to schedule rocket firings at the proper time and location. The relative mobility of a rocket launch site permits global studies which would not be feasible with ground-based installations alone.

Sounding rockets are an excellent means of studying fine structure and detail owing to the sensitivity of their instruments and high rate of data sampling. For example, the sensitivity of rocket measurements of electron density is about 10^{10} greater than that of ground-based radio. Given the greater confidence one can usually place in _in situ_ measurements, it appears likely that rockets will play an increasingly major role in calibrating indirect ground-based techniques. By comparison, these ground-based techniques provide poorer height determinations and vertical resolution. Scientifically instrumented balloons and aircraft in particular can play a similar role _vis a vis_ rockets by providing data below levels sounded by rockets and overlapping, comparative data.

The ability to recover payloads by parachute descent is an enormous advantage since it permits use of photographic film (which provides a particularly high rate of information accumulation), use of nuclear emulsions, examination of instrumentation, and post-flight calibration. The recovered instruments can normally be re-used, thus reducing costs and facilitating readjustment and redesign of experiments on the basis of the new information obtained. Rockets also permit the use of short-lived, perishable detection systems such as the liquid-helium-cooled telescope for observations in the far infrared. Because of the logistic simplicity of rocket firings, liquid helium can be added almost up to the moment of launch, and the supply carried is then adequate for the six minutes of flight.

The ability of rockets to rise above the obscuring layers of the Earth's atmosphere is largely responsible for the revolutionary development of astronomy and solar physics in recent years and for the existence of x-ray, ultraviolet, and gamma-ray astronomy. The spinning rocket is ideally suited to exploratory surveys and, at its high altitudes, extends astronomical investigations to wavelengths that cannot be observed from the ground. Satellites also have these capabilities, with the added ability of obtaining many months of data rather than only six minutes of data. It would seem clearly preferable to conduct space astronomy studies from satellite bases when substantial observing time is needed; yet the fact remains that almost all the important space astronomy results obtained so far have been obtained from rockets, and rocket-borne studies still contribute dominantly to space astronomy knowledge. Among the reasons are the following. Six minutes of rocket data are a very great deal, anough to saturate the data analysis and interpretation efforts of a small group for more than a year. (In one case the high resolution echelle spectra of the Sun obtained on a single flight have required more than five years of analysis, and much information of scientific value still remains for future study.) Recoverable payloads and short-lived detection systems permit important observations not feasible with satellites and, because of flexibility in launching schedules, flights can be made under optimal conditions -- at lunar occultations or times of best seeing, for example.

Sounding rockets also have the advantages of shorter lead times and much lower cost than satellites. The time between the conception of an experiment and the rocket flight may be about six months to a year, as compared with three or four years for satellites. Much of the high productivity of the rocket astronomy program can be attributed to the speed with which new rocket payloads can be designed and flown. The short time scale allows the investigator to adjust his program of study to continuing discovery, utilizing data from each previous experiment, and to make changes in instruments and experiments in the light of new data. It also permits the more rapid evolution of flight hardware. The lower cost of rockets makes them especially suited for experiments which are inherently brief, such as testing new instruments slated for eventual use in satellites or making chemical releases to study upper atmospheric processes. The lower cost in money and preparation time of rocket-based investigations means that more exploratory, less certain-of-success investigations can be tried. Calculated risks on less conventional equipment and experiments have brought substantial scientific rewards.

Although individual rocket vehicles and payloads are far less expensive than satellites, it is sometimes more economical to employ satellites, as when a large number of rockets would be needed to gather the data obtainable by one satellite. Moreover, there is a tendency to design increasingly complex rocket payloads to perform a variety of measurements during a single flight. The cost of such payloads is naturally a good deal higher than that of simpler payloads, but the cost in terms of the data obtained may well represent a saving. The relative cost of rocket-based research as compared with that using satellite, airborne, or ground-based techniques is thus not always a straightforward computation. This stresses the need for careful weighing by the experimenter of the alternative techniques at his disposal.

Sounding Rockets as an Educational Tool

Sounding rockets are used extensively by university space science departments for graduate education. There are very practical reasons for doing so. First there is the time element: a rocket experiment from inception through final data analysis requires about 18 months, a period that is sufficiently short to permit the student to have a significant role in the experiment from start to finish while at graduate school. The long time scale (24 to 72 months) of satellite experiments normally precludes student participation throughout the project. Second, the cost of rocket vehicles and instruments is generally not so severe that students must be excluded from meaningful participation in the experiments. Third, the reliability of standard rocket hardware minimizes systems failures and excessive delays in data acquisition.

Despite these considerations, educational institutions would probably not employ sounding rockets extensively as a teaching tool were it not for their great value in giving the student practical experience in the techniques, engineering, logistics, and discipline that are so essential to a successful experiment. In taking on responsibility in the planning, testing, and flying the experiment and analyzing the results, the student also learns that his ideas must be rigorously thought out and that they must be constantly checked: although some allowance for mistakes is possible since a re-flight can sometimes be supported, the pressure to do it properly the first time is very great. Rocket work provides excellent training for complex technological pursuits, including satellite research. Finally, rocket experiments lend themselves well to M.S. and Ph.D. programs since they provide excellent thesis material and data that can in many cases be examined and digested by one individual. As one experimenter has said, "The launch pad has become a part of the scientific research laboratory and, therefore, graduate students must become involved. Rocket research provides the best opportunity to accomplish this important facet of the space program."

The greater likelihood of experimental failure, owing to student inexperience, causes some university experimenters to have reservations about the suitability of rocket programs for the majority of students. This appears to be particularly true of astronomy payloads, probably because they tend to be the most complex, costly, and time consuming, and the risks of mission failure - through no fault of the student - are greater. It is a very significant disadvantage for student experimenters that in rocket research all the operational parameters of an instrument must be correctly determined on the first try. Additional flights for refining the measurements introduce both the difficulty involved in additional funding and stretch out the program longer than may be desirable. The student who must build his own flight instrument is likely to be very tempted to place more emphasis in his thesis on describing the instrument and the experimental difficulties he encountered than on analyzing and interpreting his findings.

These negative aspects are not so important at institutions where adequate technical and financial support are available and where experienced advisors can guide the student into an experimental project that is likely to succeed on the first or second try. Even then it is helpful if the program has enough depth to provide data for theses regardless of occasional failures, and if less expensive types of rockets are used. The most successful experiments by graduate students seem to have in common the features of simplicity of instrumentation and the small size of rockets.

In cases where direct student involvement in rocket flight programs is not feasible or is undesirable, participation in related laboratory studies or in analysis and interpretation of existing rocket data has proved very successful.

<u>Funding for Rocket Research</u>

According to information supplied to this Committee by government agencies, the total support for United States rocket research in fiscal year 1968 was approximately $37 millions, of which the NASA program accounted for $20 millions. The information indicates further that support for rocket research is decreasing: The NASA FY 1969 program is nearly unchanged in support level; the National Science Foundation is generally withdrawing from support of rockets; the Naval Research Laboratory and Air Force programs are active but apparently at the expense of exhausting their reserve supply of rockets without expectation of adequate replacements; the Atomic Energy Commission will probably continue its program at about the same level largely, however, on a closed basis and without sharp focus on problems of upper atmospheric or space research. (The U. S. Army program was not reported; it contributes significantly to the meteorological rocket program.) At the same time that rocket support available to the research community is decreasing, costs are rising steadily: the reduction of effort is even more pronounced than the reduction in funding.

Rocket experimenters consider that inadequate financial support is the principal problem in rocket research today. Funding levels, far more than technological, scientific, or operational difficulties, are the determinants in rocket research of the rate of scientific advance.

Recommendations

A substantial number of scientific questions bearing on the upper atmosphere and space are either accessible only to rocket experiments or can be answered more efficiently by sounding rockets than by other methods. Despite the modest cost of rockets relative to artificial satellites and space probes, these research opportunities have generally not been exploited as vigorously as those involving use of the latter techniques. In a period of sharply reduced budgets such as now exists, the relatively low cost of rockets and hence of the scientific results they obtain causes rockets to be a particularly attractive method of conducting space research.

Opportunities for research using artificial satellites and space probes have recently decreased markedly owing to budget reductions for space activities. The penalties are severe: reduced scientific productivity, disbanding of experienced research teams, reduced opportunities for graduate training, and loss of momentum in scientific and technological progress.

The slow-down in space research using satellites and space vehicles has the effect of increasing the availability of research talent capable of utilizing sounding rockets productively. Many groups are involved in both rocket and satellite projects and the reduction in the number of flight opportunities for large vehicles will cause them to turn to other tasks. They can be kept productively engaged in space research for relatively small cost if the number of sounding rocket opportunities is increased. Obviously, when space budgets are being severely curtailed, there is reluctance to allow expenses in any area to increase. Nevertheless, a fiscal economy can be effected while maintaining a high level of research productivity if research workers can utilize rockets rather than more expensive vehicles. A substantial increase in support of rocket research is required, however, to compensate for the far more substantial decreases in satellite and space probe support. It is unfortunate that such an adjustment has not been effected, and that attrition of space research capability in university groups has occurred.

(1) The National Aeronautics and Space Administration is to be commended for its support of rocket research. Over fiscal years 1966 to 1968, funding was increased by an average of 12.5 percent annually. We believe that this rate of increase is the minimum necessary to sustain the current level of effort, with barely minimum growth, in the face of escalating costs for hardware, launch support operations, and pointing systems of increased capability. Unfortunately, this rate of increase has not been sustained in the fiscal year 1969 budget, when the impact of curtailed satellite flight opportunities could have been usefully mitigated by more emphasis on sounding rocket research.

We recommend that NASA restore the previous rate of increase in rocket support, achieving roughly a 36-percent increase above the FY 1968 level by 1971, and a 12-percent increase each year thereafter until 1975.

(2) Support for rocket research by agencies other than the National Aeronautics and Space Administration has not been sufficient to keep pace with escalating costs of research. National Science Foundation support has been reduced markedly and programs previously funded by NSF are being assisted with NASA funds, to the deprivation of other on-going NASA programs. The level of effort of other agencies, including the Naval Research Laboratory and the U. S. Air Force, has been sustained only by using up inventories of rocket hardware without replacement.

We recommend that, to compensate for the last several years of frozen or declining funding levels, support for rocket research by these agencies be immediately increased by 36 percent (equivalent to about three years' increment) and that sufficient additional funds be allocated for replacement of depleted rocket hardware inventories. We further recommend an average annual increase of 12-percent in total support by the National Science Foundation, the Air Force and the Navy until 1975.

(3) We believe that rocket-based research provides a partial substitute to satellite research, and an alternative means, at less cost per experiment, of maintaining scientific and technological productivity. Some groups that have been utilizing satellites can turn to rockets, reversing the trend of the last decade. We recommend that, in addition to the increases recommended above, support for rocket research be increased by an appropriate ratio to compensate for any reduction in satellite support.

(4) A major new requirement for rocket technology development during the last several years is related to heavier classes of payloads for x-ray and ultra-violet astronomy including related pointing and stability control systems. Many experimenters now have a need for an economically feasible

means of launching up to 150 miles altitude experiments and related systems weighing as much as 300 lbs. Still others need lifting capabilities for payloads in the 800-1200 lb class. We commend NASA for the progress made in developing the new Aerobee 170 for the 250 lb/150 mile class payload and urge that these systems be made available to the rocket research community as soon as possible. If support for rocket research is substantially increased, we recommend further development of rockets, with optional stability and pointing control systems, to meet the needs for the still heavier classes of experiments at reasonable cost. If support cannot be substantially increased, we feel that the scientific opportunities accessible to present rocket systems are sufficiently large that increased expenditures for technological capabilities can be deferred.

(5) Up to the present time, with relatively minor exceptions, research projects using rockets have not been charged pro rata for use of the firing range. When funding is scarce, a direct charge to the project for range use is almost inevitably entertained. If such a charge should be imposed, a further substantial decrease in rocket research will result.

If the decision is made to assess a charge against the individual experimental group for use of the firing range, we recommend that this charge be recognized and that the budget for sounding rockets be increased accordingly.

APPENDIX

Rocket Results 1965-1968

Appendix

ROCKET RESULTS: 1965-1968

We summarize here the progress and findings in sounding rocket research in the United States and, in some cases, Canada in 1965-1968 as reported by experimenters and in the scientific literature.

ASTRONOMY AND SOLAR PHYSICS

From the first availability of rockets for space research, astronomical investigators have been important users of research rockets. The astronomical investigations undertaken have differed considerably in accordance with the specific disciplines involved, i. e., solar physics, and x-ray, far ultraviolet, and far infrared astronomy. In each case, the initial investigations were exploratory in nature and were designed to obtain first observations of astronomical objects in previously unavailable spectral bands. With the development of inertially stabilized platforms and accurate solar pointers, the exploratory studies quickly gave place to relatively sophisticated spectral and imaging experiments in all but the far infrared portion of the spectrum.

The oldest discipline of rocket astronomy is solar physics. Relatively few simple studies of the Sun are carried out from rockets today despite the continuing need for simple but accurate photometric measurements throughout much of the x-ray and uv spectrum. Today's solar studies are typically concerned with observation of features of the solar image such as noneclipse observations of the corona, streamer observation, studies of chromospheric fine structure, and x-ray photography of plages; or with detailed spectral studies e. g., such as Bragg-reflection analysis of the solar x-ray spectrum or profile studies of the stronger x-ray and uv lines. These investigations all require solar pointing control to keep instrumentation accurately pointed at the Sun throughout the period of measurement, and they lead to information in many nonvisible wavelengths almost as detailed as that obtained from ground observation in the visible.

Studies of astronomical objects other than the Sun have not reached the same degree of positional and spectral resolution, but nevertheless they have provided important astrophysical data. Most celestial observations rely on gyro-referenced inertial stabilization systems to provide orientation and stability to an optical detection system. In the far ultraviolet, workers have been concerned with obtaining spectra and energy flux data on bright blue stars. Such studies have provided a check on radiation transfer theory applied to such stars and have identified high-velocity mass loss in hot supergiant stars. They have also provided the most accurate measure of interstellar density and have set limits to the role played by molecular hydrogen as a reservoir of galactic matter. In the x-ray portion of the spectrum, totally new types of astronomical objects have been discovered, namely, the type 1 x-ray stars. In addition, several previously identified radio-wave-emitting objects have been found also to be x-ray emitters. The studies of these objects is basically the study of high energy astrophysics. Most of the work so far carried out has been concerned with obtaining pulse-amplitude spectra of individual sources, with discovering new sources, and with localizing and measuring the angular size of sources previously found. The precision localizing of the strongest x-ray source, Scorpius XR-1, with its subsequent identification as a 12th magnitude variable star, has been one of the high points of the sounding rocket program. A technique in considerable current use is the slow scan, in which a gyro-stabilization system is used to slowly scan a large-area x-ray detection system across a small portion of the sky. In this fashion the limited observing time in a rocket flight is spent on a small angular area, and the detectability of weak sources is increased. Much mapping has been carried out along the galactic equator in this manner.

Far infrared rocket astronomy is in its infancy. It has required the development of the technology of the liquid-helium-cooled telescope. This technology now seems to be mastered, and initial astronomical results at wavelengths longer than 20 microns have been obtained. Far infrared astronomy has much room for growth, since the most sensitive detectors are still several decades away from being photon-limited and since many of the most basic questions regarding cosmology and galactic and stellar evolution can likely be answered by measurements in this region. Simple, but rewarding, scanning photometer measurements can be expected to be employed in examining the sky in future pioneering explorations.

X-ray Astronomy

Lawrence Radiation Laboratory. The Atomic Energy Commission's rocket development program is largely carried out by the Sandia Corporation. For the past three years the LRL group has been building scientific instruments to fly on the Sandia-launched rockets, which are multi-stage, solid fuel, sounding rockets. Since mid-1965, LRL has had 15 flights carrying scientific experiments, nine of them successful. All the experiments have been in the field of x-ray astronomy. The proportional counters and scintillation detectors have been greatly improved but no breakthrough has occurred.

The most significant results of the group have been the measurement of the spectra of the brighter x-ray sources with proportional counters sensitive to photons in the energy range of about 1 to 80 keV. The spectra of Sco XR-1 were obtained on several occasions, as well as Cyg XR-1, Tau XR-1 (the Crab Nebula), and some fainter sources.

There has been some interest in looking for x-rays from novae. Rockets are well suited for this since an experiment can be built, put on a shelf, and launched with a few weeks' notice. The group attempted last December to look at RS Ophiuchi. The experiment was built, put on the only vehicle available, and launched in six weeks' time. The group is also attempting optical x-ray correlations of the variable source Sco XR-1. The rocket is held in readiness to launch until the source is observed to be in the correct optical condition.

MIT Norman Bridge Laboratory of Physics. The principal results of work have been in the precise determination of the location of the brighter x-ray sources. In the Crab Nebula the x-ray and visible light distributions were found to have a common center to within the 15-arc sec precision of the measurement. Also, the source is about 2 arc min wide. Studies of the source Sco XR-1 yielded a position accurate to about 1 arc min and an upper limit to the diameter of 20 arc sec. This information, in turn, has led to the optical identification of the source as an intense ultraviolet object of about 18th magnitude.

Lockheed Palo Alto Research Laboratory. The most significant advance was verification of a 1960 assumption that many of the brightest x-ray sources at low galactic latitudes are associated with Population 1 objects. This verification was quantitative and established the average galactic latitude and mean departure from the average latitude of the brightest x-ray sources that were relatively time invariant and had the softest spectra.

X-ray optical techniques were successfully applied to nonsolar x-ray phenomena for the first time in a 1967 flight. A Venetian-blind optical system was used to measure x rays less energetic than a 3 keV from the brightest x-ray source in Scorpius. This type of optics is important because of the high sensitivity that can be obtained in a system capable of simultaneously providing spectral and precise position information.

A CsI photocathode was also used in an image intensifier to convert 8 and 23 A x rays dispersed by a mockup of a spectrograph which has been proposed for satellite use. The photoelectrons were accelerated to 20 kV and recorded on photographic film.

Two rocket flights have studied the x-ray emission of the quiescent Sun in the 1-to-30 keV range. Preliminary analysis indicates a definite hardening of the x-ray spectrum at energies higher than 4 keV. It has not yet been established whether this energetic x-ray emission is thermal or nonthermal; if thermal, temperatures of 10-to-12 million K are required. The occurrence of such energetic processes at a time when the Sun by all indications was extremely quiescent is a new and significant result. A second finding is that the level of solar x-ray emission recorded on the latest flight was more than a factor of 10 higher than anticipated on the basis of the results of the first flight. Ground-based observations gave no hint of such a large increase in x-ray emission.

University of California, Berkeley. Analysis of rocket data obtained by Bowyer while at Catholic University has been continued at Berkeley and has revealed the existence of an anistropic soft x-ray background flux, stronger from the direction of the galactic pole than from the direction of the plane. Analysis of this flux indicated that interstellar absorption is less by a factor of 3 than what had been predicted at this energy. In addition, the observations set limits of $10^5 < T < 3 \times 10^5$ °K for the temperature of the intergalactic medium for a density required to close the universe.

Naval Research Laboratory. The sky mapping program resulted in identification of about 34 sources, including a source close to the extragalactic object M87. The study also identified one x-ray source, Cyg XR-1, as variable. The program was switched from use of Geiger counters to use of proportional counters. A slow scan study of the 3C273 region showed a marginally statistical significant response, indicating that 3C273 is probably an x-ray source. High resolution pulse amplitude spectra of x rays in the 1-to-15 keV energy range were obtained for Sco XR-1, Cyg XR-1, and Cyg XR-2. As observed by others, the Sco XR-1 and Cyg XR-2 spectra had the appearance of thermal bremsstrahlung spectra, whereas the Cyg XR-1 spectrum was of the "power law" form. Lack of a distinctive shoulder to the SCO XR-1 spectrum in the neighborhood of the Fe XXV and XXVI emission lines ruled out an iron-rich plasma emitting in accordance with Tucker's 5-percent model. A source in Vulpecula was observed in the 44-to-60 A band and not in the 1-to-10 A band, indicating a new type of cooler x-ray star. Observations of diffuse x rays at high galactic latitude indicated that background emission exists at 44 to 60 A, and is greater than would be expected from an extrapolation of 1-to-10 A data to longer wavelengths.

Massachusetts Institute of Technology. MIT has been carrying out a medium precision x-ray astronomy mapping program using proportional counters and attitude-controlled Aerobees, with the following recent results: confirmation of x radiation from M87; celestial positions of x-ray sources in Sagittarius with a precision of about 15 min; spectral measurements of Sco XR-1 to 18 A; upper limit to x radiation from a two-week old supernova. The MIT group is exploiting the modulation collimator techniques to measure source sizes and locations in its forthcoming flights. Long wavelength measurements are being made with thin-window proportional counters and with photoelectric detectors.

American Science and Engineering, Inc. A. S. & E. has been engaged in a program of precise localization of x-ray stars through use of modulation collimators, proportional counters, and a photographic aspect system integral with the modulation collimators. With this system an outstanding result was achieved: optical identification of the x-ray source Sco XR-1, and the subsequent identification of Cyg XR-2. These identifications have apparently established the existence of a new class of objects in the galaxy and have stimulated a variety of observational and theoretical work. The optical objects are being intensively studied from the ground to learn more of their nature, and a variety of experiments, such as correlated x-ray/optical observations are contemplated. Several specific models of x-ray sources have been proposed on the basis of the optical identifications; the one receiving the widest attention is that the x-ray objects are close-binary pairs and the x-ray emitting region results from gas streams flowing between the two stars that make up the pair. This model results directly from the optical observations; namely, that the objects resemble old novae in their spectroscopic properties and in the erratic variations in intensity. The model is plausible on the basis of the x-ray spectral data which can be accounted for by a hot-gas emission model.

Other notable results include: (1) Pinpointing of the x-ray emission region in the Crab Nebula with a precision of 20 arc sec and the demonstration that the angular size is consistent with filling the entire nebula.

This restricts the kinds of models that can be invoked to account for the x rays; and, (2) Evidence for low-energy absorption effects in several x-ray sources, which can be taken as evidence for opacity effects in the sources of interstellar absorption.

Instrumentation advances include development of the modulation collimator which provides a means of obtaining high angular resolution (< 1 arc min) and techniques of background rejection (pulse shape discrimination) which have substantially improved the sensitivity of these experiments.

Ultraviolet Astronomy

Naval Research Laboratory. An ultraviolet astronomy program was carried out using newly developed far uv image converters and electronographic recording of star field spectra. The Carruthers image converters utilize front-surface alkali halide photocathodes on which a spectrally dispersed star field is imaged, and a 20-keV acceleration of the resultant electron pattern which is magnetically focused onto nuclear track emulsion film. Using this type of instrumentation on attitude-stabilized Aerobees, the spectra of Zeta Puppis and Gamma Velorem were recorded from about 1050 to 1300 A, and the spectra of several of the brighter Orion stars from about 1150 to 1300 A. The observations of Morton were confirmed, namely that early-type supergiants are surrounded by rapidly expanding gas shells which are optically thick in strong far uv resonance lines such as the C IV lines, and that interstellar atomic hydrogen produces a nonshifted Lyman-alpha absorption line whose equivalent width corresponds to interstellar hydrogen densities equal to one tenth those indicated by radio measurements at the 21-cm line. A new result was the observed lack of molecular hydrogen band absorption in the Zeta Puppis and Gamma Velorem spectra near 1100 A. This result established an upper limit on the interstellar molecular hydrogen concentration at ten percent of the atomic hydrogen concentration deduced from the interstellar Lyman-alpha absorption line.

Far uv stellar photometry was carried out using band sensitive photon counters sensitive in the ranges 1050-1180 A and 1230-1350 A. The results continue to indicate that stellar fluxes at wavelengths shorter than 1200 A are lower than predicted by theory.

Princeton University. A program of far ultraviolet astronomy has been carried out from ACS-equipped Aerobees, based mostly on the use of slitless spectrographs mounted on a platform incorporating fine stabilization in the dispersion direction provided by a passive gyro system. Most of the spectra were photographed with f/2 Schmidt cameras with far uv transmitting correctors, though some data have been obtained with an f/2 all-reflective spectrograph.

Outstanding discoveries have resulted from the five successful flights. A Princeton rocket spectrograph obtained the first uv spectra having enough resolution to show the line features in stars other than the Sun. These spectra demonstrated that in hot stars the far uv lines are primarily in absorption, unlike the Sun which has only emission lines at short wavelengths.

Another Princeton rocket discovered that in the uv spectra of hot supergiant stars many of the strongest absorption lines are shifted to shorter wavelengths, showing that these stars are ejecting matter at remarkably high velocities, some as large as 2000 km sec -1. Absorption lines due to interstellar matter also were seen in the far uv for the first time. Some lines have been attributed to oxygen, carbon, silicon, and aluminum -- elements which have no features in visual spectra. Of particular interest were the measurements of the interstellar Lyman-alpha absorption line. The strength of this line corresponded to about one tenth the density of hydrogen atoms in nearby parts of the galaxy as deduced from observations of the 21-cm radio emission. This intriguing discrepancy has not yet been resolved. Several hundred absorption lines and a few emission lines have now been measured in the Princeton stellar spectra. Many of these have been identified with known lines from atoms and ions in the photospheres, circumstellar shells, or the interstellar medium, but at least a hundred features remain unidentified.

Spectra from 2100 to 3000 A of sunlight reflected from the atmospheres of Venus and Jupiter have revealed a general absence of absorptions, except for a few weak features which can be attributed to the planets. Upper limits for the abundances of O_3, NH_3, SO_2, NO_2, NO and C_3O_2 were derived for the Venus atmosphere. The lack of ozone suggested that oxygen may be nearly absent on Venus.

Kitt Peak National Observatory. For several years KPNO has been involved in an Aerobee program designed to make spectrophotometric surveys of hot stars brighter than fifth magnitude in the spectral range from 1050 to 2100 A. The spectrophotometer employed is designed to obtain low resolution (~25 A) spectra of 20 to 30 stars in a single flight, yielding data on the continuum intensity distribution for a range of spectral types. The instrument consists of a 12-in. Cassagrain telescope with a grating spectrometer mounted on the back. This combination is mounted in a biaxial gimbal mechanism that scans the telescope in a 20° x 20° area of the sky while the rocket is held in a predetermined orientation by an attitude control system. The data are telemetered to ground stations during flight. In February 1968, the fourth rocket of this series (and the first successful one) was flown from White Sands. The instrument scanned the Orion region and spectra were obtained for about 20 stars, most of which yielded usable data covering spectral types from 08 through A3. The data are now being analyzed.

A second program at KPNO has been the study of the planetary spectra in the 1600-to-3200 A range. In this program, a 13.5-in. aperture Cassegrain telescope in conjunction with a concave-grating spectrometer has been used to obtain photometric spectra of Venus and Jupiter at 16 and 28 A resolutions, respectively. The rocket was pointed to the target to an accuracy of about 1 arc min with the separable payload orientation system built by Ball Brothers Research Corporation. An effective pointing accuracy of 2 arc sec was achieved by a closed-loop servo-system incorporated into the telescope. The spectra are of high photometric accuracy and show no sign of the previously suggested ozone absorption in Venus or the absorption feature at 2600 A in Jupiter. The Venus albedo shows a short wavelength cut-off beginning at about 2100 A which is consistent with the CO_2 absorption that could result of CO_2 were the principal atmospheric constituent. Absorption by NH_3 appears to be present in the Jupiter spectra, but in a concentration orders of magnitude less than suggested by ground-based observations.

University of Florida - Kitt Peak National Observatory. On 4 December 1967, six photoelectric spectra of Venus were obtained between 1600 and 3200 A with approximately 16-A resolution. These were obtained with a scanning spectrometer and a 32-cm aperture telescope pointed with a Ball Brothers Corporation SPCS-1 guidance system. These data have not been completely analyzed at this time so that final conclusions cannot be given. However, one feature that has not been observed before was a cutoff at approximately 1850 A. Between 1850 A and 1600 A the planet was completely black.

Johns Hopkins University. Workers at Johns Hopkins are conducting a program to observe spectra of planets and stars in the far ultraviolet using a 14-in. servo-controlled astronomical telescope with 2-arc sec spatial resolution and 1-arc sec pointing accuracy. In the first flight, Lyman-alpha and 1304 A (OI) emissions were observed from Venus and Jupiter. The albedo of these planets at 1650 A was also measured. A crude spectrum of the B3 star η Ursa Majoris was also obtained.

Infrared Astronomy

Cornell University. Cornell has developed, partly in collaboration with NRL, cryogenically cooled rocket-borne telescopes capable of covering the entire infrared spectral range from 1 micron to 1 millimeter. In the near infrared, Cornell has flown liquid-nitrogen-cooled telescopes, while a recently flown liquid-helium-cooled telescope covered the range out to 1.5 mm, thus entering the domain where ground-based observations once again become possible. The far ir results are too recent to be usefully discussed at this time. The near ir flights gave upper limits on diffuse background levels in the universe and current analysis of older data will permit statements about limb darkening on the Earth's nightside in the near infrared. One byproduct appears to be the feasibility of flying a variety of liquid-helium-cooled experiments -- a fact of some importance since many devices work at the lowest noise levels when cooled to very low temperatures.

Naval Research Laboratory. A far ir program based on a flight of cryogenically cooled telescopes, choppers, and solid-state detectors was carried out. What appear to be valid data at 30 microns were obtained using a liquid-helium-cooled system, but interpretation is not sufficiently advanced to permit conclusions.at this time.

Solar Physics

Naval Research Laboratory. New spectra of the quiet Sun at solar maximum were obtained that extend to wavelengths below 8 A, and line emissions from Si XIII and Al XII were identified at 6.7 and 7.7 A. The solar corona was photographed in the band 170 to 400 A and was observed to extend out to 3 solar radii. The base of a brush-like structure in a plage was photographed in both Fe XV and Fe XVI radiation using a spectroheliograph. Other spectroheliograms recorded the chromospheric fine structure pattern in He II radiation at 304 A. The white-light corona was photographed from a rocket in the circular aperture between 3 and 10 solar radii.

Two high angular resolution studies of chromospheric fine structure were carried out in Lyman-alpha with about 2-arc sec resolution. For the quiet Sun, local brightness variations were found to be limited to $\pm$ 30 percent with steep gradients between regions of different brightness, and structures as small as the 2-arc sec resolution limit were observed.

NASA Goddard Space Flight Center. Spectroheliograms in the MgII line at 2802.7 A have been obtained using a Solo-type birefringent filter. High quality x-ray photographs of the Sun were obtained in several wavelength bands between 3 and 70 A with a resolution of 20 arc sec or better. The high resolution photographs were made possible by use of grazing incidence x-ray telescopes. Studies of the composition of solar cosmic rays were carried out from three small rockets and data on the relative solar abundance of elements heavier than hydrogen have apparently been obtained.

American Science and Engineering, Inc. The A. S. & E. group has obtained x-ray photographs of the Sun using grazing incidence optics with 20-arc sec resolution, and plan to fly an advanced version of the telescope (several arc sec resolution) in the near future. The results convirm the x-ray appearance of the Sun indicated by pinhole camera pictures and eclipse experiments; namely, that the active regions are the principal loci of x-ray emission, that these regions are very small, and that the coronal emission is much softer and shows decreased emission in the polar regions. The telescopes offer the advantage of a speed typically several thousand times greater than that obtainable with pinhole cameras.

Instrumentation developments include the grazing incidence telescope and the slitless spectrometer. These devices offer great potential in both solar and stellar x-ray astronomy.

Air Force Cambridge Research Laboratories. Since mid-1965, AFCRL has used rockets to extend experimental data on solar extreme ultraviolet radiation and its dissipation in the Earth's upper atmosphere. Most of the experimental results on the euv spectrum and atmospheric absorption analysis obtained through January 1967 have been published. Data from later rocket experiments (March, August and September 1967, and March 1968) are being analyzed and significant results will be presented for publication in the near future. These later experiments were oriented toward acquisition of data in support of satellite observations made during this period (AFCRL spectrometer for λ 260 to 1300 A, and GSFC spectrometer for λ=400 A, on OSO-3; the Harvard spectrometer for λ 500 to 1300 A on OSO-4). These rocket experiments were nevertheless valuable in their own right; the information on absolute fluxes still depends on the rocket results even for the periods when OSO-3 and OSO-4 were operating successfully. At shorter wavelengths the absolute intensities of solar x rays were measured during quiet Sun conditions in 1965 and again in 1967 using proportional counters and a grazing incidence monochromator.

University of Colorado. High resolution profiles have been obtained of the solar lines of hydrogen Lyman-alpha, the oxygen triplet at 1302 to 1306 A, and the silicon line at 1206 A. The analysis of the Lyman-alpha line and comparison with existing theory indicates that the latter is unable to account at present for the shape in the wings of the line. A lower temperature than indicated by previous results has been found. There also is evidence of a "hot" component of the Earth's hydrogen geocorona. The Earth's oxygen absorption is evident for all lines of the triplet and appears to be strong enough (altitudes about 180 km or less) to completely mask details of any intrinsic solar reversal. The silicon line data are poor, but they point to a solar reversal.

MAGNETIC AND ELECTRIC FIELDS

Magnetic and electric field measurements by sounding rocket have been directed toward study of two rather distinct scientific problems. The first, and older, of the two is the global ionospheric electric current system. Although magnetic fields produced by the currents are detectable on the ground, rocket flights alone can determine the vertical profile of current density. The goal of the studies is description of the global current system through investigation of ionospheric conductivity, ionospheric winds, and electric fields, as well as of the ionospheric currents. Investigation of ionospheric currents is closely related to the more general study and description of the ionosphere and might be called dynamics of the ionosphere. The second major problem is auroral physics. Auroral phenomena are but manifestations, near 100 km in the auroral ionosphere, of processes occurring in the magnetosphere. Auroral ovals are tightly connected to the outer magnetosphere by magnetic lines of force (labeled $L = 5$ to $L = 7$ according to their equatorial crossing distances in Earth radii). Magnetospheric parameters of interest include electric current density (as recorded by magnetic field measurements), electric fields, low energy (including thermal) particle densities, and energetic particle spectra. The most crucial event in the dynamics of the magnetosphere is the magnetic storm. Particularly during the development of a magnetic storm, with inflation of the magnetosphere commencing in the evening quadrant, there occur large auroral disturbances, called auroral or polar substorms.

Energetic particle precipitation from the magnetosphere, visible auroral displays, enhanced ionization, Electric fields, and intense ionospheric currents (electrojets), form the roster of auroral parameters to be observed by sounding rockets. Obviously, a unified approach to auroral studies should involve measurement of all possible parameters on a single rocket payload or several payloads launched in close spatial and time conjunction. Extensive ground support through observation of the ionosphere, auroral displays, and electrojet magnetic fields is essential to the full value of rocket experiments. The auroral investigations must also be tightly coupled to magnetospheric studies by satellite. The auroral physics problem combines several disciplines -- geomagnetism, aeronomy, ionospheric and energetic particle physics; it also is closely and essentially related to magnetospheric physics. Magnetospheric studies using satellites and auroral studies using sounding rockets contribute significant strength to both facets of the central problem -- dynamics of the magnetosphere.

Recent Low and Mid-Latitude Ionospheric Current Measurements

GSFC-AFCRL-University of New Hampshire. In the spring of 1965 a strong attack on the low latitude ionospheric current system was launched. Under NASA Wallops Station sponsorship the USNS Croatan, cruising off the west coast of South America, made a latitude survey of the equatorial electrojet, an anomalous ribbon of high current density flowing along the magnetic dip equator. Research teams from Goddard Space Flight Center, Air Force Cambridge Research Laboratories and the University of New Hampshire (UNH) flew magnetometer payloads to detect the electrojet, measure its vertical structure, and delineate its latitudinal extent. The value of the studies was greatly enhanced by the combined efforts of several groups, launching a total of 15 rockets during a week or two. Progress was also enhanced by a theoretical model of the electrojet by Sugiura and Cain of GSFC. The experimental studies confirmed the main features of the model -- a narrow belt of current centered on or near the dip equator at about 100-km altitude with a higher altitude contribution of lower current density, part of the general low latitude global current pattern. The global current system at mid-latitudes was detected during a flight from Australia in 1964; the existence of these currents was confirmed during the 1965 survey by flights well to the north of the equatorial electrojets.

NASA-UNH-Indian Committee on Space Research (INCOSPAR). Since 1965, there has been little activity in low and mid-latitude studies of the ionospheric current system. Sastry in India conducted one flight in 1967, extending studies commenced in 1964 as a joint NASA-INCOSPAR-UNH project. Results indicate that the current density near midday is lower than that measured in South America; and confirm a longitudinal asymmetry in electrojet intensity. Moreover, in 1967 when the solar activity had started to rise, the current density was found to be greater and the electrojet apparently wider than in 1965.

New Techniques

Although ionospheric current measurements have been sparse since 1965, three new techniques have been introduced to allow measurement of the electric fields that drive the currents.

Barium Ion Cloud (Max Planck Institute-GSFC). Release of an ionized vapor cloud in the ionosphere at dusk permits observation of the movements of the luminous cloud under the influence of electric fields that are present. The Max Planck Institute has carried out a vigorous program at several geographic locations using this technique. Other teams, notably the GSFC group, have also utilized it. Observations at mid-latitudes confirm the directions of electric fields earlier predicted from observed current patterns and the tensor conductivity of the ionosphere.

Electric Field Probes (University of California, Berkeley-Royal Technological Institute-GSFC). By measuring the potential difference between two metallic probes extended beyond the plasma sheath surrounding the rocket, small static electric fields can be measured. The RTI was active in studying the feasibility of using such probes. Berkeley and GSFC have flown booms and have measured fields of tens of millivolts per meter.

Magnetic Vector Measurements (Rice University). A recent important experimental technique has been introduced by Rice University. Hitherto, all observations of ionospheric currents have depended on measurement of the scalar magnitude of the total magnetic field vector. Since the magnetic field component due to ionospheric currents is seldom aligned with the total geomagnetic field, interpretation becomes a vector-addition problem. Scalar results are usually ambiguous. A first flight of the Rice experiment indicates that the system is satisfactory and further flights are planned.

Auroral Studies

The aurora is a complex phenomenon involving precipitation of particles from the magnetosphere, enhanced ionization, auroral light, electrojet currents, and electric fields. Rocket payloads equipped to measure several of these parameters are more valuable than payloads that measure only one variable. Several groups have been preparing related experiments for flight on the same rocket or on several rockets to be launched at the same time and location.

NASA Goddard Space Flight Center. During the past few years rubidium-vapor magnetometers have measured the total field magnitude in the auroral electrojet. Also, electric-field booms and vapor clouds have been used to measure electric fields in the auroral zone. Intense fluxes of monoenergetic electrons have been detected near auroral areas. VLF measurements have been made with a 3-axis sensor.

Rice University. Energetic particles and auroral light have been observed in flights through auroral displays. Techniques for vector magnetic field measurement of ionospheric currents are being developed.

University of California, Berkeley. Balloon and rocket investigations of precipitated charged particles have been made. Rapid fluctuations in particle flux have been shown to be related to magnetic fluctuations. Electric fields near an auroral display were observed employing booms.

University of Alaska. Auroral electrojet measurements with the Rb-vapor magnetometer have been made in conjunction with ground observations of the moving auroral displays. A flashing light on the rocket provides location of the payload with reference to the display.

University of New Hampshire-University of California, San Diego. These two groups have joined forces in developing an experiment to observe auroral-energy protons and electrons together with magnetic and electric field measurements.

University of Saskatchewan. This group, which made an early measurement of electric fields, is continuing their program using electric field probes. The probes are contained in self-stabilizing packages, originally flush with the rocket body, and ejected from the rocket. A device for measuring the magnetic field has recently been added to the experimental package.

ENERGETIC PARTICLES

The sounding rocket has been used extensively for basic research on particles and fields, including magnetospheric, ionospheric, and auroral physics on the one hand, and cosmic ray physics on the other. Sounding rocket techniques have been immensely valuable scientific tools whenever it was advantageous or necessary to extend the reach of instruments to regions above the Earth's atmosphere.

Progress in sounding rocket investigations of magnetospheric, ionospheric, and auroral phenomena has been steady and rewarding, and even on some occasions, spectacular. This progress has been due not only to advances in conceptualizing experiments, but also to development of more sophisticated and complex instrumentation. Sounding rocket experiments have identified the types of particles in auroral fluxes, measured their intensities and energy spectra, and have offered clues to the origin of auroral particles and the mechanisms responsible for their acceleration. Closely coupled with auroral particle measurements have been rocket-borne measurements of auroral-light emissions, both at optical wavelengths and at ir and uv wavelengths inaccessible to ground study. Sounding rockets have been used to probe the density, temperature, and composition of the ionosphere and studies of this sort on the auroral ionosphere, combined with energetic particle measurements, have been extremely useful in determining interactions between the ionosphere and incoming particle fluxes. Sounding rockets have also played a role in Van Allen radiation studies, having been used in experiments to determine the composition of the inner zone.

The contributions of sounding rockets to cosmic ray studies are no less significant. Studies of low energy cosmic rays, and in particular the occurrence and composition of solar cosmic rays, have contributed valuable data not only for Earth-oriented applications such as ionospheric disturbances but also for studies of astrophysical interest. Neutron-albedo studies have determined the latitude dependence of the neutron flux above the Earth's atmosphere, with the corresponding implications in the field of interactions between cosmic rays and the upper atmosphere.

To date, rocket measurements have concentrated mainly on particle measurements, ranging from thermal particles in the ionosphere to high energy cosmic rays. With the development of sensitive magnetometers the potential of sounding rockets for measurement of magnetic fields and current systems both in the ionosphere and in the lower magnetosphere is being realized and exploited. Coordinated experiments involving particle and magnetic field measurements can lead to second and third generation experiments in magnetospheric and auroral physics. The sounding rocket is an indispensable tool for experimental work in the particles and fields discipline. Most rocket measurements of energetic (nonthermal) charged particles have been concerned with the following research areas, listed in decreasing order of activity (though not necessarily in order of importance): auroral; solar cosmic rays, e.g., polar cap absorption (PCA); photoelectrons; Van Allen radiation zone; neutron-albedo; wave-particle interactions.

Auroral Particles

University of California, Berkeley-Rice University. Several groups have been active in auroral-particle rocket research which has been much more rewarding recently due largely to improved particle detectors able to detect energies in the previously unmeasurable ranges of ~ 10 eV to ~ 1 keV. Thus auroral processes can be related to plasma and magnetospheric phenomena even in such fields as applied fusion research.

The Berkeley group has studied the time fluctuations in the intensities and the spectra of auroral electron fluxes. An electrostatic spectrometer experiment was flown on four Nike-Tomahawk rockets at Fort Churchill in the fall of 1966; electron, proton, and alpha particle flux measurements were obtained in all four launches. Three of the flights were made in the daytime during x-ray microburst activity which was simultaneously monitored by balloons. The fourth was made at night during a visible aurora. The elextron spectra apparently reveal the presence of monoenergetic primary electrons in the visible auroral display, a finding which implies the existence of electric fields along magnetic field lines above the auroral zone. On the other hand, since the minimum energy detectable by the instruments was about 1 keV, these results must be combined with more recent findings by the Rice group that the spectrum starts to rise again when measurements are made down to energies of about 20 to 30 eV. Further, the spectrum outside visible auroras appears to be a continuum as far as the electron energies from the order of a few tens of eV to about 100 keV. The so-called monoenergetic electrons of energies of 1 to 10 keV are found only over bright visible auroras. It is thus possible that the continuum of electrons gives the necessary reservoir of energy and particles from which wave-particle interactions and other complex plasma phenomena may occasionally concentrate their total energy on the electrons of a few keV which then produce the visible aurora. The possibility exists that the visible aurora may be caused by what in applied fusion research are called "runaway electrons" -- a few electrons which for imperfectly understood reasons acquire higher energy than the others. If true, the magnetosphere becomes a tremendous laboratory for plasma research.

The long-sought-for source of the particle fluxes that bombard the atmosphere to cause auroras has recently been found. Measurements by workers at Rice of the ratio of the alpha particle-proton flux above an active aurora and simultaneous comparison of this flux in the interplanetary solar wind indicate that auroral ions ultimately come from interplanetary space and hence from the solar atmosphere, rather than from the terrestrail atmosphere.

Rocket probes of the electron fluxes that cause the bright, visible auroral formations have found periodicities in electron precipitations into the atmosphere, ranging in frequency from hundreds of Hz to 0.01 Hz. Whereas balloon studies discovered some of these effects, only rockets able to rise above the bulk of the atmosphere can further investigate the energy domain below $\sim$30 keV. Satellites cannot be effectively used because their velocity of some 8 km sec^{-1} perpendicular to the magnetic field renders it impractical reliably to distinguish spatially repetitive patterns from those periodic in time.

Attempts have been made to utilize the periodicities of temporal changes found by rockets to deduce the altitude at which auroral acceleration and modulation occur. Theoretical estimates range from a few hundred to a few million kilometers; thus the rocket experiments are designed to measure time delays in the arrival of fast and slow electrons, and by knowledge of their velocity to deduce the altitude of interest. To date, experimental results from several groups and several rocket flights can imply source altitudes over almost as large a range as the theoretical predictions. Whether this is due to deficiency in the measurements or in their interpretation, or whether indeed given different auroras one should expect different answers, is still unclear and remains an outstanding problem in auroral and plasma research.

The occasional occurrence of "abnormal" directionality in auroral particles, in particular of their scattering or reflection by the atmosphere, has been detected with rocket-borne instruments. The number and variety of measurements leads one to conclude that the auroral particle-atmospheric interaction is far from a simple Coulomb backscatter phenomenon. Whether the effect is due to electric fields in the ionosphere as some suggest is uncertain, but there must clearly be atmospheric "feedback" (such as heating) to auroral bombardment. One definitive finding by workers at Rice is that a feedback associated with the ionization, current flow, and magnetic field of the auroral electrojet leads to periodic fluctuations in particle precipitation, with large amplitudes and periods of tens of seconds.

<u>PCA or Solar Cosmic Ray Events</u>

<u>NASA Goddard Space Flight Center</u>. Rockets have provided vital data on energetic solar cosmic rays and their precipitation into the atmosphere. Recoverable payloads and flexibility in launch times to conform with special events have been particularly advantageous in such investigations.

Rocket studies of this atmospheric bombardment, which enhances ionization and often leads to PCA events or radio blackout, have found that the Störmer theory is violated due to perturbations in the geomagnetic field during storms and perhaps even during quiet-time conditions. Of marked interest has been the detection of energetic heavy nuclei in these events, providing clues to the relative nuclear composition of the Sun and the hydrogen-helium ratio in particular.

It is also noteworthy that rocket flights from 1963 through 1965 measured low energy galactic cosmic rays. These particles cannot be observed from the ground or with balloons and are of vital importance to the resolution of long-standing problems about cosmic rays. These studies have stimulated a great interest in theoretical studies of solar modulation and propagation of cosmic nuclei.

Photoelectrons

Lockheed Palo Alto Research Laboratory. Scientists at Lockheed have conducted rocket measurements of photoelectron fluxes and compared the results with theoretical predictions. Rocket photoelectron studies to date have been somewhat sparse in comparison with studies of auroral processes, partly because some of them can be made from the ground. For example, facilities at Arecibo can determine the F-region temperature changes resulting from photoelectron fluxes, and ground-based observations of the 6300 A line provide data on some of the photoelectron processes. However, only rockets can measure directly the photoelectron fluxes and their energy and angular distributions.

Van Allen Radiation Zone

In the early days after the discovery of the existence of the Van Allen radiation zone, rockets played a major role in clarification of many of the problems. For example, a rocket-borne experiment in 1959 established that the inner-zone radiation consists of penetrating protons. The use of rockets for radiation-zone investigations has tended to diminish with the increased sophistication of satellite instrumentation, and for the past few years relatively little rocket work has been performed in this field except to test instrumentation for later flight on satellites.

Neutron Albedo

University of New Hampshire. The principal neutron-albedo studies with rockets have been carried out by the New Hampshire group using Nike-Apache and Nike-Tomahawk vehicles. Instrumentation used is a neutron detector that is a moderated He^3 proportional counter surrounded by a bank of charged particle counters. In all, eight flights were made successfully, and the data have permitted determination of the latitude variation of the neutron flux above the Earth's atmosphere. The latitude dependence is somewhat flatter than predicted by theory and the absolute magnitude of the leakage flux is less than calculated.

Wave-Particle Interactions

Very little rocket work has been done in this field. It has been generally recognized only in the past few years that the interactions of electromagnetic and other waves with charged particles are critical in the processes that occur, for example, in the magnetosphere, in the auroral regions, or in controlled fusion research in the laboratory.

IONOSPHERIC PHYSICS

Ionospheric physics is concerned with physical phenomena in the lowest energy portion of the ionospheric plasma. The electron energy spectrum extends from the MeV range of trapped radiation, through photoelectrons having energies of tens of electron volts, to the most abundant electrons with energies of one eV which comprise the so-called "thermal" or "ambient" plasma. Energy distributions of the electrons and positive ions are approximately Maxwellian, and electron and ion temperatures can be readily defined.

For convenience, we divide the ionosphere into three regions. The D region, at altitudes up to 90 km, contains electrons and a mixture of positive and negative molecular ions; the E region, from 90 to 160 km, contains mainly electrons and molecular ions; the F region, at altitudes above 160 km, contains primarily electrons and atomic ions. The particular ranges of wavelength in the solar spectrum absorbed at altitudes in the E region are called E layers; similarly, layers F1 and F2 are defined for the F region.

Four general properties of the ionosphere -- chemical, thermal, dynamical, and electromagnetic -- are pertinent for the purposes of this study. (1) Chemical properties concern the nature of the neutral constituents ionized by incoming solar radiation (or other means) to give electrons and positive ions and the subsequent processes of attachment, charge exchange, ion-atom interchange, electron detachment, and dissociative recombination. These processes are quite different in different altitude regimes. (2) Thermal properties concern the degradation of incoming solar energy through photoionization, including the results of elastic and inelastic collisions of photoelectrons with neutral and charged species, till the energy is finally absorbed into the thermal sink represented by the neutral atmosphere. Conduction of heat by the electron and ion gases also is important through most of the ionosphere. (3) Dynamical properties of the ionosphere are represented by processes such as: the ambipolar diffusion of the ionization; its collisional interaction with the moving neutral atmosphere; the convection of ionization by electric fields, either in the dynamo region or in the outer part of the magnetosphere; and the effects of these motions on the ionization distribution itself. (4) Electromagnetic properties of the ionosphere concern its ability to propagate natural or man-made radio signals as an anisotropic magnetoionic medium, and to generate, through various types of instabilities, plasma waves and oscillations of various types.

Because of the fact that these four aspects of the ionosphere overlap considerably into other disciplines, there is an increasing tendency to make rocket measurements of ionospheric characteristics simultaneously with measurements of related physical properties of the atmosphere which are relevant to the particular phenomena under study, e.g., solar ionizing fluxes, minor-constituent density, atmospheric temperature, and particle fluxes.

Electron and Ion Density

Air Force Cambridge Research Laboratories. Positive ion and electron densities were measured in two night experiments on November 10 and 17, 1965. Strong irregularities were found in the E-region electron and ion density profiles. Electron and ion densities were also measured as a function of obscuration during the 1966 total solar eclipse in southern Brazil. These are now being used to improve models of D-region chemistry.

GCA Corporation. Rockets containing sodium releases and Langmuir probes have studied the vertical profile of horizontal winds in the E region, and the data compared with vertical profiles of electron density. These results seem to show that simple wind-shear theory does not explain the observations. The most recent data were obtained from a series of five combined payloads measuring winds and electron density at 90-minute intervals during a winter night at Wallops Island. It is expected that these data will allow a significant study of the relation of winds and electron density during the 7-hour period.

NASA Goddard Space Flight Center. This program has involved the use of small rockets (Arcas, Nike-Cajun, Nike-Apache) for lower ionosphere studies, and of large rockets (Javelin) for investigations above the F-layer peak. Six boosted-Arcas rockets were launched for the study of the D region during the solar eclipse of 20 May 1965 in New Zealand; in 1966, an additional six boosted-Arcas were launched during the annular eclipse in Greece. Two boosted-Arcas rockets were launched from Resolute Bay, Canada in October 1967 to study the high latitude D region; because of vehicle malfunction no results were obtained, but another series in the summer of 1968 was designed to study PCA events from Resolute Bay. Two boosted-Arcas rockets are soon to be launched from Thumba, India for the measurement of equatorial D-region electron density. For this project a new experimental technique based on quasi-transverse (Q-T) radio propagation was devised.

The laboratory also participated in the 1966 NASA Mobile Launch Expedition with the launch of six Nike-Apaches. The main results of this series were the first observation of the nighttime equatorial E region, indicating the presence of a layer at about 110 km that may be produced by scattered solar uv radiation; and in contrast with temperate latitudes no evidence of a sporadic-E layer was found. Recently two Nike Apaches were launched to study the lower ionosphere during a solar x-ray event; several rockets will be launched during a solar flare from Wallops Island in the near future.

Naval Research Laboratory. An Aerobee rocket launched at night in August 1967 from White Sands carried ion mass spectrometers, an ion trap, a Langmuir probe, three uv-radiation detectors, a Lyman-alpha ionization chamber, and two thin film window photometers sensitive in the 770-to-1080 A and 150-to-750 A bands, respectively. The thin film window photometers detected radiation in the night sky capable of ionizing the major atmospheric constituents, thought to be Lyman-beta and helium resonance radiation at 584 or 304 A. Theoretical calculations indicate it is sufficiently intense to maintain the nighttime E and F1 regions.

Pennsylvania State University. Three separate rocket programs have been undertaken recently. The first, the "mother-daughter" experiment, used a Javelin rocket to measure F-region electron densities by propagating a radio wave between two separated parts of the rocket. This program has resulted in the direct calibration of ion traps and has shown that wake effects are negligible, although large errors result when the trap dimensions become comparable with those of the sheath.

A second program has involved 16 Arcas rockets, carrying parachute-borne blunt probe experiments to measure electron and ion densities. Principal results have been a demonstration of the applicability of simple mobility theory for subsonic blunt probes. Previously reported nighttime ion density measurements are found to be about 30 percent too high, but the cosmic ray control, absence of electrons, and constant mutual neutralization coefficient model still fit the data well. A night measurement in Alaska during a PCA event showed a positive ion density of about 4000 cm^{-3}, nearly constant with altitude over the 40-to-70 km altitude range. A winter daytime measurement at White Sands under somewhat disturbed conditions showed a positive ion density minimum at a lower altitude than that obtained in 1964 under quiet solar conditions. The electron density was greater than 100 cm^{-3} in the 50-to-60 km range, but the negative ion/electron ratio increased above 60 km indicating the predominance of a readily detached negative ion below 60 km and of a much more stable negative ion above that height.

A third program has involved measuring electron densities as a function of altitude from the field strength of a 183-kHz radio wave reflected from the ionosphere. Five experiments using this technique were carried out in southern Brazil in connection with the 1966 solar eclipse. This experiment has stimulated an investigation into the applicability and limitations of solutions (specifically WKB method) of wave propagation problems in the ionosphere.

A fourth program carried out at Fort Churchill has used two experiments: a differential absorption experiment using partial reflection transmitter and an AC conductivity probe.

University of Illinois. The joint program with GCA Corporation and the University of Michigan has included studies of the ionosphere up to 200 km using integrated payloads carried by 29 Nike-Apache rockets. The principal instrumentation consists of a CW propagation experiment (Illinois), a DC/Langmuir probe and solar uv detectors (GCA), magnetic and solar aspect sensors, and an FM/FM telemetry system. On some flights other instruments were flown, including a quadrupole mass spectrometer (Michigan) and an AC electron temperature probe (GCA). These investigations, while using basically similar instrumentation, have been carried out in various series to study specific problems.

The development of the ionosphere at sunrise has been studied by a series of five rockets from Wallops Island, carried out in conjunction with steep-incidence VLF absorption measurements in order to clarify the well-known VLF absorption commencements which occur around zenith angles of 98° and 94°. These experiments showed that the initial ionization of the upper E region at sunrise is caused by Lyman-alpha radiation and the density of nitric oxide has thereby been determined. Another result concerns the initial formation of the D layer. The observations show that the layer is normally formed by photodetachment by solar radiation having a wavelength between 2000 and 3000 Å, implying that the negative ions of the region at night are not O_2^- or O_3^-. The variability observed in presunrise VLF absorption measurements suggests that there are changes in the negative-ion species in the D region, and this has been partially confirmed by the coordinated rocket and ground-based VLF measurements. The latitudinal behavior of the lower ionosphere was studied by a series of four rockets as part of the 1965 NASA Mobile Launch Expedition. Electron density profiles were obtained for geographic latitudes of 12°S, 29°S, 44°S, and 58°S. These shots were conducted around 60° zenith angle, with the exception of the 58°S shot which was made at 67°. Between 70 and 80 km, the electron densities for 29°S and 44°S are three times larger than for 58°S, with the 12°S densities falling midway. Between 80 and 90 km, the 29°S and 44°S densities are about four times the 12°S and 58°S densities. There is a strong suggestion that the South Atlantic anomaly produces enhanced D-region electron densities between 29°S and 44°S because of energetic electron precipitation effects.

Two rocket experiments on anomalous winter days were carried out in 1966 and 1967. The electron density profiles are generally similar in the 65-to-80 km height range, being roughly the same as the summer profile for 60° zenith angle. The 1966 profile had a steep gradient of electron density at 82-km altitude, and the electron densities between 82 and 90 km were about 10 times greater than normal. Electron densities below 65 km were greater in 1966 than in 1967.

Four rocket electron density profiles from southern Brazil during the total solar eclipse in November 1966 reveal several features which have implications regarding D-region photochemical processes. The decay of D-region electron densities during totality appears to be caused by an enhancement in ozone concentration which increases rapidly in the absence of oxygen photodissociation. The height of a sporadic-E layer during the eclipse, observed by the probe experiment, appears to coincide with a layer of metallic ions observed on a separate but nearly simultaneous rocket flight (see AFCRL Section on Ion Composition).

In addition to comparing probe and propagation data on each flight, arrangements were made to compare the electron density and electron temperature data from a series of 3 flights with those obtained at the Arecibo Observatory in Puerto Rico using the Thomson-scatter radar technique. Launch times were chosen to be representative of daytime, nighttime, and sunrise conditions. The daytime flight was successful but the other two were not. The results of the experiment are not yet available, but will be of great interest.

Seasonal launches from Wallops Island near 60° zenith angle were carried out in April and November 1964 and June, September, and December 1965. Electron densities between 85 and 90 km exhibit few seasonal differences. Around 80 km, electron density increases in the following order: December, November, September, April and June. Below 80 km, electron densities in summer are generally higher by a factor of 4 or 5 than those in winter. There appears to be higher variability in winter below 70 km, and equinoctal electron densities tend to fall between the summer and winter values.

University of New Hampshire. A number of rocket experiments measuring Faraday rotation of high frequency radio signals were made on the 1965 NASA Mobile Launch Expedition, from Wallops Island, and from Fort Churchill. Attention has been principally given to the interpretation of Faraday rotation measurements in the light of the generalized magnetoionic theory.

Electron and Ion Temperature

GCA Corporation. Langmuir probe measurements of electron temperature have been made on a large number of rockets which also made electron density measurements in the E region (see previous University of Illinois Section). A compilation of observations of E-region electron temperature measurements from 1960 to 1967 shows a strong solar cycle variation at 145 km. This is at variance with current theoretical treatments and should stimulate reconsideration of the problem.

Measurements of electron temperature during the November 1966 solar eclipse in southern Brazil showed that the E-region temperature remained constant during the eclipse although apparently not in equilibrium with the neutral gas. At greater altitudes (150 to 190 km) a decrease during the eclipse was noted.

Lockheed Palo Alto Research Laboratory. Ion temperatures have been measured in the topside ionosphere. A vertical temperature gradient of 0.8 K km^{-1} was derived in the height range 700 to 1000 km after removal of local-time variations.

NASA Goddard Space Flight Center. In a program carried out jointly between the Aeronomy Branch and the University of Michigan, rocket launchings in day-night pairs at Fort Churchill and Wallops Island have permitted comparison of the differences in the heating mechanisms which occur inside and outside the polar cap. The daytime E- and F-region heating (electron energy loss ratio) do not differ significantly at these two locations. The F region is heated primarily by solar uv radiation while the E-region electrons are heated by x rays and some not as yet well-defined source. Calculations suggest that more than enough energy is available in vibrationally excited N_2 which tends to be quenched by collisions with electrons. This explanation also satisfies the requirement that electrons remain heated at night and throughout a solar eclipse. The nighttime F region results suggest that downward heat conduction from the protonosphere is important at Wallops Island but, as expected, there is no evidence of such conduction at Fort Churchill since no protonosphere exists at that latitude. There is strong evidence for a particle-precipitation source of heating and ionization in the nighttime E and F regions at Fort Churchill.

In a joint program with the Southwest Center for Advanced Studies, two Javelin rockets launched in conjunction with passages of the Alouette 2 satellite have carried ion temperature experiments. The prime purpose of the program is to interpret the topside sounder profiles. It is found that significant deviations from diffusive equilibrium can exist.

A Javelin rocket launched by the Planetary Ionospheric Branch in September 1965 from Wallops Island simultaneously measured ion composition and temperature, and electron density and temperatures in the F region and topside ionosphere. The major ionic constituent was atomic oxygen, with some protons and helium ions. An ion temperature gradient of 1.7 K km^{-1} was found from 300 to 600 km; and an electron temperature gradient of 9 K km^{-1} from 400 to 500 km.

University of Michigan. A cylindrical Langmuir probe on a Journeyman sounding rocket in 1965 measured electron temperatures and densities to an altitude of about 1700 km. These results, together with temperature and density profiles obtained the year before from a similar experiment flown on a Javelin, showed that the source of nighttime heating of the ionosphere is conduction from the protonosphere, as predicted by theory. In January 1967, six Nike-Tomahawk payloads were launched within 24 hours from Cape Kennedy. Each payload included a cylindrical Langmuir probe to study the diurnal variation of electron temperature and density in the F region. Two similar payloads were flown in April 1967 in a combination day-night experiment. The experiment was designed to study the behavior of the electron temperature and density at sunrise and to better understand the coupled ionization and energy transfer mechanisms during rapidly changing conditions.

Ion Composition

Air Force Cambridge Research Laboratories. Eight quadrupole mass spectrometers were flown in 1966-67, seven of them successfully. Instrumentation consisted of a cryogenically pumped mass spectrometer for positive ion composition measurements in the D and E regions. The ion composition of the normal ionosphere showed iron and magnesium ions (correlated with meteor showers and sporadic E) in addition to the molecular oxygen and nitric oxide in the E region and a surprising dominance of mass 37 at altitudes below 82 km, probably a multiply hydrated proton. Ion composition measurements were also made during a total eclipse and at sunrise and sunset.

NASA Goddard Space Flight Center. A Bennett RF ion spectrometer was flown on a Javelin rocket to 630-km altitude above Wallops Island in March 1966. Mass ranges of 1-to-5 and 7-to-40 amu were measured; atomic oxygen ions were found to be a significant constituent amounting to 10 percent of the ion concentration. A somewhat greater concentration of negative helium ions was found than in 1965. A 7-to-40 amu ion spectrometer was flown to 300 km at Wallops Island in August 1966, generally confirming the above results. Molecular oxygen ion concentration in the E region was found to be less by an order of magnitude than either nitric oxide of molecular oxygen ions.

Progress has been made in reducing data sampling requirements of the ion mass spectrometer both by compressing the dynamic range and selectively sampling only the amplitude and position of prominent ion spectral peaks.

Naval Research Laboratory. An Aerobee rocket, launched from White Sands at ionospheric sunset, carried two Bennett ion mass spectrometers and a planar ion trap; it traversed a dense blanketing type of sporadic-E layer on both ascent and descent. Metallic ions, primarily Mg^+, were the main ion species detected within the layer. Normal E-region molecular ions of nitric oxide and molecular oxygen were absent within the layer although NO^+ was detected above and below the layer. Without question, these results show that the mid-latitude blanketing sporadic-E layer is composed of metallic ions.

A Javelin rocket launched in an August 1966 afternoon from Wallops Island obtained the first complete daytime altitude distributions, 150 to 700 km, of the positive ions in the 1-to-32 amu mass range. Prior to this flight only an incomplete composite picture of rocket and satellite results had been constructed for this mass and altitude range. The new results clearly show how the molecular species N_2^+, NO^+, and O_2^+ decrease and the light ions H^+ and He^+ increase in abundance with increasing altitude. In the topside ionosphere, N_2^+ becomes the dominant molecular ion over NO^+ and O_2^+ before their density falls below the sensitivity limit of the ion spectrometer. Extrapolation of the rocket results agrees with data obtained by a similar ion mass spectrometer aboard Explorer 31 which overflew the Javelin trajectory at the time of the flight.

University of Michigan, High Altitude Engineering Laboratory. A quadrupole mass spectrometer has been adapted to obtain sequential mass scans of both neutral and ion composition. In an August 1967 rocket flight at White Sands, the presence of metallic ions of sodium and magnesium was confirmed in the 110-km region.

VLF Noise

University of Minnesota. The Minnesota group will soon fly an Astrobee-1500 rocket to measure electron and magnetic components of plasma waves in the frequency range 10 Hz to 100 MHz. The payload carries four electric antennas of the Storey type (i.e., 2- to 3-in. metal balls on the ends of conducting rods) and two perpendicular loop antennas. It is designed to survey all types of plasma waves in hot plasmas, ion acoustic waves, ion cyclotron waves, upper hybrid waves, electron cyclotron oscillation, plasma oscillations, etc. The signals from the antennas are analyzed by a number of sweeping receivers which scan one decade in frequency every second. The 0-to-25 kHz band will also be telemetered broadband. A second plasma wave experiment is intended to detect possible instabilities generated when a beam of 40-keV electrons is injected into the magnetosphere.

Antenna Impedance and Other Plasma Experiments

Canadian Defence Research Telecommunications Establishment. Although this group is primarily interested in auroral particles and emissions, two VLF receivers have been flown to study VLF propagation characteristics and antenna impedance. Secondary objectives were to deduce electron density and ion composition. The flights were associated with the Alouette-ISIS satellite program.

NASA Goddard Space Flight Center. Nike-Apache rockets have been used to investigate the interaction of an electrically short dipole antenna with the magnetoionic medium. Instrumentation was developed and used to measure both the real and reactive components of the antenna driving-point impedance. The variations of complex impedance with observing frequency, plasma frequency, aspect angle, and the like have been measured and compared with theory. Measurements, including the effect of antenna DC bias, are currently being analyzed. In addition a capacitive probe has also been flown to obtain the reactive component of antenna impedance very accurately. These data have permitted a study of both magnetoionic effects and the nature of the disurbance in the ambient plasma produced by the rocket motion.

Southwest Center for Advanced Studies. In collaboration with ITSA/ESSA, an experiment was conducted in a Nike-Cajun rocket to evaluate several different types of ionospheric plasma probes, including the resonance relaxation probe; a large spherical probe; a mutual admittance probe pair; and a high-frequency capacitance probe. On the basis of experience from topside sounder satellites, the resonance relaxation probe was taken as the standard for comparison. The admittance probe was shown to have its main resonance rectification peak. The mutual admittance probe had distinctive features at several frequencies including the plasma frequency, the electron gyrofrequency, and the upper hybrid frequency.

University of Michigan. This group has developed an RF probe for measurement of local electron density. The theory of antenna impedance in a compressible anisotropic plasma has been extended and agreement with recent measurements of a balanced electrically short dipole antenna in the ionosphere has been obtained. Swept-frequency impedance measurements were continuously made from below the local electron cyclotron frequency to above the local plasma frequency, 100-to-290 km altitude. The electron density profile obtained from the antenna data agreed with the ground-based ionosonde profile taken during the flight. Two other experiments to determine local plasma frequency were also flown.

AURORA AND AIRGLOW

Airglow experiments carried out on sounding rockets have fallen into two broad categories. Early flights were of a survey nature. Scanning spectrophotometers were employed to identify airglow features that could not be detected from the ground either because of the opacity of the lower atmosphere in the ultraviolet or because of the bright background of scattered visual light during the daytime. With the main spectral features identified, recent studies have concentrated on determining altitude profiles of selected emissions. Normally filter photometers are employed as detectors in this work but spectrophotometers and specialized detectors have also been used.

In some cases, particularly where resonance lines and bands are under observation, the height profile of the emission rate gives the altitude distribution of the atmospheric constituent in question. Examples are: atmoic hydrogen, atomic oxygen, sodium, helium, oxygen molecules in the $a^1\Delta$ ground state (and indirectly ozone), nitric oxide, and ions of molecular nitrogen. In other cases, the variation in altitude of selected radiation features has been used very effectively to analyze the energy budget in the atmosphere. With the help of laboratory measurements of cross sections and rate constants it has been possible to determine from observed excitation rates the sequence of processes by which solar uv and x-ray energy is converted to heat. The importance of energetic photoelectrons, some of which even escape into the magnetosphere, was first realized as a result of this sort of analysis.

The history and present practice of auroral research with rockets parallels that of airglow studies. In the case of the aurora, however, it is necessary to equip the rocket payloads with particle detectors, energy spectrum analyzers, and electric and magnetic field sensors along with photometric devices. The objective of the research is to determine the nature and properties of the primary auroral particles and the source of their energy as well as to catalogue and analyze the processes involved in energy loss. Rockets, of course, provide the only means of rapidly traversing the entire region of energy transfer vertically or (approximately) along magnetic field lines. This kind of probing, particularly in the case of a steady aurora, is the only way to obtain information relating to the complete sequence of energy gain and loss processes.

Night and Late-Twilight Airglow

Naval Research Laboratory. An Aerobee flight from White Sands in October 1965 determined the variation of emission rate with altitude of the OI 5577 A and 6300 A forbidden lines. The (^1S - ^1D) green line emission occurs in two layers, most of it in the region near 100 km, the rest above 200 km. The lower layer is presumably photochemical in origin. (It would, however, require the presence of more than 10^{12} O atoms cm^{-3} at 97 km if the mechanism is the Chapman three-body association of atomic oxygen.) The upper layer coincides more or less with the (^1D - ^3P) red doublet layer. However, the assumption that both ^1S and ^1D terms have a common source in dissociative recombination of O_2^+ runs into difficulties. It appears that there must be a supplementary source for the red line. Another Aerobee experiment in March 1965 employing liquid-nitrogen-cooled photomultipliers succeeded in determining the altitude profile of three OH band systems in the 90-km region.

Johns Hopkins University. The height dependence of the OI resonance triplet (1302 to 1306 A) and Lyman-alpha airglow radiation were determined in an Aerobee experiment when the solar zenith angle was 105°.

Rice University. Upper Limits were set on the contribution of particle excitation of night airglow features such as the N_2^+ 3914 A first negative band. Simultaneous measurements were made of precipitating particle fluxes and airglow emission rates up to about 1000 km at night in a Javelin experiment flown from Wallops Island.

Utah State University. The program at this university has consisted of flying night airglow detectors on AFCRL rockets. Emission versus altitude profiles were obtained for the OI 5577 A, the OH (8,3) band and continuum (5775 A) radiations in an Aerobee launched from White Sands on April 28, 1966. The maximum in the OH emission rate was found to occur at 98 km which is rather high for the commonly accepted O_3, H reaction mechanism. As in the NRL experiments the green line absolute excitation rate, but not the altitude profile, is hard to understand in terms of the Chapman excitation mechanism in that more than 10^{12} atoms cm^{-3} are required. Similarly the continuum (peaking at about 90 km) is much too strong to be understood in terms of the NO,O reaction if reasonable values of NO and O densities and laboratory rate coefficients are assumed. In a Nike-Tomahawk experiment a 5577 A photometer and high energy electron detectors were flown. Only 10^{-8} R radiation from the excited OI were attributable to high energy electron collisions with O, whereas the O(^1S) excitation rate reached a value as high as 35 R km^{-1}.

Day Airglow

University of Colorado. The day airglow spectrum between 1100 and 3900 A has been measured in a number of Aerobee flights. The existence of a photoelectron-excited dayglow has been clearly demonstrated by the discovery of the molecular nitrogen second positive bands at 2973, 3157, 3370, 3576, and 3804 A. The 1356 A atomic oxygen line has been shown to be produced by photoelectron excitation as are the molecular nitrogen Lyman-Birge-

Hopfield bands at 1325, 1354, and 1384 A. The existence of the 1200 A atomic nitrogen line in the dayglow has been verified and the presence of the 1493 and 1743 A lines established. The gamma and delta bands of nitric oxide dominate the spectrum between 1750 and 2750 A. Horizon brightening and zenith-nadir intensity ratios of the atomic hydrogen 1216 A and atomic oxygen 1304 A lines have been measured. Most important, the dayglow emissions have been used as a tool to determine the density distribution of the atoms and molecules in the mesosphere and thermosphere.

Kitt Peak National Observatory. The day airglow spectrum from 3900 A to 1.27 microns has been the subject of intensive study from both the observational and theoretical points of view at the Kitt Peak National Observatory. Spectrometers flown on rockets have been used to identify the brightest emission features of the spectrum in this region. These are the first negative N_2^+ sequences at 3914 and 4278 A, the forbidden NI line at 5200 A, the forbidden OI lines at 5577, 6300 and 6364 A, the sodium resonance doublet at 5890 to 5896 A, the O_2 atmospheric bands at 7620 and 8645 A, the permitted OI lines at 7774 and 8446 A, a first positive N_2 band at 8912 A, and the sequence of $N+_2$ Meinel bands at 9200 A. Of these, only the red forbidden lines of OI and the lines of sodium have been observed from the ground. Rocket-borne photometers were subsequently used to obtain altitude profiles of those features at 3914, 5200, 5577, 6300 to 6364, 5890 to 5896, 7620 and 8645 A, which in turn have led to a better understanding of a number of atmospheric processes. The principal channels of excitation and de-excitation of the excited states leading to most of these emissions have been identified. In the case of the sodium doublet, the altitude distribution of sodium inferred was shown to imply the probable existence of a source of metal atoms in the form of dust in the mesosphere. A recent achievement was obtaining the vertical profile of O_2 ($^1\Delta$) and the identification of this species as an important source of ionization and chemical processes. A by-product was a deduction of O_3 density to 100 km.

Johns Hopkins University. A dayglow experiment using a scanning uv spectrophotometer in a Javelin launched from Wallops Island determined the variation of airglow emissions from about 250 km to 900 km. From the variation of Lyman-alpha with altitude it was inferred that telluric hydrogen is optically thick during a time of low exospheric temperature. From the variation of the OI resonance lines the oxygen density and the excitation rate by photoelectrons could be determined (see below, University of Pittsburgh).

University of Pittsburgh. In four Javelin flights from Wallops Island (1965-1968) a novel detector employing retarding potential analysis of photoelectrons measured the variation in altitude between 90 km and 1000 km of the resonance lines of H, O, O^+ and He. From these data the distribution of these atmospheric constituents was obtained with the help of radiative transport theory. In the case of He, it has been found that the density decreases more rapidly up to 600 km than expected for diffusive equilibrium. This theoretical analysis has also been used to interpret the results obtained in the Johns Hopkins experimental program.

An Aerobee experiment using a resonance cell detector measured with precision the distribution of sodium near 95 km in the daytime. A large daytime increase in sodium abundance was verified and the sodium found to be concentrated in a very thin layer. An aerosol layer has been suggested as the source of the sodium.

Aurora

Air Force Cambridge Research Laboratories. Seven rockets have been launched into active nighttime auroras at Fort Churchill since 1965. The energy spectra of electrons in the range from 2 to 50 keV, electron temperatures and densities, electric field strengths, and emission rates of OI 5577 A and N_2^+ 3914 A have been measured simultaneously. The ionic composition of the D, E, and F regions during auroras has also been determined with rocket-borne ion mass spectrometers. Among notable results obtained were the observation that NO^+ is the principal ion even as high as 150 km, the evidence that 0.5 eV of each 35 eV expended in ion pair creation goes into kinetic energy of the electron, and the observation of electric field strengths of 2 V m^{-1} during the passage of auroral line currents above the rocket.

Four rockets studied D- and E- region effects during daytime auroral absorption events. These probes showed that during these events the maximum in electron density descends to 90 km and the electron temperature at low altitudes rises to 6000 K.

Los Alamos Scientific Laboratory. Two Nike-Tomahawks were launched in 1965, one in 1966, and two in 1968 at Fort Churchill into diffuse post-breakup glows and arcs. Scanning uv spectrophotometers and visual photometers were carried in all flights. These have determined vertical profiles of emission rates in the Lyman-Birge-Hopfield system of N_2, Lyman-alpha OI (1304 A), NI (1200 A), the OI red and green lines, N_2^+ 3914 A and the second positive system of N_2. In the 1968 flights electron energy spectrometers were also flown. One of these indicated that the spectrum varied as E^{-1} from 0.5 to 27 keV.

University of Alaska. The rocket program at Fort Churchill has concentrated on optical studies. Emission features have been scanned in a plane perpendicular to the rocket spin axis. Three flights, including one Nike-Tomahawk whose apogee was 300 km, have yielded horizontal distributions of N_2^+ 3914 A, 4278 A and OI 5577 A and support ground-based data obtained at the University which indicate these distributions are different. The altitude profile of the Balmer beta line of hydrogen was measured in all flights. In the Tomahawk flight the ratio of the 6000 A to 5577 A OI emissions was measured continuously to 300 km.

University of Maryland. Optical emission features and electron energy spectra in diffuse auroral arcs have been measured at Fort Churchill. An enhancement in the electron flux below 200 eV near 140 km was detected that cannot be ascribed to secondary production by auroral primaries. Since such soft electrons cannot penetrate to 140 km an internal source seems to be required -- probably an electric field.

Johns Hopkins University - University of Pittsburgh. Beginning in 1965 one Aerobee each winter has been launched into post-breakup steady auroras at Fort Churchill by Johns Hopkins workers. During the past three years the payloads have been shared by Hopkins and Pittsburgh. Optical uv spectrophotometers, photometers for both visual and uv emissions, electron energy analyzers capable of scanning from rocket potential to 50 keV, and ion mass spectrometers have been flown in coordinated experiments. During the past two years a photometer which observes both upward and downward at 2972 A (OI ^1S - ^3P) has been used to help separate temporal from spatial variations.

The results have permitted a detailed study of the processes by which auroral primaries gain and lose energy. They have led to a theory that the OI 5577 A radiation is excited not by electron impact but predominantly by dissociative recombination. They have also shown the presence of large densities of He^+ ions below 120 km. A comparison of ion production rates with the densities of NO^+, O_2^+, O^+, and N_2^+ has led to the conclusion that the chemistry (and possibly composition) of the disturbed atmosphere differs radically from that of the normal atmosphere.

AERONOMY

Neutral Composition

The composition and structure of the upper atmosphere is determined by the action of the Sun on the mixture of gases that are held by the gravitational field of the Earth. The details of the composition and structure at any particular time and place are determined by the following physical phenomena: photodissociation and chemistry, diffusive and gravitational forces, vertical and horizontal mass transport, global and turbulent mixing, and changes in the energy input. To understand the interaction of these phenomena it is necessary to have a global picture of the distribution of the major constituents and of certain of the minor constituents as well. The reactions between the chemically active species are coupled so that the measurement of one species very often leads to the determination of the abundances of others.

Rockets can uniquely measure the vertical profile of all of the neutral species of the atmosphere. In the region between 60 and 120 km small rockets are used. It is necessary to measure not only the major constituents, molecular nitrogen, molecular oxygen, and atomic oxygen, but such minor constituents as electronically excited molecular oxygen, ozone, and nitric oxide. The measurements of the vertical profile of these species as a function of geographic location and time provides the basic data for understanding the motions and energy balance of the atmosphere, and the formation of the ionosphere in this region.

In the thermosphere between 120 and 300 km, larger rockets measure the vertical profiles of the atomic as well as the molecular constituents. Since this is the region where diffusive equilibrium is established, the composition here determines the composition of the entire atmosphere above.

Rocket measurements of the vertical profiles as a function of geographic location and time provide the data needed to determine the influence of conditions at the bottom of the diffusion region on the entire atmosphere.

NASA Goddard Space Flight Center - University of Michigan.

Since the middle of 1965 five flights have been made carrying mass spectrometers in thermospheric probes: a day-night pair at Fort Churchill in November 1965; a day-night pair at Wallops Island in August 1966; a single flight at Wallops Island in July 1967. Four more launchings are scheduled for early 1968 in Puerto Rico in conjunction with simultaneous ionospheric measurements by the Arecibo radar. The mass spectrometer in a thermospheric probe is a small omegatron permanently tuned so as to measure molecular nitrogen. The instrument itself is contained in a small chamber which connects to the ambient atmosphere through a sufficiently large hole so that the gas in the chamber is always in equilibrium with the atmosphere as the thermoprobe tumbles during its trajectory. Incoming gases are "thermalized," and there is a calculable relationship between the measured density of particles in the chamber and that in the ambient atmosphere.

The thermospheric probe measurements provided useful data on the nitrogen concentration in the altitude range from approximately 150 to 300 km. From scale height measurements, temperature was determined. The program is regarded as closely related to future satellite experiments. A neutral mass spectrometer of the same type as flown on Explorers 17 and 32 was used in the geoprobe experiment. The ion source in the experiment was surrounded by a silver-oxide-coated thermalization chamber in an attempt to enhance atomic oxygen recombination. While the oxygen measurements were only partially successful, molecular nitrogen and helium measurements proved satisfactory. The N_2 profile appeared about as expected and agreed well with one obtained by uv absorption on a companion flight. The helium profile showed a very low scale-height in the lower thermosphere, suggesting that helium was not in diffusive equilibrium at altitudes below about 200 km.

University of Michigan. Quadrupole mass spectrometers have been flown with exposed ion sources, and have found that atomic oxygen is higher in the daytime than at night and is less at high latitudes. Measurements have been taken at Fort Churchill, Wallops Island, and near the Equator. Ar/N_2 separation ratios suggest that the turbopause occurs between 100 and 105 km.

Based on altitude rates of change in ratios of selected pairs of constituents, rather than on absolute abundance measurements of particular species, it is concluded that mid-latitude temperatures are higher than those given in CIRA models or those published by the University of Minnesota group. A falling sphere experiment was flown at approximately the same time to compare with calculated mass numbers yielding close agreement.

In an experiment launched August 8, 1967 at White Sands, in which a POGO-type mass spectrometer was employed, values of the N/N_2 ratio suggest a ratio lying considerably above the values previously assumed. O/O_2 ratios are in the general range of those measured in 1963 and 1965 at White Sands by the Minnesota group. In ion measurements made during the same flight, ions are observed at masses 23, 24, and 25. These are attributed to Na+ and Mg+.

Six thermoprobes were flown at the Eastern Test Range in Florida, January 1967, to study the diurnal variation of N_2 density and temperature profiles, and electron densities and their temperature profiles. Another pair of rockets to study diurnal types was launched in April 1967. These experiments show N_2 densities about half those derived from satellite drag data. Results agree with the CIRA 1965 nighttime temperatures but are lower than CIRA 1965 daytime temperatures. Measured temperatures below 200-km altitude varied more than current model atmospheres would predict. Empirical formulas derived by Jacchia, giving exospheric temperatures as a function of several different parameters, agree with the mass spectrometer results.

University of Minnesota. Seven Aerobee flights at the White Sands Missile Range have been flown since early 1965. In each case the rocket carried three magnetic deflection mass spectrometers to observe neutral composition. The mass range 3 to 50 amu was covered. One of the instruments had its ion source exposed directly to the atmosphere in order to measure atomic oxygen. The other two instruments had their ion sources inside of a chamber connected to the ambient atmosphere through a hole, the expectation being that incoming particles would be "thermalized" before being measured by the spectrometers, and hence there would be a better known relationship between measured and ambient densities than would be possible with the open ion source instrument.

In general, N_2, O_2, and Ar concentrations agreed well between flights. Atomic oxygen varied from flight to flight, and in a day-night pair in late 1966, the nighttime atomic exygen actually was higher than the daytime. Helium concentrations also varied from flight to flight, the highest values being reported for the late 1966 flights. Except for helium, all the other constituents appeared to be in diffusive equilibrium above 120 km. Helium concentrations fell off with altitude much faster than is predicted if diffusive equilibrium prevailed. Atmospheric temperature determinations were attempted from both scale-height calculations and from the modulation of data as a result of rocket spin. Unlike a similar 1963 flight when there was excellent agreement between the spin-determined temperature and that found from scale-height measurements, the newer measurements do not show such good agreement.

Incidental to the flights, a comprehensive program of mass spectrometer development and improvement has been conducted with the result that in the future much more accurate measurements of neutral concentrations should be feasible.

University of Colorado. The ultraviolet dayglow between 1150 and 1450 A was measured from an Aerobee rocket in April 1966. The results showed that it is possible to measure the density distribution of molecular nitrogen and atomic oxygen in the thermosphere from the photoelectron-excited dayglow. This technique is directly applicable to a satellite experiment where it would be possible to continuously measure both the height and latitude variations of the major constituents in the thermosphere.

The uv dayglow at 2150 A was used to determine the nitric oxide density as a function of height. The data were obtained from a Nike-Apache rocket flown in December 1967 from Wallops Island, Virginia. This data will be used to determine the mechanisms creating and destroying nitric oxide between 60 and 85 km.

An Aerobee launched from White Sands Missile Range in October 1967 measured the solar Lyman-alpha profile. This measurement has been used to determine the density distribution of atomic hydrogen as a function of height.

Air Force Cambridge Research Laboratories. Since mid-1965, the rocket program has continued to extend experimental information on solar extreme ultraviolet radiation and its dissipation in the Earth's upper atmosphere. Many results on the euv spectrum and atmospheric absorption analysis have been published. The planning of the rocket experiments of March 1967 and later has emphasized the acquisition of data in support of satellite observations made during this period (OSO-3: AFCRL spectrometer for wavelengths 260 to 1300 A and GSFC spectrometer for wavelengths 400 A; OSO-4: Harvard spectrometer for wavelengths 500 to 1300 A). Nevertheless, information on absolute fluxes still rests on the rocket results even for the periods of successful operation of OSO-3 and OSO-4.

Rocket measurements of ionospheric electrons in the non-Maxwellian part of their energy distribution (up to 20 eV) have recently been made and have been subjected to a greatly improved interpretational theory. Results on electron energy distribution functions ranging from energies of $E \sim 20$ eV (for the height range from about 120 to 230 km) are currently in progress toward publication.

The structure and composition of the 90-to-200 km altitude region has been studied by the chemical seeding technique. Diffusion coefficients are obtained from the radial growth of chemiluminous and fluorescent trails and clouds. Temperatures are obtained from the vibrational-rotational spectrum of aluminum oxide clouds. Densities are computed from D and T. Atomic oxygen concentrations and profiles are obtained from the radiant intensity of nitric oxide trails. The latter trails also permit estimates of total density from the initial jet diameter.

Since mid-1965 about 10 rocket releases of TMA and NO have been carried out, resulting in estimates of evening-to-morning, summer-to-winter, and year-to-year variation of some atmospheric properties at a particular latitude. In addition, the diurnal variability of molecular oxygen density between 90 and 105 km has been measured by the technique of absorption spectroscopy.

Meteorology

While meteorology may be broadly defined as the study of atmospheres and their phenomena, discussion is restricted here to the motion, temperature, pressure, and density of the neutral atmosphere. The phenomena displayed in these quantities involve a wide range of temporal and spatial scales: from seconds to years, and from meters to planetary dimensions. These phenomena are dynamic, their energy deriving for the most part from solar radiation absorbed by the ground, water vapor, ozone, and molecular oxygen. On the long time scale the general circulation of the atmosphere can be considered to consist primarily of a zonal wind whose coriolis acceleration is in balance with the north-south pressure gradient resulting primarily from similar gradients in solar heating, but significantly influenced by secondary meridional circulations and mean fluxes due to smaller scale motions (sometimes called eddies). Other long-period phenomena of great interest are the approximately 26-month oscillation which dominates the zonal wind in the equatorial stratosphere and the semiannual oscillation which dominates the zonal wind in the equatorial mesosphere. On shorter time scales (about one week) are the sudden warmings of the winter stratosphere and the potentially related planetary-scale waves, associated with weather disturbances, which propagate to great heights. At still shorter scales are tides generated primarily by daily variations in insolation absorption by water vapor, ozone, and molecular oxygen; internal gravity waves whose precise origin is uncertain but which are at least in part generated by flow over mountains and by weather disturbances; and turbulence whose origins and nature are still relatively unknown. These short-scale phenomena become increasingly important in the upper mesosphere and above. The physics of these phenomena is complex and involves, in various regions of the atmosphere, infrared radiative cooling, ozone photochemistry, ion drag resisting motion across field lines, and other processes.

Given this complexity of meteorological processes, much of our knowledge must be derived from direct observation. However, the atmospheric behavior we describe is defined by the details of its temporal and spatial variations, and hence cannot be properly described by isolated observations. Programs of frequent observations at many locations are essential. Thus the development of reliable, reproducible, inexpensive, and easy-to-use instrumentation assumes special importance.

Meteorological studies of the atmosphere below 35 km have used surface instruments, balloons, and indirect sensing from satellites. Satellite drag measurements have been invaluable in studying the variations in density of the atmosphere above 200 km. Between 35 and 200 km rockets (and more recently, gun-launched probes) have been the principal, though by no means the only, tool for sounding the atmosphere. This region, which covers the upper stratosphere, mesosphere, and lower thermosphere, forms an important bridge between the lower atmosphere which is primarily influenced by conditions at the Earth's surface, and upper atmosphere which is directly influenced by conditions on the Sun. The meteorology of this region is of great practical importance for it influences the composition, including the ionization distribution (and hence radio properties) within the region and the flight of vehicles through the region. The region also displays a variety of intrinsically interesting phenomena.

The last three years have seen important progress in the development of instrumentation (including cost reduction and simplication of use), establishment of network coverage, data analysis, new discoveries, and developments in theoretical understanding.

Instrumentation

The use of TMA (trimethyl aluminum) to provide chemiluminescent trails for obtaining detailed wind profiles has become routinely operational at AFCRL, GCA, ESSA, and elsewhere. More specific achievements include the following:

GCA Corporation. At GCA a method of triangulation photography of vapor trails from airplanes has been developed and used. The technique avoids certain weather problems. Attempts to use vapor trails to measure temperatures directly are being made at GCA and NASA. GCA scientists, in this connection, examined the fluorescence of sunlit aluminum oxide in September 1966 at Fort Churchill. A heating rate of 7 K min^{-1} was claimed to be associated with an aurora during that period.

NASA Langley Research Center. Rocket smoke trail methods have been developed to study detailed characteristics of wind up to altitudes of 20 to 25 km. Accuracy appears to be better than that obtained by routine sounding balloons. This represents a rare application of rocketry to research on the lower atmosphere.

The search for new chemiluminescent agents continues. TML (trimethyel lead) is being investigated at Langley Research Center and elsewhere.

Environmental Science Services Administration - White Sands Missile Range. These and other groups have been developing gun-launched probes. Sequences of nighttime wind profiles between 90 and 120 km have been obtained using gun-launched vapor trail systems by the Army at Yuma, Arizona. For experiments requiring frequent, multiple ascents, the probes show evidence of being as good as and cheaper than rockets.

Air Force Cambridge Research Laboratories. Grenade techniques are being combined with TMA techniques to permit temperature soundings in the region 100 to 150 km. A tri-axis accelerometer sphere for use in the mesosphere and lower thermosphere has also been developed at AFCRL. It can be used with a Sparrow-Arcas vehicle for relatively inexpensive synoptic measurements of density.

White Sands Missile Range. Scientists associated with the Range have developed, for use in the Meteorological Rocket Network, a rocket-borne parachute wind-measuring system with a claimed accuracy of $\pm$ 3 m sec^{-1} from

25 to 55 km, a thermistor bead temperature sensor with a claimed accuracy of ± 2° from 25 to 55 km and ± 5° from 55 to 65 km, and a chemiluminescent rocket ozonesonde with a claimed accuracy of ± 10 percent from 25 to 65 km. These accuracies have been a major source of controversey in the meteorological community.

Observations

NASA - Meteorological Rocket Network. NASA is conducting rocket launchings from ships to obtain much needed meteorological data in the Southern Hemisphere. The Meteorological Rocket Network (centered at WSMR) has expanded its coverage and Southern Hemisphere data are now available. Both the MRN and NASA have obtained rocket data during stratospheric warmings and noctilucent cloud occurrences. NASA data show these clouds to be associated with mesopause temperatures of about 140 K. Closely spaced (in time) soundings have been made by the MRN at various stations to investigate tidal variations, and NASA has taken pairs of soundings approximately 12 hours apart for similar purposes. Twelve-hour temperature differences as large as 100°C near 100 km were noted with high temperatures at night at some altitudes (in agreement with theory, see GCA section below). The MRN has carried out a special series of soundings to study high latitude mesospheric winds in summer.

GCA Corporation. Sequences of closely spaced vapor trail soundings have been performed by GCA to examine the time development of wind structure. They found that the usual spiral profiles often appear to collapse in a period of six hours -- suggesting the nonlinear breakdown of tidal fields.

White Sands Missile Range. The WSMR has fired its ozone rocketsonde several times; results show a secondary ozone maximum between 35 and 45 km, at variance with all previous observations and theoretical studies.

University of Michigan. Comparison soundings using sphere, grenade, and Hasp systems by the High Altitude Engineering Laboratory produced discrepancies which suggest the possibility of vertical winds as large as 3 m sec^{-1} in the stratosphere.

Analysis

U. S. Weather Bureau. MRN data have been used by the Upper Air Branch to prepare weekly constant pressure maps up to 0.4 mb (~ 55 km). Partially automated procedures have also been developed to convert these maps to constant-level analyses. Such maps are invaluable for studies of sudden warmings, interhemispheric relations, and the general circulation. Rocket data have been analyzed by this group to obtain information on small-scale wind and apparent temperature oscillations, diurnal variations, and other parameters. Observations of pressure, density, and temperature at different altitudes, together with the hydrostatic pressure relation, have led to semi-empirical formulae for altitude variations in density. This, however, remains a major area of controversy, with scientists at AFCRL and elsewhere interpreting matters differently.

Massachusetts Institute of Technology. A group at MIT has investigated small-scale wind structure between 30 and 70 km using data from rocket-borne Robin balloons and smoke trails. NASA has performed similar analyses below 25 km with smoke trail data.

GCA Corporation. The time evolution of vapor trails has been analyzed for evidence of turbulence. Both the early diffusion of the trail and the later development of irregularities are claimed to be inconsistent with theoretical expectations.

University of Washington. MRN and other rocket data have been used to detect and describe the semi-annual zonal wind oscillation that appears to dominate the circulation in the equatorial mesosphere. MRN data have also been applied to describe the diurnal and semi-diurnal tidal winds in the stratosphere and mesosphere. Attempts to extend these analyses to higher altitudes with data from gun-launched probes are in progress.

University of Chicago. Vapor trail measurements of wind at dawn and sunrise have permitted estimates of the contribution of the diurnal tide at heights between 90 and 130 km.

Theory

Harvard University. On the basis of vapor trail wind soundings from GCA, the possibility of gravity shocks is proposed.

University of Chicago. MRN observations of strong diurnal oscillations led to the development of a classically based theory of the diurnal tide. The presence of a semi-annual wind cycle in the equatorial mesosphere, detected by rockets, plays an important role in a recently developed theory of the quasi-biennial cycle in the lower atmosphere.