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FINAL REPORT

ROCKET STUDIES OF THE LOWER IONOSPHERE

Sidney A. Bowhill, Principal Investigator

NASA NGR 14-005-181

Period: August 1, 1971 to February 18, 1989

Prepared for
Louise Bozman
NASA Goddard Space Flight Center
Wallops Flight Facility
Wallops Island, Virginia 23337

Submitted by

Department of Electrical and Computer Engineering
College of Engineering
University of Illinois at Urbana-Champaign
1406 West Green Street
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TABLE OF CONTENTS

1. INTRODUCTION

The ionosphere, in the altitude range of 50 to 200 km, has been investigated, in this program, by rocket-borne sensors, supplemented by ground-based measurements. The rocket payloads, carried on vehicles ranging from the Nike-Apache to the Taurus-Orion, have included mass spectrometers, energetic particle detectors, Langmuir probes and radio-propagation experiments. Where possible, particularly in the later years of the project, the rocket flights have been included in campaigns studying a specific phenomenon, where the availability of data from other experiments has greatly increased the significance of the results.

The principal ionospheric phenomena studied during the course of this program have been:

Winter anomaly in radiowave absorption

Ozone and molecular oxygen densities

Mid-latitude sporadic-E layers

Energetic particle precipitation at middle and low latitudes

Ionospheric instabilities and turbulence

Solar eclipse effects in the D and E regions

The experimental program began in 1962, when the Aeronomy Laboratory was established within the Department of Electrical Engineering (as it then was) of the College of Engineering at the Urbana-Champaign campus of the University of Illinois. The grant, NASA NGR 14-005-181, began on August 1, 1971, with an initial period of one year. It was followed by 35 supplements, 18 of which did not involve additional cost. The grant was terminated on February 28, 1989.

In the following sections of this final report we present details of the technical personnel who participated in the program and a compilation of publications from the Aeronomy Laboratory, most of which, from 1971 onward, are partially, if not totally, supported by the NASA grant.

2. PERSONNEL

The program covers a span of more than 17 years. In that period 23 staff members and 76 graduate students have participated. (Two of the graduate students subsequently became staff members.) The graduate students earned 64 M.S. degrees and 19 Ph.D. degrees.

The professors and academic professionals who contributed to the science and engineering of the project are listed in Table 2.1. Only the Principal Investigator participated for the full duration of the grant. Others were full-time or part-time contributors over periods ranging from part of a year to many years. It should be noted that the qualifier "visiting" implies a quasi-temporary position; it does not, except in a few cases, imply that the person held a permanent position elsewhere.

The graduate students who participated in the program are listed in Table 2.2. This table also gives the year in which the graduate student received the M.S. and/or Ph.D. degree. Students earned the degrees mainly from the Department of Electrical and Computer Engineering (the graduate degrees are only in Electrical Engineering) although a few are from the Department of Physics.

Each thesis (with very few exceptions) was published as an Aeronomy Report and most became the basis of a paper in a major journal.

Table 2.1: Professors and Academic Professionals

Susan R. Avery	Assistant Professor
Sidney A. Bowhill	Professor, Principal Investigator
Prakash M. Dolas	Visiting Research Associate
Jane Fox	Assistant Professor
Jay D. Gooch	Research Engineer
Kenneth G. Gray	Visiting Research Associate
George W. Henry, Jr.	Research Engineer
Stanley W. Henson	Research Engineer
Lorenzo J. Johnson	Senior Research Engineer
Thomas W. Knecht	Research Engineer
Paul Lehmann	Visiting Research Associate
Eugene A. Mechtly	Associate Professor
Peter E. Monro	Visiting Research Associate
P. K. Rastogi	Visiting Research Associate
Ola Royrvik	Visiting Research Associate
Stephen Schutz	Research Associate
Chalmers F. Sechrist, Jr.	Professor
Tatsuo Shimazaki	Visiting Professor
Leslie G. Smith	Professor
Henry D. Voss	Visiting Research Associate
Eric K. Walton	Visiting Research Assistant Professor
David R. Ward	Research Engineer
David S. Wratt	Visiting Research Associate

Table 2.2: Graduate Research Assistants

Abert, James R.	M.S. 1975	
Allman, Michael E.	M.S. 1976	
Backof, Charles A., Jr.	M.S. 1974	
Barnes, Bruce C.	M.S. 1978	
Bean, Thomas A.	M.S. 1973	
Bliss, Harry M.	M.S. 1980	
Braswell, Frank M.	M.S. 1981	
Cerny, Timothy M.	M.S. 1980	
Countryman, Ian D.	M.S. 1973	Ph.D. 1979
Damico, Dennis F.	M.S. 1972	
Davis, Lemuch L.	M.S. 1979	
Davis, Roger L.	M.S. 1985	
Dean, Lloyd	M.S. 1982	
Denny, Ben W.	M.S. 1973	
Denslow, David A.	M.S. 1977	
Dettro, Gregory J.	M.S. 1983	
Dinschel, Duane E.	M.S. 1987	
Durkin, Christopher	M.S. 1981	
Enge, Per K.	M.S. 1979	Ph.D. 1983
Evans, John C.	M.S. 1975	
Fildes, Roger D.	M.S. 1976	Ph.D. 1979
Fillinger, Rudolph W., Jr.	M.S. 1976	
Fries, Keith L.	M.S. 1980	
Gaffigan, Robert J.	(incomplete)	
Gibbs, Kenneth P.	M.S. 1980	Ph.D. 1983
Gilchrist, Brian E.	M.S. 1979	
Ginther, Jack C.	M.S. 1975	
Golshan, Nasser	—	Ph.D. 1974
Grossman, Barry G.	M.S. 1973	Ph.D. 1977
Guha, Dipak	(M.S. 1968)	Ph.D. 1972
Halpern, Benjamin M.	M.S. 1982	
Harper, Richard M.	M.S. 1974	
Harrington, Timothy A.	M.S. 1975	
Henton, Raymaud F.	M.S. 1973	
Herrington, Lawrence, Jr.	M.S. 1983	
Hess, Garry C.	—	Ph.D. 1976
Hill, Reginald	—	Ph.D. 1976
Houshmand, Bijan	M.S. 1985	
Hull, Clayton	(incomplete)	
Josephs, Louis C.	M.S. 1982	
Kinter, Thomas M.	M.S. 1977	
Klaus, Douglas E.	M.S. 1979	
Klein, Richard K.	M.S. 1979	
Kruczek, Jerome A.	(incomplete)	
Kwong, Yu-Hong	M.S. 1980	
Lee, Warren	M.S. 1973	
Leung, Wing Yu	M.S. 1979	
Loane, Joseph T., III	M.S. 1982	Ph.D. 1986
Lodato, Robert F.	M.S. 1971	
Martz, John H.	M.S. 1974	
McEwen, Robert S.	M.S. 1982	

McInerney, Michael K.	M.S. 1984	
Miller, Kent L.	—	Ph.D. 1977
Mueller, Walter J.	M.S. 1981	
Munninghoff, Donald E.	M.S. 1974	Ph.D. 1978
Owens, William R.	M.S. 1975	
Paarmann, Larry D.	M.S. 1977	
Padgitt, David G.	M.S. 1985	
Parker, Jay W.	M.S. 1986	Ph.D. 1989
Pliskin, Joel A.	M.S. 1979	
Pozzi, Michael A.	M.S. 1979	
Richter, Eric S.	M.S. 1973	Ph.D. 1978
Ryan, Patrick M.	(incomplete)	
Samples, John C.	M.S. 1977	
Schoeberl, Mark R.	M.S. 1973	Ph.D. 1976
Shelton, John D.	M.S. 1979	Ph.D. 1982
Silva, Luiz Costa da	—	Ph.D. 1974
Stoltzfus, Rodney B.	M.S. 1985	
Teitelbaum, Kenneth	M.S. 1979	
Tomei, Bruce A.	M.S. 1986	
Voss, Henry D.	M.S. 1974	Ph.D. 1977
Ward, David R.	(incomplete)	
Weiland, Richard M.	M.S. 1978	Ph.D. 1982
Wiersma, Daniel J.	M.S. 1972	
Wiesenmeyer, Frank M.	(M.S. 1969)	
Yurkovich, Dale A.	(incomplete)	

3. PUBLICATIONS

The results of research in the Aeronomy Laboratory, including those from NASA NGR 14-005-181, are initially published as Aeronomy Reports. In most instances these are graduate student theses with the thesis advisor included as co-author.

A complete list of Aeronomy Reports is given in Table 3.1. In addition to the reports derived from theses, there are several which represent conference proceedings. These are easily identified: the authors are specified as editors.

It has been the policy in the Aeronomy Laboratory to make the research results available more generally by publication in refereed journals of international repute. The Aeronomy Report then serves as a useful repository of the details of the instrumentation and of computer programs, for instance, which are not allowed in journal articles. The paper also allows for expansion in the discussion of the results.

A complete list of papers emanating from the Aeronomy Laboratory is given in Table 3.2. Again it is not practical to separately identify all of those which were partially or totally supported from the NASA grant.

Table 3.1: Aeronomy Reports

1. Bowhill, S. A. (Ed.), December 1963, Direct aeronomic measurements in the lower ionosphere – An informal record.
2. Balmain, K. G., July 1964, The impedance of a short dipole antenna in a magnetoplasma.
3. Hodges, R. R., Jr., November 1964, Gyro-interaction rocket experiments in the lower ionosphere.
4. Rzeszewski, T. S., and S. A. Bowhill, January 1965, The design and operation of a pulse compression system.
5. Geisler, J. E., and S. A. Bowhill, January 1965, An investigation of ionosphere-protonosphere coupling.
6. Rao, G. L. N., June 1965, Horizontal drifts and anisotropy of irregularities in the lower lonosphere – A review.
7. Appel, R. L., and S. A. Bowhill, September 1965, An automatic recording system for the determination of ionospheric absorption.
8. Kostelnicek, R. J., September 1965, The admittance and resonance probe characteristics of a spheric plasma probe.
9. Rao, G. L. N., June 1966, Horizontal drifts and anisotropy of irregularities in the upper ionosphere – A review.
10. Sechrist, C. F., Jr., and J. S. Shirke (Eds), December 1965, Second conference on direct aeronomic measurements in the lower ionosphere – An informal conference record.
11. Balmain, K. G., May 1966, Plasma probe studies.
12. Gliddon, J. E. C., June 1966, Theoretical investigations of the structure of the protonosphere and upper F region.
13. Henry, G. W., Jr., August 1966, Instrumentation and preliminary results from shipboard measurements of vertical incidence ionospheric absorption.
14. Salah, J. E., and S. A. Bowhill, August 1966, Collision frequencies and electron temperatures in the lower ionosphere.
15. Paramasivaiah, P., and S. A. Bowhill, August 1966, E-region ionization and thermal structure.
16. Wippermann, D. R., March 1967, The application of pulse compression techniques to ionosphere sounding.
17. Evans, J. V., April 1967, Design considerations for a Thomson scatter radar.
18. Subcommittee on Aeronomy, Committee on Institutional Cooperation, May 1967, Program study for a Thomson scatter radar.

19. Evans, J. V., (Ed), May 1967, Thomson scatter studies of the ionosphere – An informal conference record.

20. Rao, M. M., 1967, Studies of the equatorial ionosphere using rockets.

21. Cicerone, R. J., and S. A. Bowhill, June 1967, Positive ion collection by a spherical probe in a collision-dominated plasma.

22. Shirke, J. S., September 1967, Studies of ionospheric absorption measurements.

23. Evans, J. V., October 1967, Antenna design for a Thomson scatter radar.

24. Evans, J. V., and S. A. Bowhill, January 1968, Plan for the implementation of a Thomson scatter radar.

25. Evans, J. V., June 1968, Antenna feasibility studies for a Thomson scatter radar.

26. Fish, R. M., and S. A. Bowhill, June 1968, Instrumentation for the measurements of airglow.

27. Guha, D., August 1968, Studies of lower ionosphere drifts by the three-receiver technique.

28. Mantas, G. P., J. V. Evans, and J. V. Ceferin, August 1968, F-region theory: Part 1, The thermal structure of the ionosphere; Part 2, The shape of the daytime ionospheric F2 layer.

29. Pirnat, C., and S. A. Bowhill, December 1968, Electron densities in the lower ionosphere deduced from partial reflection measurements.

30. Condon, R. C., K. Seino, and E. A. Mechtly, December 1968, Part 1, Design of polarization adjustment instrumentation for a rocket propagation experiment, Part 2, Analysis of a rocket experiment to measure ionospheric electron density.

31. Shere, K. D., and S. A. Bowhill, January 1969, Gravity waves in a viscous atmosphere.

32. Sechrist, C. F., Jr. (Ed), April 1969, Meteorological and chemical factors in D-region aeronomy.

33. Viertel, W. A., and C. F. Sechrist, Jr., June 1969, Full-wave calculation of reflection coefficients from D-region electron density profiles.

34. Forbes, J. M., January 1970, Production and loss of $O(^1D)$ in the nighttime F region.

35. Slekys, A. G., and E. A. Mechtly, March 1970, Aeronomy Laboratory system for digital processing of rocket telemetry tapes.

36. Reynolds, D. A., and C. F. Sechrist, Jr., May 1970, Measurement of average electron density between 75 and 80 kilometers.

37. Mechtly, E. A., P. E. Monro, N. Golshan, and R. S. Sastry, July 1970, FORTRAN programs for calculating lower ionosphere electron densities and collision frequencies from rocket data.

38. Radicella, S. M., and D. W. Stowe, July 1970, D-region ion chemistry.

39. Cicerone, R. J., and S. A. Bowhill, September 1970, Monte Carlo and Thomson-scatter plasma-line studies of ionospheric photoelectrons.

40. Forbes, J. M., and M. A. Geller, October 1970, Lunar semidiurnal component of the OI (5577 A) airglow.

41. Turco, R. P., and C. F. Sechrist, Jr., December 1970, An investigation of the ionospheric D-region at sunrise.

42. Birley, M. H., and C. F. Sechrist, Jr., June 1971, Partial-reflection data collection and processing using a small computer.

43. Horton, B. E., and S. A. Bowhill, August 1971, Computer simulation of supersonic rarefied gas flow in the transition region, about a spherical probe; a Monte Carlo approach with application to rocket-borne ion probe experiments.

44. Carpenter, L. A., and S. A. Bowhill, September 1971, Investigation of the physics of dynamical processes in the topside F region.

45. Lodato, R. F., and E. A. Mechtly, September 1971, Rocket measurements of electron collision frequency.

46. Wuebbles, D. J., T. Shimazaki, and C. F. Sechrist, Jr., January 1972, A mathematical model for the radon density distribution in the 1-20 km region.

47. Wiersma, D. J., and C. F. Sechrist, Jr., March 1972, Differential phase measurements of D-region partial reflections.

48. Sechrist, C. F., Jr., and M. A. Geller (Eds), June 1972, COSPAR Symposium on D and E-region ion chemistry – An informal symposium record.

49. Damico, D. F., and S. A. Bowhill, May 1972, Monte Carlo studies of ion collection in a supersonic flowing plasma.

50. Guha, D., and M. A. Geller, June 1972, Computer simulation of the three-receiver drift experiment.

51. Oliver, W. L., and S. A. Bowhill, February 1973, Investigation of the ionospheric response to the solar eclipse of 7 March 1970 by the Thomson scatter radar technique at the Millstone Hill ionospheric observatory.

52. Lee, W., and M. A. Geller, March 1973, Preliminary design study of a high resolution meteor radar.

53. Slightam, R. J., and S. A. Bowhill, May 1973, Improved calibration of incoherent-scatter electron densities from ionograms.

54. Mantas, G. P., September 1973, Electron collision processes in the ionosphere.

55. Bean, T. A., and S. A. Bowhill, October 1973, Analysis of partial-reflection data from the solar eclipse of July 10, 1972.

56. Denny, B. W., and S. A. Bowhill, October 1973, Partial-reflection studies of D-region winter variability.

57. Countryman, I. D., and S. A. Bowhill, October 1973, Investigation of incoherent-scatter spectral asymmetries in the topside F region.

58. Gray, K. G., and S. A. Bowhill, January 1974, The transient response of stratified cold plasma electromagnetic waves by analytical and numerical methods.

59. Backof, C. A., and S. A. Bowhill, April 1974, Collection and processing of data from a phase-coherent meteor radar.

60. Harper, R. M., and S. A. Bowhill, July 1974, Digital ionosonde studies of F-region waves.

61. Golshan, N., and C. F. Sechrist, Jr., September 1974, An investigation of odd nitrogen in the ionospheric E region.

62. Voss, H. D., and L. G. Smith, October 1974, Design and calibration of a rocket-borne electron spectrometer for investigation of particle ionization in the nighttime midlatitude E region.

63. daSilva, L. C., and S. A. Bowhill, October 1974, An evaluation of the partial-reflection technique and results from the winter 1971-1972 D region.

64. Ginther, J. C., and L. G. Smith, December 1974, Studies of the differential absorption experiment.

65. Harrington, T. A., and M. A. Geller, March 1975, Performance of the University of Illinois meteor-radar system – A preliminary report.

66. Evans, J. C., and L. G. Smith, April 1975, Rocket measurements of ozone and molecular oxygen by absorption spectroscopy.

67. Ratnasiri, P. A. J., and C. F. Sechrist, Jr., April 1975, An investigation of the solar zenith angle variation of D-region ionization.

68. Rastogi, P. K., and S. A. Bowhill, April 1975, Remote sensing of the mesosphere using the Jicamarca incoherent-scatter radar.

69. Owens, W. R., and S. A. Bowhill, May 1975, Measurement of electron densities below 70 km by partial reflections.

70. Schoeberl, M. R., and M. A. Geller, January 1976, The propagation of planetary-scale waves into the upper atmosphere.

71. Allman, M. E., and S. A. Bowhill, February 1976, Feed system design for the Urbana incoherent-scatter radar antenna.

72. Ryan, P. D., and S. A. Bowhill, April 1976, Error analysis of radial wind velocity measurements using the University of Illinois meteor radar.

73. Fillinger, R. W., Jr., E. A. Mechtly, and E. K. Walton, July 1976, Analysis of sounding rocket data from Punta Chilca, Peru.

74. Hess, G. C., and M. A. Geller, October 1976, The Urbana meteor-radar system: Design, development, and first observations.

75. Hill, R. J., and S. A. Bowhill, November 1976, Small-scale fluctuations in D-region ionization due to hydrodynamic turbulence.

76. Miller, K. L., and L. G. Smith, December 1976, Midlatitude sporadic-E layers.

77. Paarmann, L. D., and L. G. Smith, May 1977, A rocket-borne airglow photometer.

78. Voss, H. D., and L. G. Smith, November 1977, Energetic particles and ionization in the nighttime middle and low latitude ionosphere.

79. Richter, E. S., and C. F. Sechrist, Jr., May 1978, Theoretical and experimental studies of the atmospheric sodium layer.

80. Klaus, D. E., and L. G. Smith, June 1978, Rocket observations of electron-density irregularities in the equatorial ionosphere below 200 km.

81. Weiland, R. M., and S. A. Bowhill, September 1978, D-region differential-phase measurements and ionization variability studies.

82. Pozzi, M. A., L. G. Smith, and H. D. Voss, February 1979, A rocket-borne electrostatic analyzer for measurement of energetic particle flux.

83. Leung, W., L. G. Smith, and H. D. Voss, March 1979, A rocket-borne pulse-height analyzer for energetic particle measurements.

84. Davis, L. L., L. G. Smith, and H. D. Voss, April 1979, A rocket-borne data-manipulation experiment using a microprocessor.

85. Gilchrist, B. E., and L. G. Smith, April 1979, Rocket measurement of electron density in the nighttime ionosphere.

86. Munninghoff, D. E., April 1979, Ion and electron temperatures in the topside ionosphere.

87. Enge, P. K., and S. K. Avery, May 1979, Day-to-day variations of atmospheric tides as observed by meteor radar.

88. Teitelbaum, K., and C. F. Sechrist, Jr., June 1979, A microcomputer control system for the Urbana sodium lidar.

89. Countryman, I. D., and S. A. Bowhill, October 1979, Wind and wave observations in the mesosphere using coherent-scatter radar.

90. Gibbs, K. P., and S. A. Bowhill, December 1979, The Urbana coherent-scatter radar: Synthesis and first results.

91. Fries, K. L., L. G. Smith, and H. D. Voss, December 1979, A rocket-borne energy spectrometer using multiple solid-state detectors for particle identification.

92. Zimmerman, R. K., Jr., and L. G. Smith, April 1980, Rocket measurements of electron temperature in the E region.

93. Bliss, H. M., and L. G. Smith, May 1980, Rocket observations of solar radiation during the eclipse of 26 February 1979.

94. Cerny, T., and C. F. Sechrist, Jr., August 1980, Calibration of the Urbana lidar system.

95. Durkin, C., and L. G. Smith, April 1981, A rocket-borne Langmuir probe for high resolution measurement of the ionospheric electron temperature profile.

96. Braswell, F. M., and L. G. Smith, May 1981, A rocket-borne microprocessor-based experiment for investigation of energetic particles in the D and E regions.

97. Colbert, R. O., and S. A. Bowhill, June 1981, Implementation of context independent code on a new array processor: The super-65.

98. Tetenbaum, D., and S. K. Avery, October 1981, Correlative studies of the mesospheric sodium layer at Urbana.

99. Shelton, J. D., and C. S. Gardner, November 1981, Theoretical and lidar studies of the density response of the mesospheric sodium layer to gravity wave perturbations.

100. Weiland, R. M., and S. A. Bowhill, December 1981, Investigation of the winds and electron concentration variability in the D region of the ionosphere by the partial-reflection radar technique.

101. Dean, L., and L. G. Smith, February 1982, An improved pulse-height analyzer for energetic particle measurements in the upper atmosphere.

102. Zendt, F. L., and S. A. Bowhill, March 1982, A preprocessor for the Urbana coherent-scatter radar.

103. Jones, G. A., and S. K. Avery, May 1982, The transport of nitric oxide in the upper atmosphere by planetary waves and the zonal mean circulation.

104. Peterson, M. J., and S. K. Avery, August 1982, Microcomputer data collection for the meteor radar system.

105. Dettro, G. J., and L. G. Smith, December 1982, A rocket-borne electric field for the middle atmosphere.

106. Ruggerio, R. L., and S. A. Bowhill December 1982, New advances in the partial-reflection-drifts experiment using microprocessors.

107. Loane, J. T., S. A. Bowhill, and P. E. Mayes, December 1982, Feed system design and experimental results in the UHF model study for the proposed Urbana phased array.

108. Tanner, D. R., P. E. Mayes, and S. A. Bowhill, December 1982, Phased array design including consideration of mutual coupling with application to the Urbana coherent-scatter radar.

109. Herrington, L. J., Jr., and S. A. Bowhill, April 1983, Phase modulating the Urbana radar.

110. Gibbs, K. P., and S. A. Bowhill, April 1983, An investigation of turbulent scatter from the mesosphere as observed by coherent-scatter radar.

111. Goss, L. D., and S. A. Bowhill, July 1983, Observations of the upper troposphere and lower stratosphere using the Urbana coherent-scatter radar.

112. Voelz, D. G., and C. F. Sechrist, Jr., September 1983, Design and implementation of a preprocessing system for sodium lidar.

113. McInerney, M. K., and L. G. Smith, May 1984, Rocket observations of the ionosphere during the eclipse of 26 February 1979.

114. Burton, D. L., and L. G. Smith, July 1984, An improved rocket-borne electric field meter for the middle atmosphere.

115. Rennier, A. D., and S. A. Bowhill, February 1985, FORTH system for coherent-scatter radar data acquisition and processing.

116. Stoltzfus, R. B., and S. A. Bowhill, June 1985, Rocket measurements of mesospheric ionization irregularities.

117. Houshmand, B., and L. G. Smith, July 1985, Rocket observations of energetic particles at the geomagnetic equator.

118. Parker, J. W., and S. A. Bowhill, January 1986, Solar flare ionization in the mesosphere observed by coherent-scatter radar.

119. Tomei, B. A., and L. G. Smith, January 1986, Rocket experiments for spectral estimation of electron density fine structure in the auroral and equatorial ionosphere and preliminary results.

Table 3.2: Papers

1. Bowhill, S. A., The ionosphere, Astronautics, *7*, No. 10, 80 (1962).

2. Bowhill, S. A., Electron density measurements by the radio propagation technique, COSPAR Information Bulletin No.17, 7-35 (1964).

3. Bowhill, S. A., Geomagnetism and the ionosphere, URSI National Committee Report, XIV General Assembly, Tokyo, Sept. 1963; Commission 3 Ionospheric Radio, Radio Sci. J. Res. NBS/USNC-URSI, *68D*, 572-573 (1964).

4. Hodges, R. R., Electron attachment rate measurements in the lower ionosphere, J. Geophys. Res., *70*, 185-190 (1965).

5. Geisler, J. E., and S. A. Bowhill, The relation between the dispersion of a whistler and the electron temperature in the protonosphere, J. Atmos. Terr. Phys., *27*, 122-125 (1965).

6. Balmain, K. G., Impedance of a short dipole in a compressible plasma, Radio Sci. J. Res. NBS/USNC-URSI, *69D*, 559-566 (1965).

7. Bowhill, S. A., IQSY rocket studies of the C, D, and E regions of the ionosphere, NASA-University Program Review Conference, March 1965, NASA Special Publication, *SP-85*, US Government Printing Office, Washington, D. C., 269-275 (1965).

8. Geisler, J. E., and S. A. Bowhill, Ionospheric temperatures at sunspot minimum, J. Atmos. Terr. Phys., *27*, 457-474 (1965).

9. Geisler, J. E., and S. A. Bowhill, Exchange of energy between the ionosphere and the protonosphere, J. Atmos. Terr. Phys., *27*, 1119-1146 (1965).

10. Gliddon, J. E. C., Ambipolar diffusion and drift in the F2 region, Planet. Space Sci., *13*, 959-967 (1965).

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12. Balmain, K. G., Impedance of a radio frequency plasma probe with an absorptive surface, Radio Sci., *1*, 1-12 (1966).

13. Bowhill, S. A., A rocket experiment on the structure of sporadic E, Radio Sci., *1*, 187-190 (1966).

14. Bowhill, S. A., Summary and conclusions from the Estes Park sporadic E seminar 4. Theories, Radio Sci., *1*, 248-249 (1966).

15. Balmain, K. G., Impedance of a spherical probe in a magnetoplasma, IEEE Trans. Antennas Propagat., *AP-14*, 402-403 (1966).

16. Bowhill, S. A., and J. E. Geisler, The interpretation of rocket and satellite measurements of electron and ion temperature, Space Res., *VI*, Spartan Press, Washington, 487-498 (1966).

17. Bowhill, S. A., and L. G. Smith, Rocket observations of the lowest ionosphere at sunrise and sunset, Space Res., *VI*, Spartan Press, Washington, 511-521 (1966).

18. Bowhill, S. A. (Editor), U.S.A. National Committee Report, Fifteenth URSI General Assembly, Munich, Sept. 1966: Commission 3, Ionospheric Radio, Radio Sci., *1*, 1351-1370 (1966).

19. Bowhill, S. A., Origin of field-aligned irregularities in the F2-1ayer, in Spread-F and its Effects Upon Radiowave Propagation and Communications, AGARDograph 95, edited by Newman, Technivision, Maidenhead, England, 579-590 (1966).

20. Geisler, J. E., On the limiting daytime flux of ionization into the protonosphere, J. Geophys. Res., *72*, 81-85 (1967).

21. Sechrist, C. F., Jr., A theory of the winter absorption anomaly at middle latitudes, J. Atmos. Terr. Phys., *29*, 113-136 (1967).

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4. CONCLUSION

The results of the scientific investigations conducted during the course of this program have considerably increased our knowledge of the physics and chemistry of the lower ionosphere. It has, incidentally, demonstrated the important role of sounding rockets for research below 200 km. It has also shown the advantages of cooperation in research, particularly in international campaigns.

Finally, we must express our thanks to the many NASA personnel who have, over the years, made all this possible. At NASA Headquarters and at the Wallops Flight Facility, in particular, there has been a sense of mutual satisfaction over the successful completion of all but a very few of the missions.