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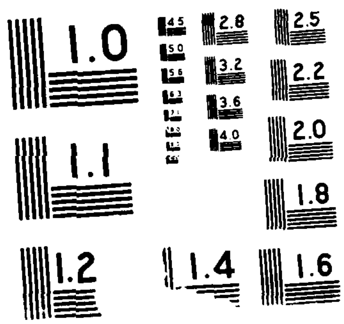
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Investigations into the Properties, Conditions, and Effects of the Ionosphere

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15 January 1988

Scientific Report No. 8

Approved for public release; distribution unlimited

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731

This technical report has been reviewed and is approved for publication.

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FOR THE COMMANDER

ROBERT A. SKRIVANEK, Director
Ionospheric Physics Division

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Northwest Research Associates (NWRA), as prime contractor, and its two team subcontractors, Science Applications International Corp. (SAIC) and the University of Lowell Center for Atmospheric Research (ULCAR), provide members of their technical staffs to conduct and support scientific and engineering investigations of the ionosphere. The investigations address ionospheric composition, structure, specification, scintillation and chemistry as well as remote sensing of the ionosphere through ultraviolet sensors. Specific work is carried out under individual Task Requirement Notices (TRNs) written for conduct and/or support of investigations in the following six categories: laboratory measurements; field measurements; aircraft measurements; rocket, balloon, shuttle, and satellite measurements; analytical and theoretical investigations; and scientific and engineering analysis. This report provides a summary of the work performed during the period 4 December 1986 through 15 December 1987

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SECURITY CLASSIFICATION OF THIS PAGE

SUPPORT OF INVESTIGATIONS INTO THE PROPERTIES, CONDITIONS, AND EFFECTS OF THE IONOSPHERE

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I. INTRODUCTION

This is an hour-rate contract under which Northwest Research Associates (NWRA), as prime contractor, and its two team subcontractors, Science Applications International Corp. (SAIC) and the University of Lowell Center for Atmospheric Research (ULCAR), are providing Members of their Technical Staffs (MTS) at negotiated hourly rates, and with reimbursement of other direct and indirect costs, to conduct and support scientific and engineering investigations into the properties, conditions, and effects of the ionosphere. Specific work is carried out under individual Task Requirement Notices (TRNs) written for conduct and/or support of investigations in the following six categories: laboratory measurements; field measurements; aircraft measurements; rocket, balloon, shuttle, and satellite measurements; analytical and theoretical investigations; and scientific and engineering analysis.

II. ADMINISTRATIVE MATTERS

Work under a given TRN is authorized only upon mailing to the contractor/subcontractor of a corresponding contract/subcontract modification following full-cycle approval thereof (by the Contracting Officer's Technical Representative; the contractor and, if appropriate, a subcontractor; and the Contracting Officer). Table 1 shows the administrative status of all TRN's known to the contractor as of this writing.

Tables 2(a) and 2(b) show the status of the MTS budget for FY87 and FY88 respectively through commitments to all contract modifications let and all TRN's returned to the Contracting Officer, or withdrawn, as of this writing. Table 3 shows the status of the overall budget for other direct and indirect costs (CLINS 4 and 5, including subcontract-administration costs) through the same TRNs.

Table 1. TRN Administrative Information

#	AMOUNT	ORG	TITLE	DATE ARRIVED FROM AFGL	DATE SENT TO SUBCONTRACTOR	DATE RETURNED TO AFGL	DATE CONTRACT MODIFIED	END DATE
1	$ 44K	ULCAR	Meteor Burst System Upgrade	12/21/86	12/22/86	12/30/86	1/12/87	2/28/87
2	$285K	ULCAR	Support for High Latitude Ionosphere Research and OTH Test Support	1/12/87	1/13/87	1/17/87	2/4/87	9/30/87
3	$ 40K	SRI/SAIC	Assess HF Configuration for Optimum Power Delivery	1/8/87	1/9/87(SRI)	WITHDRAWN		
4	$ 30K	Team	Technical Management & Administrative Support			WITHDRAWN		
5	$ 50K	SAIC	Radio Blackout Modification Study	3/19/87	3/19/87	3/24/87	4/20/87	9/30/87
6	$135K	ULCAR/NWRA	Meteor Scatter Polar Ionospheric Propagation Studies Control Systems Development and Data Analysis	2/9/87 3/20/87(rev)	2/9/87 3/23/87	2/17/87 3/24/87	4/20/87	9/30/87
7	$ 97K	SAIC	Investigation of D-Region Electron Sampling Processes	2/9/87	2/9/87	2/17/87	3/20/87	9/30/87
8	$ 30K	Team	Studies and Technical Support	5/21/87	5/21/87	6/3/87	6/17/87	9/30/87
9	$122K	NWRA	Image Processing Algorithm Development and Quick Look Support	2/3/87	2/3/87	2/3/87	2/20/87	9/30/87

Table 1 (Continued). TRN Administrative Information

#	AMOUNT	ORG	TITLE	DATE ARRIVED FROM AFGL	DATE SENT TO SUBCONTRACTOR	DATE RETURNED TO AFGL	DATE CONTRACT MODIFIED	END DATE
10	$ 79K	NWRA	Support for FY87 Midlatitude Electron Density Calibration Campaign	4/23/87	-	4/23/87	6/4/87	9/30/87
11	$ 56K	ULCAR	Bermuda Ionosonde Tests in Support of OTH-B	5/15/87	5/15/87	5/21/87	6/17/87	9/30/87
12			Aircraft-mounted UV Camera			WITHDRAWN		
13	$ 40K	NWRA	Studies of Multipath Mitigation for TEC Measurements from GPS	5/21/87	-	5/21/87 & 6/3/87	6/17/87	9/30/87
14	$138K	NWRA	Transionospheric Scintillation & TEC studies	6/11/87	-	6/11/87	7/7/87	9/30/88
15	$ 30K	NWRA	Space Radar Ionospheric Effects Studies	6/11/87	-	6/11/87	7/7/87	2/28/88
16	$ 20K	ULCAR	Meteor Scatter Polar Ionospheric Propagation Studies Control System Development & Data Analysis	11/9/87	11/9/87	11/13/87	12/4/87	1/31/88
17	$ 48K	SAIC	Investigation of D-Region Electron Sampling Proceses	11/19/87	11/20/87	11/23/87	12/22/87	6/22/88
18	$ 90K	SAIC	Feasibility of Radio Blackout Modification	11/9/87	11/9/87	11/13/87	12/4/87	9/30/88
19	$ 30K	ULCAR	Meteor Scatter Polar Ionospheric Propagation Studies Control System Development & Data Analysis	11/9/87	11/9/87	11/9/87	11/16/87	12/31/87

Table 1 (Continued). TRN Administrative Information

#	AMOUNT	ORG	TITLE	DATE ARRIVED FROM AFGL	DATE SENT TO SUBCONTRACTOR	DATE RETURNED TO AFGL	DATE CONTRACT MODIFIED	END DATE
20	$ 35K	ULCAR	Bermuda Ionosonde Tests in Support of OTH-B	10/28/87	10/28/87	10/28/87	11/2/87	3/15/88
21								
22								
23								
24	$190K	ULCAR	Bermuda Sounder Tests and Over-the-Horizon (OTH) Test Support	11/19/87	11/19/87	11/23/87	12/22/87	9/30/88
25	$ 26K	Team	*Studies and Technical Support*	11/9/87	11/9/87	11/13/87	12/4/87	9/30/88
26	$150K	NWRA	Image Processing Algorithm Development & Data Management Support	11/9/87	11/9/87	11/9/87	12/4/87	9/30/88

Table 2(a). Status of MTS Budget, FY87

Northwest Research Associates

Labor Category	Budgeted	Committed	Remaining	TRN Numbers
Technician	1,040		1,040	
Draftsman/Designer	694		694	
Engineer 1-2	1,877	1,160	717	6,10,14
Engineer 3-4	984	823	161	9,13
Scientist 1	1,344		1,344	
Scientist 2	3,111	735	2,376	13,14
Scientist 4-5	1,440	1,440	0	8,9,10,15

Science Applications International Corporation

Labor Category	Budgeted	Committed	Remaining	TRN Numbers
Technician	1,040	500	540	7
Draftsman/Designer	693		693	
Engineer 1-2	983		983	
Engineer 3-4	983	335	648	7
Scientist 1	1,333		1,333	
Scientist 2	4,100		4,100	
Scientist 4-5	1,333	1,333	0	5,7,8

University of Lowell

Labor Category	Budgeted	Committed	Remaining	TRN Numbers
Technician	1,040	1,040	0	2,11
Draftsman/Designer	693	693	0	2,6
Engineer 1-2	983	983	0	1,6
Engineer 3-4	983	983	0	1,2,6
Scientist 1	1,333	1,333	0	2,6
Scientist 2	4,100	4,023	77	2,6,11
Scientist 4-5	1,333	1,413	-80	1,2,8,11

Table 2(b). Status of MTS Budget, FY88

Northwest Research Associates

Labor Category	Budgeted	Committed	Remaining	TRN Numbers
Technician	1,387		1,387	
Draftsman/Designer	694		694	
Engineer 1-2	1,387	1,285	102	14
Engineer 3-4	1,387	1.214	173	26
Scientist 1	1,387		1,387	
Scientist 2	4,160	1,279	2,881	14,15
Scientist 4-5	1,387	1,232	155	14,15,25,26

Science Applications International Corporation

Labor Category	Budgeted	Committed	Remaining	TRN Numbers
Technician	1,387	55	1,332	17
Draftsman/Designer	693		693	
Engineer 1-2	1,387		1,387	
Engineer 3-4	1,387	862	525	17,18
Scientist 1	1,387		1,387	
Scientist 2	4,160		4,160	
Scientist 4-5	1,387	910	477	17,18,25

University of Lowell

Labor Category	Budgeted	Committed	Remaining	TRN Numbers
Technician	1,386	76	1,310	16
Draftsman/Designer	693		693	
Engineer 1-2	1,386	160	1,226	19
Engineer 3-4	1,386	160	1,226	19
Scientist 1	1,386	471	915	16,19,24
Scientist 2	4,160	2,360	1,800	16,19,20,24
Scientist 4-5	1,386	1,003	383	16,20,24,25

Table 3. Other Direct and Indirect Costs, FY87-90

Northwest Research Associates

	Budgeted	Committed	Remaining	TRN Numbers
CLIN 0004	$68,000	$44,401	$23,599	6,8,9,10,13,14,15,25,26
CLIN 0005	$37,000	$58,080	-$21,080	8,10,14,26
Support Services	$105,000	$32,633	$72,367	1,2,5,6,7,8,11,16,17,18,24

Science Applications International Corporation

	Budgeted	Committed	Remaining	TRN Numbers
CLIN 0004	$68,000	$6,039	$61,961	5,7,8,17,18,25
CLIN 0005	$37,000	$21,300	$15,700	5,7,17,18

University of Lowell

	Budgeted	Committed	Remaining	TRN Numbers
CLIN 0004	$68,000	$79,641	-$11,641	1,2,6,11,16,19,20,24
CLIN 0005	$37,000	$75,864	-$38,864	1,2,6,11,19,20,24

III. SCIENTIFIC AND ENGINEERING PROGRESS

We report in this section the technical status of each TRN active during this report period, including the performing organization(s), start and end dates, the task Principle Investigator (P.I.), and other participating personnel. For this annual report, related tasks are grouped together. The task activity report combines a condensed summary of work completed during the first three quarters with a more detailed discussion of activities performed during the last quarter. Please refer to the quarterly reports for a more detailed discussion of previous activities. A report is included on all TRNs active during the reporting period except for TRN 0003018, which was added to the contract during December.

A. METEOR SCATTER

Performing organization: ULCAR, NWRA

Dates: 12 January through 15 December 1987

Personnel: J. A. Weitzen (co-P.I.) (ULCAR), J. E. Powers (co-P.I.)(ULCAR), E. Li (ULCAR), and C. C. Andreasen (NWRA)

This section summarizes the work performed under TRNs 0003001, 0003006, 0003016, and 0003019. The objectives of the work performed under the named TRNs are to develop and provide continuing support for meteor scatter analysis software and to support the implementation of control and interface systems for data acquisition and on-site analysis.

1. Meteor Scatter Analysis Software Development and Maintenance

The purpose of this continuing task is to provide AFGL/LID the capability to process data from the High-Latitude Meteor Scatter Test Bed. Software that was initially developed by RADC/EEPS (RADC-TR-86-165) was modified to be operable on either a mainframe VAX or an IBM-PC/AT-compatible computer. A package of analysis routines was developed to ascertain the effects of a polar cap absorption event. The meteor-trail classification software (AUTOCLASS 1.5, cf. RADC-TR-86-117) was modified to run without operator intervention. The fully automated classification program (AUTOCLASS 2.0) was documented and evaluated by comparing the results to those obtained manually by an experienced meteor scatter scientist. This comparison (1000 data records) revealed a significant improvement, as there were no first-degree errors (sporadic E classified as a meteor trail), less than 2% second-degree errors (meteor trail classified as sporadic E). Disagreements between the autoclassification and the expert occurred on less than five percent of the records. This compares favorably with the approximate 10% error rate for AUTOCLASS (without operator intervention) and five to eight percent with operator intervention.

With the upgrade to a continuously recording, dual-polarization, six-frequency system, the analysis software must be modified further . These new data will provide an improved capability to distinguish overdense trails from sporadic E. Plans were drafted to modify the software.

2. Meteor Scatter Test-bed Controller/Transmitter Interface

The objective of this task was to develop and implement programmable control of the meteor scatter transmitter system. The computer-based system was developed and implemented to replace an electromechanical relay system. The system was expanded further to allow transmission on any of six frequencies vice the four of the original High-Latitude Meteor Scatter Test Bed. Results reported in "The Modification of the Real-time Software and Hardware Interface for a Meteor Burst Transmitter System."

3. Meteor Scatter Receive and Data Acquisition System

A personal computer controlled receiver and data-acquisition system was developed and deployed to the Thule, Greenland site. An improved six-frequency, dual-polarization, synchronous receiver, developed in Denmark, was interfaced successfully to the upgraded receive and data acquisition system. The new system consists of a Zenith Z-248 personal computer, the synchronous receiver, a Best 500VA uninterruptable power unit, an Interdyne tape drive, a 2400-baud dial-up modem, and an on-line printer. The Z-248 computer digitizes (using a MetraByte Dash 16 A-D converter board) the phase-locked signals (amplitude and quadrature data from 35, 45, 65, 85, 104, and 147 MHz) from the synchronous receiver. The data are stored after a 400 Hz FM trigger tone is activated. The Zenith Z-248 operates in a multi-tasking mode. The primary data-acquisition module runs in background while secondary modules serve the peripherals. At present, there are three secondary modules: an interface to the power unit, the modem, and the printer. The modem allows for remote system monitoring. This provides a capability for checking the Thule system status from Hanscom AFB, MA or from any location where phone service is available. The new system has been operating continuously since installation in November 1987. Occasionally the Interdyne tape drive will jam. Interdyne was contacted; Interdyne acknowledged a quality-control problem and has offered replacement drives that are claimed to be more reliable. However, a Kennedy 1/4-inch tape drive is being used until tests prove the reliability of the Interdyne replacement drives.

B. BERMUDA IONOSONDE TESTS

Performing organization: ULCAR
Dates: 26 June through 15 December 1987
Personnel: B. W. Reinisch (P.I.) and D. F. Kitrosser

This section summarizes the work performed under TRNs 0003011, 0003020, and 0003024 that relates specifically to the installation and testing of a Digisonde 256 ionosonde in Bermuda in support of the Over-the-Horizon Backscatter (OTH-B) Radar Program.

1. Site Selection

Technical advice and counsel were provided to the Air Force on the selection of a suitable site to achieve acceptable low-power operation of the Digisonde 256 ionosonde. The site-selection criteria gave weight to the minimization of interference to an existing, nearby high-frequency receiver facility. A Digisonde site was selected that maximized the distance between the ionosonde and this receiver facility.

In retrospect, insufficient attention was paid to another nearby high-frequency transmit/receive communication facility used in support of submarine operations. The site selected necessitated the use of a low-loss transmission cable (to minimize power loss over the distance of approximately 2300 feet from the transmitter to the antenna) from the Digisonde 256 electronics trailer to the transmit antenna. The University of Lowell Center for Atmospheric Research (ULCAR) recommended such a cable, and purchased and shipped the cable to Bermuda.

2. Ionosonde Installation

Following site selection, ULCAR shipped the Digisonde 256 and associated electronics trailer to Bermuda. The Digisonde was installed with the seven-antenna receive array located on a water cachement area adjacent to the site selected for the electronics trailer. The transmit antenna was supplied and installed under the auspices of SRI International.

3. Ionosonde Tests

An intensive three-week test period in November 1987 established that ionograms of acceptable quality could be acquired at low power such that the Digisonde operation was compatible with the aforementioned high-frequency receive facility. ULCAR was tasked to provide a remote terminal to the receive facility such that if the Digisonde transmissions became objectionable, the receive facility could control the Digisonde.

The operation of the nearby submarine transmit/receive facility was still impacted to the degree that necessitated a fix. ULCAR designed, developed, fabricated and tested several "antenna clippers" (blankers) that permit simultaneous operation of the Digisonde and the submarine transmit/receive facility. These were tested on site and tentatively approved in concept by the Navy. Final installation and acceptance of the six clippers is scheduled for early CY88. A second remote terminal was requested and provided for use by the submarine transmit/receive facility.

C. IONOSPHERE RESEARCH AND OTH-B TEST SUPPORT

Performing organization: ULCAR
Dates: 4 February through 15 December 1987
Personnel: B. W. Reinisch (P.I.), D. F. Kitrosser, and J. G. Moore

This section summarizes the work performed under TRNs 0003002 and 0003024. The objectives of the work performed under the named TRNs are to support AFGL work during the OTH-B Radar tests, including evaluation of selected radar functions, provide analysis reports and radar studies, upgrade existing AFGL systems for propagation/backscatter studies and improve data processing.

1. Support for the AFGL Airborne Ionospheric Observatory

ULCAR provided planning, instrumentation and personnel support for each of the four CY87 campaigns of the AFGL Airborne Ionospheric Observatory (AIO). The four campaigns were:

a. Polar Acceleration and Convection Studies (Polar ARCS), 10 February through 4 March 1987.

b. Argentia Target-emulator Calibration, 23 April through 3 May 1987.

c. OTH-B Radar Oblique-heating Experiments, 15-23 October 1987.

d. Puerto Rico Target-emulator Calibration, 29 November through 5 December 1987.

An expedition profile was developed and coordinated for each of the campaigns. Following each of the first three campaigns, a summary was prepared to document the missions as flown, the quality of the data collected, and present representative data that relate to the AIO campaign objectives. A summary of the most recent campaign will be completed in CY88.

ULCAR has provided a mission director (full time in FY87; 80% time in FY88) to coordinate and participate in AIO-related activities. The mission director prepared and coordinated the annual Program Introduction Document, which contains the primary aircraft equipment modifications and planned flight operations for the forthcoming fiscal years. In addition, the mission director established training schedules for Air Force and contractor personnel to attain and maintain Scientific Crew Member status.

2. Radar Environmental-assessment Operations During AIO Flights

An analysis was made of how well the Argentia ionospheric data can be used to manage OTH-B radar operations. An interim report was prepared that summarized the results of the Argentia target-emulator calibration flights. Within the analysis uncertainties, it was concluded that the Argentia midpath ionograms can be used to assess propagation conditions from the OTH-B radar to the AIO.

3. Specular Scatter as a Source of HF-radar Clutter

A technical report was prepared that summarized the understanding of specular scatter as a potential contributing source of the clutter for the proposed OTH-B Central Radar System. It was concluded, within the limits of the ionospheric and ray-tracing models used, that specular scatter would not be a source of clutter except possibly for radar azimuths toward the northeast.

4. Maintenance and Repair of Goose Bay and Argentia Digisondes

In-house as well as on-site repairs were conducted for the Argentia Digisonde. These included replacement of the ARTIST IBM-PC/AT computer, the 12 and 24 volt power supplies in the Processor Chassis, the Okidata 92 printer, repair of the receive antenna, and diagnosis and repair of faulty printed circuit cards. The relatively low reliability of the Argentia prime power suggests that an upgrade to the AN FMQ-12 configuration that includes an uninterruptable power supply would increase the utility of the Digisonde for operational support to the OTH-B Radar System.

In-house repair of the Goose Bay transmitter was completed.

D. STUDIES AND TECHNICAL SUPPORT

Performing organization: NWRA, SAIC, ULCAR
Dates: 17 June through 31 December 1987
Personnel: E. J. Fremouw (P.I.)(NWRA), B. W. Reinisch (ULCAR), and E. Szuszczewicz (SAIC)

This section summarizes the work performed under TRNs 0003008 and 0003025. The objectives of the work performed under the named TRNs are to provide studies and support to the Ionospheric Physics Division on technical tasks to include ionospheric propagation, experimental program planning, and high-latitude auroral effects.

Periodic management and technical planning meetings were held between ULCAR and AFGL/LIS and AFGL/LID personnel. These meetings were useful in defining priorities for ULCAR support to meet short-term objectives and for defining work to best support achievement of long-term objectives.

These meetings with AFGL/LID have also served as progress reviews to help ensure adherence to schedule for system development needed to upgrade the High-latitude Meteor Scatter Test Bed.

The meetings with AFGL/LIS have been used to restructure ULCAR support for the OTH-B Radar Program, to review technical approaches for achievement of Bermuda Digisonde operations compatible with other island users of the high-frequency radio spectrum, and to review plans for technique development for the use of oblique-propagation ionograms for OTH-B radar frequency management.

NWRA and SAIC, and ULCAR personnel met on August 4, 1987 with AFGL/LI personnel to define candidate FY88 TRNs and how these should be processed to increase the efficiency of contract administration. Integration of task reports to produce overall project quarterly and annual reports was also carried out under these TRNs.

E. AURORAL IONOSPHERIC REMOTE SENSOR (AIRS).

Performing organization: NWRA
Dates: 20 February through 15 December 1987
Personnel: R. D. Lucas (P.I.), F. J. LeBlanc, R. E. Robins, and N. W. Rosenberg

This section summarizes the work performed under TRNs 0003009 and 0003026. The focus of these TRNs is to derive useful products from the Auroral Ionospheric Remote Sensor (AIRS) on the Polar BEAR Satellite. The tasks included study of hardware and software approaches for the geometrical and photometric restoration of image data, and for estimation of satellite attitude. We also provided assistance in organizing and analyzing the AIRS data base, particularly its relationship to existing data sets from S3-4 and other sources.

1. Image Processing.

AIRS image data are ported to our image-processing workstation, which is an IBM PC/AT with an ITEX FG100AT image-processing board and other enhancements. The graphics algorithms employed and the microcomputer-based hardware now being used were derived from a parallel project sponsored by AFGL (Contract No. F19628-84-C-0131) for the development of an image-processing workstation for all-sky imaging photometer data.

Central to this effort is correction of AIRS data for offsets and changes in satellite attitude from its nominal nadir-directed view and for other geometrical distortions. During the geometrical restoration process each input sample is transformed, based on exact geometrical principles, and incorporates information on the output map projection and the instantaneous position and attitude of the satellite, as well as assumptions regarding the altitude of the ionospheric source.

The spacecraft underwent severe attitude variations. The resulting data exhibited underscanned regions, such as near the limb when the satellite is yawing rapidly. Also exhibited was "overpainting" by the latest observations, which occurs frequently in the presence of severe yaw and roll oscillations when the scanning spot visits a given area more than once. Overpainting results in the display of only the most recent data in the areas with multiple observations.

Two viewing modes were developed. In the interactive viewing mode, one can watch (and suspend) a geometrically corrected image being painted on the RGB monitor. One then has an opportunity to see the redundantly viewed areas before they are overpainted. The second mode provides an option to retain the maximum values for output pixels covered more than once by the scanner. This option was implemented primarily for the images recorded in conjunction with the HIPAS heater experiment, for which the detection of very localized "hot" spots is especially relevant.

The image enhancement and display processing developed includes color- and gray-scale options, a battery of image filtering options, world coastline map overlays, multiple-image displays, and annotations. These functions may be performed interactively, or a macro can be invoked to produce a specific display format. Currently, a four-window format is available for displaying the concurrent images observed in four spectral windows during any single satellite pass.

Some of the processed images were shown at the meeting of the HiLat/Polar BEAR Science Team held at Johns Hopkins University's Applied Physics Laboratory (JHU/APL) on 4 May 1987. Those examples illustrate the distortions introduced by Polar BEAR's attitude problems and the improvements obtainable from geometrical correction (Lucas and Robins,1987).

AIRS provides simultaneous records from three detectors. Count rates usually are low, so the data are best treated as a Poisson process. The errors stemming from the low count rate can be reduced by accumulating counts, effectively trading spatial resolution for a statistically acceptable error. We developed a program, FILTRAW, that provides the necessary tradeoff at each point in an image, while preserving the original percentile distribution.

To facilitate separation of auroral and airglow emissions, we developed a program, GEOMLSQ, for normalizing the latter based on column path length and solar flux. The program finds the dependence of the count on a power of path length and on a power of solar flux, the latter taken as proportional to the sine of the solar elevation angle.

The relative morphology of auroral forms in two wavelength bands may most clearly be shown after histogram equalization. For this purpose, we developed Program HISEQ, which equalizes the overall apparent intensity in the two bands while preserving relative spatial variations in the intensity of each.

We then developed Program MULBND, which permits co-display of the two bands, one in red and the other in green. Where the two bands match in their relative intensity, a yellow image of suitable intensity is displayed. Elsewhere, a tendency to red or green is displayed, again with an intensity representing the local intensity of the auroral form (Rosenberg, 1987).

2. Spacecraft Attitude.

The software developed by NWRA to geometrically correct Polar BEAR AIRS images by removing distortions arising from severe attitude variations requires good estimates of satellite attitude. Ordinarily, attitude estimates are derived from measurements and models of solar and magnetic-field direction. Since there are occasional gaps in Polar BEAR's solar position and magnetic-field measurements, and a total lack of solar data for nighttime passes, a supplementary method is needed to estimate attitude in these circumstances. The problem of estimating night-side attitude was discussed with satellite dynamics experts at JHU/APL. We investigated two approaches to determining nightside attitude.

Our first approach was to exploit the signature of the earth's limb, which may be observed as a bright emitting layer on some images. In several images, both limbs are visible, and they indicate a height of 150 $\pm$ 20 km for the emitting layer (Rosenberg, 1987). Based on these observations, we developed a program, ROLADJ, that computes the roll required to place the layer at that altitude when a limb signature is available.

As our second approach, NWRA has carried out a preliminary evaluation of an attitude estimation method based on Kalman filtering. Since this method provides attitude estimates even when there are gaps in the measured data, it is a possible solution to the problems discussed above. Kalman-filter attitude estimation software was provided by Jack Hunt and Courtney Ray of JHU/APL, and was used to estimate Polar BEAR attitude for two sunlit passes over the ROVER receiver. The Kalman-filter software requires time series of modeled and measured sun vector and magnetic-field vector data, and includes a simple linear model of the satellite dynamics. Additional inputs are estimates of process noise and measurement noise.

Files of modeled and measured sun and magnetic data for the two sample passes were obtained from a slightly modified version of the routine Polar BEAR raw data processing software. Kalman-filter attitude estimates for the two passes were compared to the routine attitude estimates which are based on an algorithm developed by Chuck Williams of JHU/APL. Pass start times (UT) for the sample passes were 87152,42355 and 87052,77283 (YYDDD,seconds after midnight).

Results for the two passes are shown in Figures 1(a),(b),(c) and 2(a),(b),(c), respectively. In each case yaw, roll, and pitch estimates are shown in (a), (b), and (c), the routine processing results are shown by solid jagged lines, and the Kalman filter results are shown by solid smooth lines. Default process and measurement noise values were used. The figures show good agreement between Kalman-filter and routine estimates for yaw, and offsets of 1 to 3 degrees between Kalman-filter and routine estimates for roll and pitch.

Dashed lines in figures 1(a),(b),(c) and 2(a),(b),(c) show what happens when the sun measurement noise value is increased and the magnetic measurement noise value is decreased by a factor of 10. Figure 1 shows that the roll and pitch agreement for the first pass is greatly improved, but that the yaw agreement has been somewhat degraded. Figure 2 shows no improvement in the roll and pitch agreement for the second pass, and some degradation in the yaw agreement.

The attitude estimates provided by the Kalman filter software thus appear to be sensitive to the noise inputs, and this sensitivity is not necessarily consistent from pass to pass. These observations and the differences between Kalman-filter and routine attitude estimates raise general questions about how well it is possible to estimate Polar BEAR attitude. Our hope has been that the Kalman-filter approach could eventually be used to estimate nighttime attitude, but it now appears that we must first understand the validity and limitations of the methods used to estimate daytime attitude.

3. S3-4 Data.

In order to render the S3-4 data more readily useable for comparative studies, we reviewed the microfiche records and constructed a table of full-orbit revs, locating the ascending node, identifying the photometer states and slit widths, and recording our assessment of data quality, with comments.

An analysis of S3-4 data was performed to investigate the variation of vacuum-ultraviolet emission strength recorded by S3-4 in the O_2, N_2, and NO bands. Products of this analysis are tables and plots showing intensity variations at selected wavelengths as well as in summed spectra.

Night spectra of selected orbits for a range of latitudes were plotted. The NO delta, NO gamma and O_2 Herzberg bands were identified, and their radiance variations with latitude were tabulated. These results were used to co-author a paper, "Observations of Ultraviolet Nightglow Emissions in the O_2 Herzberg and NO gamma bands from the S3-4 Satellite", R. Eastes *et al*. presented at the 1987 AGU meeting in Washington, DC.

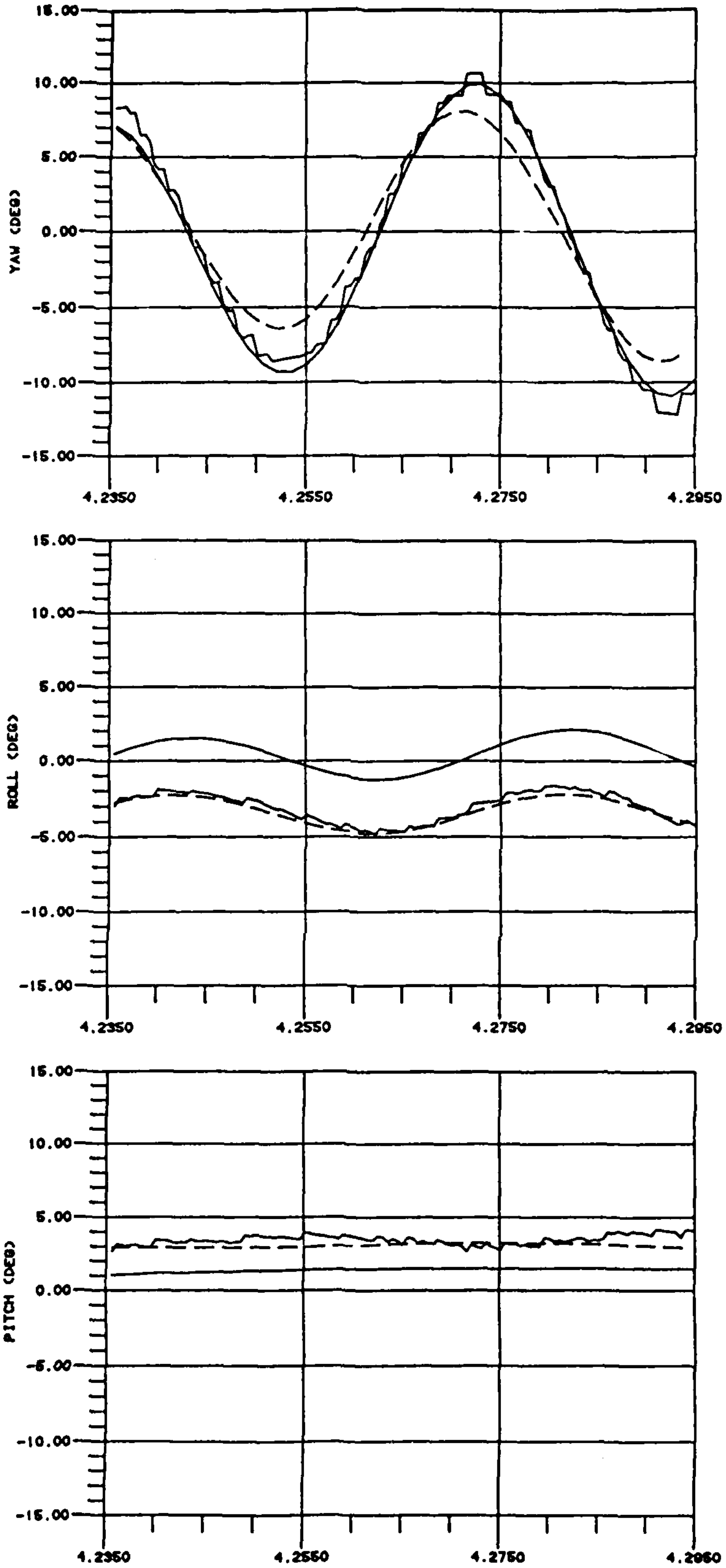


Figure 1. Yaw, roll, and pitch estimates for a Polar BEAR pass over the Rover receiver are shown in (a), (b), and (c), respectively. Solid jagged lines show the routine estimates, solid smooth lines show the default Kalman-filter estimates, and dashed lines show Kalman-filter estimates when the sun (magnetic) measurement noise value is increased (decreased) by a factor of ten.

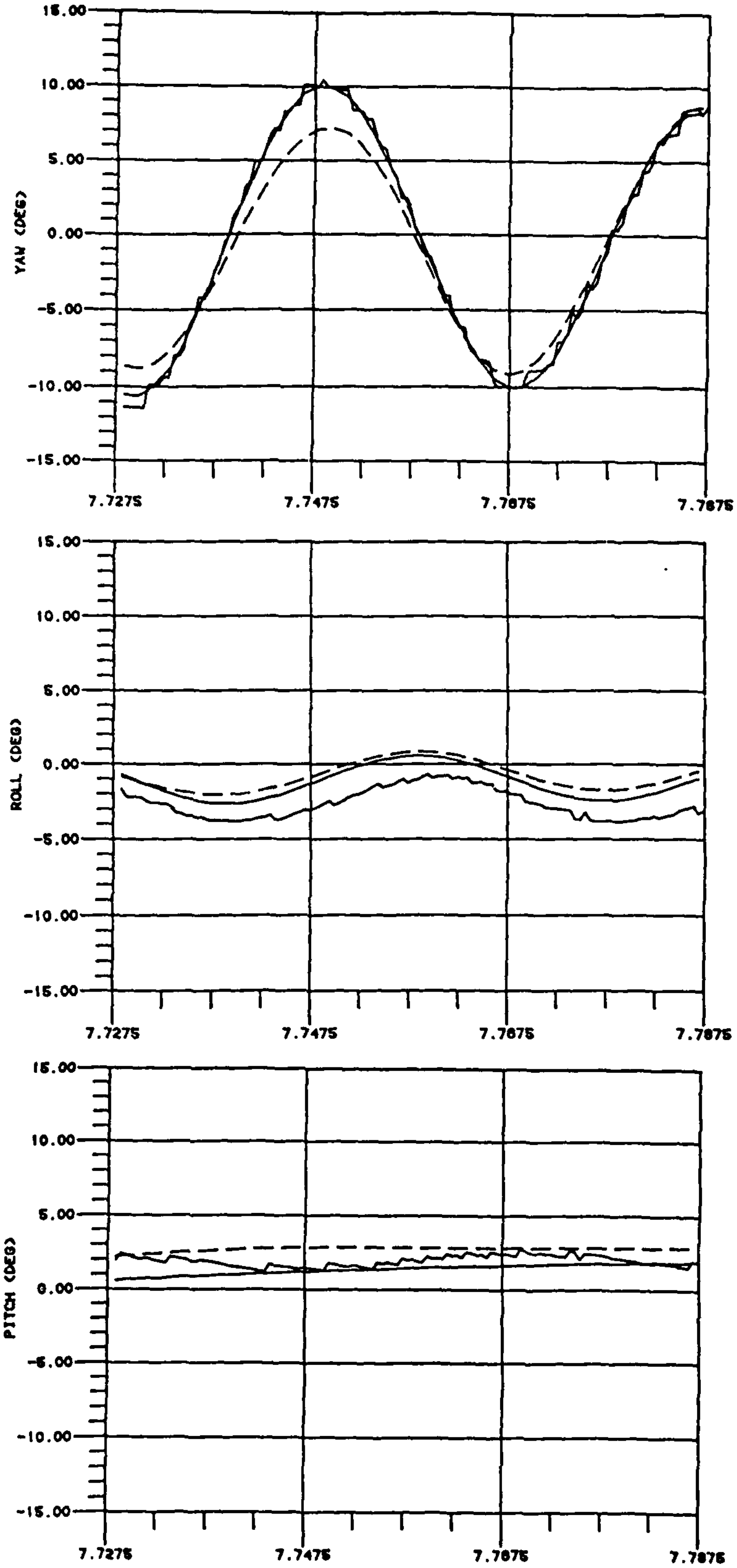


Figure 2. Yaw, roll, and pitch estimates for a Polar BEAR pass over the Rover receiver are shown in (a), (b), and (c), respectively. Solid jagged lines show the routine estimates, solid smooth lines show the default Kalman-filter estimates, and dashed lines show Kalman-filter estimates when the sun (magnetic) measurement noise value is increased (decreased) by a factor of ten.

F. TRANSIONOSPHERIC SCINTILLATION AND TEC STUDIES UTILIZING THE GPS

Performing Organization: NWRA
Dates: 17 June through 15 December 1987
Personnel: C.C. Andreasen, M.J. Klein, J.M. Lansinger (P.I.), L.E. Piper, and R.M. Bussey

This section summarizes the work performed under TRNs 0003013 and 0003014. The objective of these TRNs is to assure reliable operation of Global Positioning System (GPS) receivers located at AFGL and Thule AFB, Greenland, and to acquire and analyze high-quality data to advance empirical characterization of ionospheric scintillation and TEC affecting transionospheric RF systems.

1. Operation and Maintenance of GPS Receivers and Ancillary Equipment.

Reliable operation of the GPS receivers at AFGL and at Thule is crucial to successfully meet the scientific objectives. During the course of these TRNs, we provided engineering and technical support to enhance the operation of both receiver systems. The GPS receivers at Thule are operated by a Danish contractor. Under our responsibility to ensure reliable operations at Thule, we communicate with their technicians by telephone and make on-site visits to diagnose and fix problems and to implement new or revised testing and operating procedures.

During the course of refurbishment of the receiver at AFGL, we communicated with the manufacturer of the equipment. Based upon these discussions and other experience gained during the refurbishment, we developed a new test procedure, which provided more reliable operation through improved preventive maintenance.

In September, we travelled to Thule to perform a complete calibration of the GPS system there. During the visit, we recognized the same inadequacy of receiver test procedures that we had experienced during refurbishment of the AFGL receiver. Accordingly, we introduced our new test procedure and instructed the technicians on site at Thule in its use. C.C. Andreasen, who developed the improved test procedure, regularly travels to Thule and is bilingual in Danish and English. To assist in the application of the new test procedure by the technicians at Thule, he has translated the instructions into Danish.

Tests performed during a later trip to Thule revealed two problems. A temperature sensitivity was discovered in a portion of one GPS receiver, which necessitated swapping AFC/PLL cards to correct the problem. A second receiver developed an intermittent lock problem. Tests revealed that the problem could be fixed by inserting a capacitor to ground at a particular point in the receiver circuitry. During December, Mr. Andreasen visited Stanford Telecommunications, Inc. (STI) to obtain a better understanding of this intermittent lock problem. STI is currently studying the problem and has a tentative explanation supporting the impromptu fix implemented in the field.

2. Mitigation of multi-path Effects in the Reception of GPS Data.

Determination of ionospheric total electron content (TEC) can be accomplished by measurement of differential group delay (DGD). Due to the nature of the detection process in GPS receivers, DGD measurements can be degraded by multipath reception. Multipath is the simultaneous reception of signals directly from the GPS satellite with those that have propagation paths which reflect from ground and other objects in proximity of the receiving antenna.

The first work undertaken was to evaluate and refine the AFGL procedure to mitigate multipath effects. This work was conducted during June through September 1987 and reported in NWRA-CR-87-RO15. This study established two methods for substantially reducing multipath effects. First, was judicious selection of the antenna site. Second, a simple algorithm was developed to mitigate the effects of multipath by utilizing Differential Carrier Phase (DCP), which is two orders of magnitude less sensitive to multipath effects and is available from the GPS receiver system. DCP is linearly related to relative TEC change. The study results verified that the algorithm is capable of substantially reducing the effects of multipath for real-time applications and can correct completely for path errors of 10 to 15 TEC units.

Improvements to the GPS data-analysis software were accomplished to allow the identification and analysis of significant ionospheric events. This streamlining and upgrade entailed:

- -- implementing the multipath-mitigation algorithm described above;
- -- restructuring the program to enable individual satellite passes to be identified and obtained more quickly;
- -- adding azimuth and elevation data to the plot programs;
- -- investigating moving the code to a VAX computer system, which is more compatible with the collection hardware.

The objective of the multipath study and software improvement was to facilitate the identification and analysis of significant ionospheric events. To accomplish that goal, a validation of the multipath-mitigation algorithm was completed.

The upgrade of the GPS analysis code will allow the real-time GPS data-acquisition software to produce absolute TEC data that are free from multipath contamination. This will facilitate the compilation of useful scientific data both from the measurements currently being made at AFGL and Thule and from the many months of existing GPS data.

Active-ionosphere data from Thule taken during 1987 was identified, reduced and plotted. A naming convention has been established to allow a quick determination of the characteristics of individual satellite passes. The data have shown simultaneous large TEC variations, L-band phase and amplitude scintillation and UHF amplitude scintillation. Data acquired at Thule has also been examined in conjunction with other types of data recorded by Raytheon . Further analysis of the reduced and plotted

1987 Thule data is in progress and will include cataloging the data and locating and categorizing specific events of interest for the study.

G. SUPPORT FOR MIDLATITUDE ELECTRON-DENSITY CALIBRATION CAMPAIGN

Performing organization: NWRA
Dates: 4 June through 30 September 1987
Personnel: D.B. Keir, J.M. Lansinger (P.I.)

This section summarizes the work performed under TRN 0003010.

One of the applications of data from AFGL's Auroral and Ionospheric Remote sensor (AIRS) aboard the Polar Beacon and Auroral Research (Polar BEAR) Satellite is an attempt to produce electron density profiles from remote passive topside sensing. During development of techniques for this challenging procedure, AIRS data are needed that are simultaneous and closely co-located with data from an independent, established technique. The objective of this TRN was to provide such data.

To accomplish this objective, the transportable HiLat/Polar BEAR beacon and telemetry receiver, Rover, developed and operated by NWRA for DNA was shipped from Poker Flat, Alaska to Hanscom AFB. Rover commenced test operations at Hanscom AFB on 24 June. During the period 1 July through 7 August, 60 passes were received and recorded from Polar BEAR while the satellite overflew the Millstone Hill incoherent-scatter radar. The radar provided "ground-truth" information on ionospheric electron-density profiles, as well as measurements of electron and ion temperature, plasma drift, and the thermospheric neutral wind.

Personnel from NWRA and the Johns Hopkins University Applied Physics Laboratory (JHU/APL) established an interface between Rover and APL's AIRS ground support equipment (GSE) to display AIRS data in real time.

During the campaign, raw tapes generated by Rover and processed at NWRA's computing facility in Bellevue, WA raised the serious question of whether the attitude of the satellite could be determined suitably to correct imager data during a substantial portion of some passes monitored during the campaign. Communication with JHU/ APL revealed that, for the tests conducted at AFGL, the geometry of Polar BEAR did result in severe limitations in accurately determining the satellites attitude.

This was a result of the spacecraft-to-sun and magnetic-field directions being nearly colinear. Additional geometrically limiting problems were caused by shading of the sun sensor(s) by portions of the satellite. Methods to reconstruct the attitude, including the use of Kalman-filter techniques, was conducted under TRNs 0003009 and 0003026.

Data from all passes collected during the campaign have been processed in Bellevue and shipped to AFGL, along with quick-look summary plots from each pass.

H. SPACE-RADAR IONOSPHERIC-EFFECTS STUDIES

Performing organization: NWRA
Dates: 07 July through 15 December 1987
Personnel: E.J. Fremouw (P.I.) and J.A. Secan

This section summarizes the work performed under TRN 0003015.

The Air Force and the Navy are considering development of space-based radars for purposes of defense surveillance. System configurations under consideration include sufficiently low frequencies and grazing angles and sufficiently large apertures (synthetic or otherwise) that the effects of the ionosphere on the radar propagation path must be included in the considerations. The objectives of this TRN are to advance understanding of ionospheric effects on space-based radars, to identify areas of shortfall in analysis or data to meet design needs, and to develop approaches to mitigate shortfalls.

Toward the foregoing ends, AFGL organized a workshop to bring together engineering organizations responsible for system design and research organizations active in identifying and characterizing ionospheric effects. Among the potentially adverse affects are those arising from refractive and diffractive forward scattering through narrow angles by plasma-density irregularities, collectively termed 'radiowave scintillation.' Under this TRN, we conducted an assessment of the suitability and limitations of available computer models of scintillation, for presentation and discussion at the workshop. Our assessment was summarized in an Interim Technical Report (NWRA-CR-87-0014) on this TRN dated 30 September 1987.

During the final quarter of CY88, we assisted AFGL in logistical preparations for the workshop and participated therein. J. Secan presented our scintillation-model assessment in a talk at the workshop entitled 'WBMOD Ionospheric Scintillation Model: Current Status and Projected Efforts." Following the workshop, we assisted AFGL in obtaining annotated copies of presenters' viewgraphs and, from some speakers, brief textual summaries, both for inclusion in workshop proceedings.

Contributions from all speakers, with one exception, now have been received by AFGL. When the final one has been received, they will all be sent to NWRA for our review and evaluation of the workshop results, and we'll perform the mechanics of producing and distributing the proceedings. Our review and evaluation will concentrate on specific shortfalls in models and in analysis of existing data and on needs for specific new data sets. Our endeavor will be to assess and recommend approaches to mitigating those shortfalls. Toward these ends, we have assembled lists of existing scintillation data from AFGL and from the DNA HiLat/Polar Bear Science Team.

I. INVESTIGATION OF STRATOSPHERIC/MESOSPHERIC ELECTRON SAMPLING PROCESSES

Performing organization: SAIC
Dates: 20 March through 30 September 1987
Personnel: E. Szuszczewicz (P.I.), D. Rault, and C.-L. Chang

This section summarizes the work performed under TRN 0003007. The objective of this TRN is to investigate the electron collection processes important in the 45 to 75 *km* altitude range employing a combination of theoretical modelling and experimental testing. The expected results of this multi-year investigation include: (1) a relation between ambient electron density and collected ion/electron fluxes, (2) the altitude dependence of the electron collection efficiency, (3) the effect of rocket charging and other stray fields upon the electron collection process, and (4) a recommendation for an instrument front-end configuration which is amenable to theoretical modelling.

1. Ion Quadrupole Mass Spectrometer Experiment

A rocket-borne mass spectrometer was launched by AFGL/LID at Wallops Island, VA to an 86 km apogee. Parachute deployment and ion sampling were initiated on the upleg trajectory, with mission emphasis on ion sampling in the altitude range 75-45 *km* on downleg. The launch, deployment and sampling scenario are illustrated in the top panel of Figure 3. The sensor was a quadrupole ion mass spectrometer capable of positive and negative ion sampling modes. Its aperture plate was flush mounted with the forward surface of the main payload body (see lower panel of Figure 3). Forward of the aperture plate was a charged-particle flow control cell (called a 1-D ion flux cell) designed to confine charged-particle motion to one dimension by the application of bias potentials to a parallel-plate geometry. The ion flux cell, shown in more detail in Figure 4, had a forward injector "plate" constructed from an open helix with 0.008 inch holes for forward injection of SF_6.

While the measurements involved ion composition, the ultimate objective was the determination of the ambient free electron population, through conversion to negative ions (SF_6^-) by SF_6 injection at the forward plate (injector plate of the 1-D cell. The cell design is illustrated in Figure 4.

The approach to N_e measurement is based on the conjecture that the ambient free electron population will be directly related to the induced negative ion population (i.e., SF_6) because of its rapid attachment to SF_6. Collisionality, heavy particle fractionation, neutral SF_6 distribution, negative ion attachment time, flowfield effects, and electric field collection efficiencies all contribute to the exact relationship between the free electron density and the sampled negative ion distribution. The overall task involved: (1) the design of the front-end sampling technique, (2) the development of a first-principles model which predicts the relationship between measured values of SF_6 and the ambient free electron population, (3) the development of concepts and designs for direct N_e measurement techniques, and (4) the adaptation of the SAIC plasma facility for flight simulations (Szuszczewicz et al, Sept 1987).

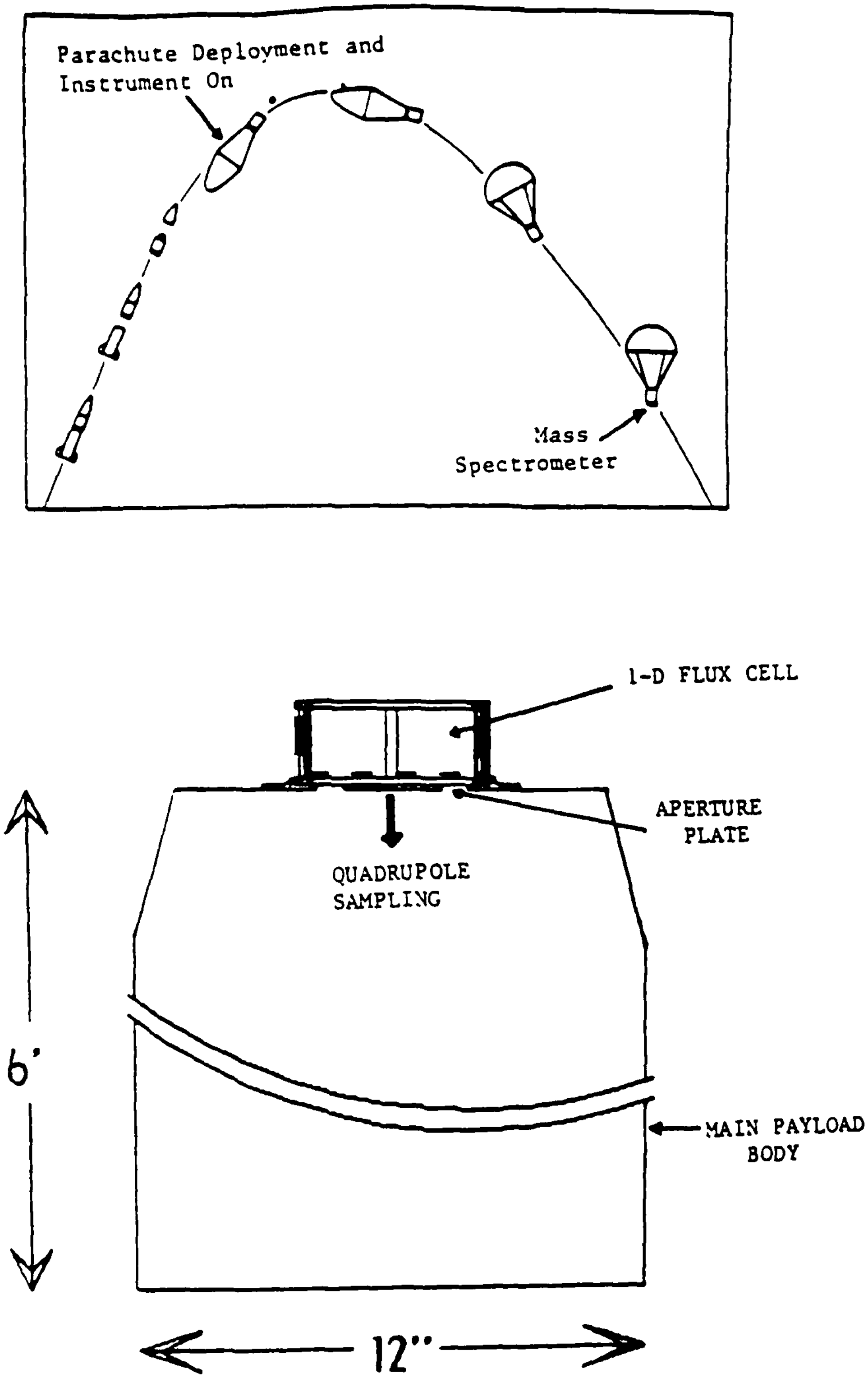
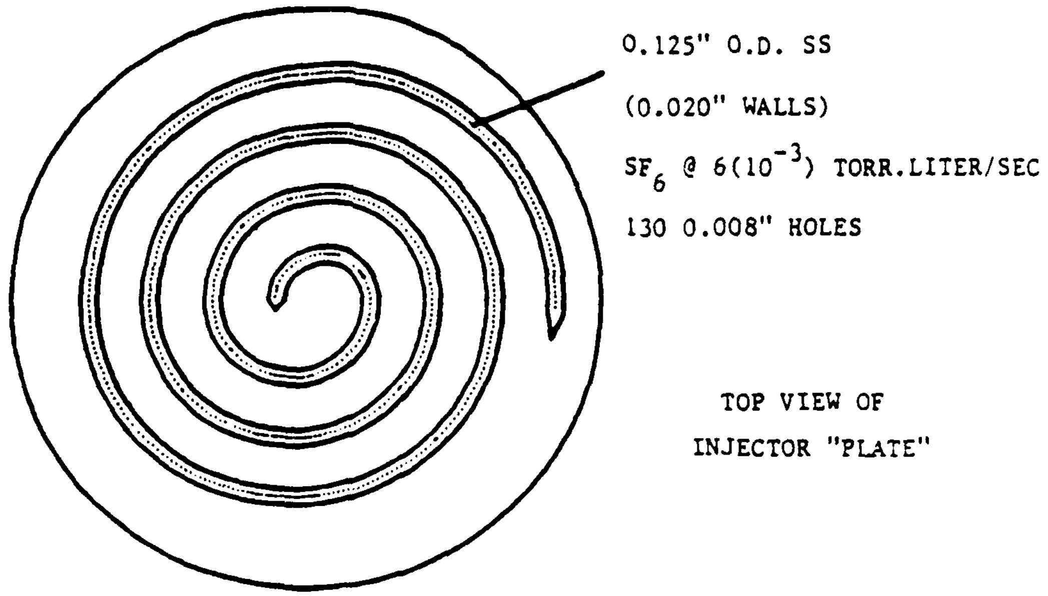


Figure 3. Illustration of launch, deployment and mass sampling scenario (top panel adapted from Project DROPMAS). Lower panel illustrates the main payload body and configuration of 1-D Ion Flux Cell relative to the aperture plate and region of quadrupole ion sampling.

1-D ION FLUX CONTROL CELL



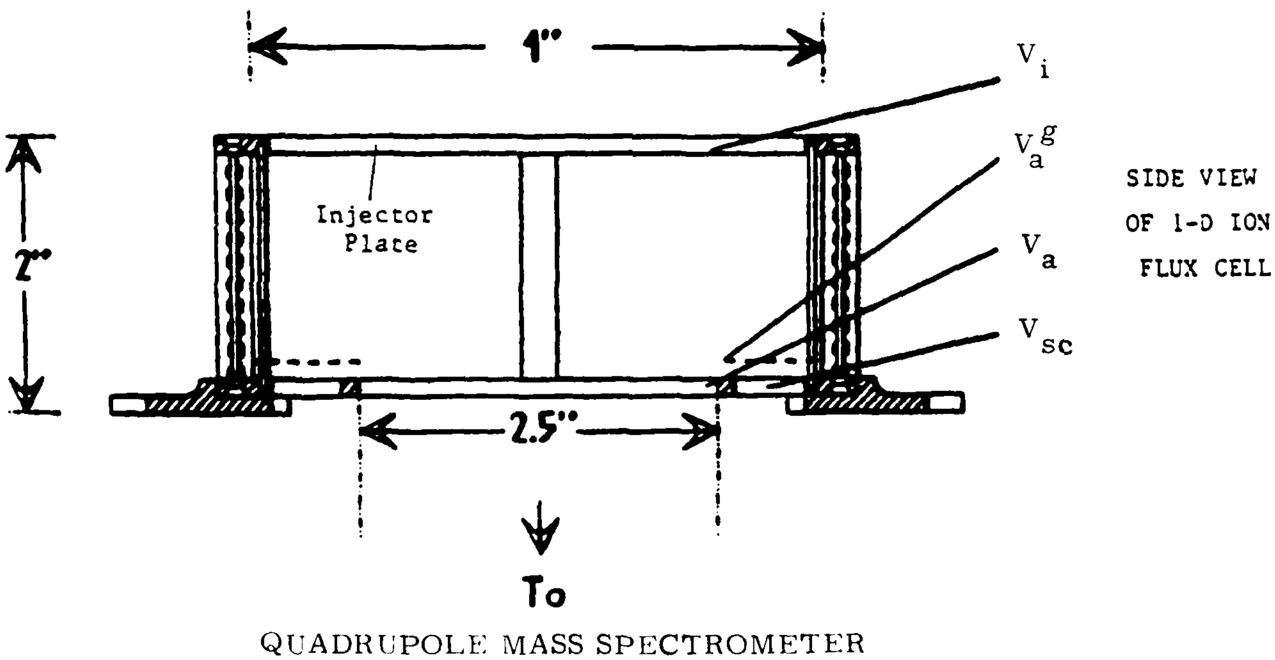


Figure 4. Bottom panel illustrates side view of the 1-D Ion Flux Cell. Applied potentials include V_I (injector voltage), V_a (aperture voltage) and V_a^g (guard voltage = V_a). V_{sc} represents the payload potential. Top panel illustrates the injector plate constructed from an open helix with 0.008" holes for forward injection of SF_6.

2. Instrument Design

The 1-D ion flux cell design focused on a pillbox geometry with a 2 inch height and the maximum diameter allowable in the launch vehicle configuration (see e.g. Figures 3 and 4). Other design drivers included a guard electrode for the aperture plate and controllable potentials to the injector plate V_i, the aperture plate V_a, and the guard electrode V_g^a. In all cases V_a and V_g^a were to be equal. Design guidelines also included the measurement capability of bipolar currents at the injector surface and the aperture plate. To minimize dielectric charging on active surfaces, all electrode surfaces were to be gold plated.

Relative to SF_6 injection and ion sampling, the following recommendations were made: (1) that ion sampling begin on the upleg portion of the trajectory before SF_6 injection was initiated. The preferred mode would involve the delay of SF_6 injection until apogee. (2) It was also recommended that the ion sampling format be based on a 'minimum mass spectrum requirement" (see Table 4), (3) that voltage differences between the injector and aperture plate not exceed an absolute value of 2 volts, and (4) that the injector plate be operated at the local plasma potential.

Figure 5 illustrates the phenomenological domains that affect the overall sampling process and accordingly drives the attendant modelling activity. Region 1 defines the domain outside the 1-D cell and forward of the payload. In this region two major elements control the charged particle flow from the ambient environment to the injector surface: (1) a penetrating electric field if the injector plate is not held at the ambient plasma potential, and (2) the ambient flowfield as defined by the ambient particle distributions and the relative velocity in the payload frame.

The optimum sampling configuration involves no field penetration into Region 1. Such a field would penetrate to relatively large distances (because of low charge densities, effects of high charge-neutral collisionality and resulting degradation of plasma shielding); it would risk modification of the ambient charged particle mass distributions (e.g. through fractionation), and necessitate a three-dimensional code with end effects and fringing fields.

Since the payload preparation and launch schedule did not allow time to prepare the electronics to track the local plasma potential and apply appropriate voltage levels to the injector plate, an approach was adopted to apply several levels of voltage to the injector, and plan for post-flight analysis to determine the values and conditions under which the injector was at or closest to the local plasma potential. AFGL/LID selected -5, -1, -.5, 0, +.5, and +1 *volts* for the positive ion collection mode and -1, -.5, 0, +.5, +1 and +5 *volts* for the negative ion collection mode. For purposes of pre-flight modelling, zero electric field penetration into Region 1 was assumed.

With zero field penetration assumed in Region 1, analysis focused on the flowfield effects on the transport of charge from the ambient environment to the injector surface. While the numerical flowfield simulation included Region 2 (i.e., the domain within the 1-D cell), initial emphasis in the simulation focused on the flowfield input to the 1-D cell, and the use of those results as an input boundary condition for a Particle-in-Cell (PIC) code which calculated the transport of all charged species from the injector

Table 4. Minimum Mass Spectrum Requirements.

POSITIVE IONS Mass	Specie	NEGATIVE IONS Mass	Specie
19	H_3O^+, F^+	19	F^-
30	NO^+	32	O_2^-
32	O_2^+	35	Cl^-
37	$H_3O^+ \cdot (H_2O)$	60	CO_3^-
38	F_2^+	61	HCO_3^-
55	$H_3O^+ \cdot (H_2O)_2$	62	NO_3^-
		78	$CO_3^-(H_2O)$
73	$H_3O^+ \cdot (H_2U)_3$	80	$NO_3^- \cdot (H_2O)$
		93	$NO_2^-(HNO_2)$
109	$H_3O^+ \cdot (H_2O)_5$	97	HSO_4^-
145	$H_3O^+ \cdot (H_2O)_7$	125	$NO_3^-(HNO_3)$
		127	SF_5^-
		146	SF_6^-

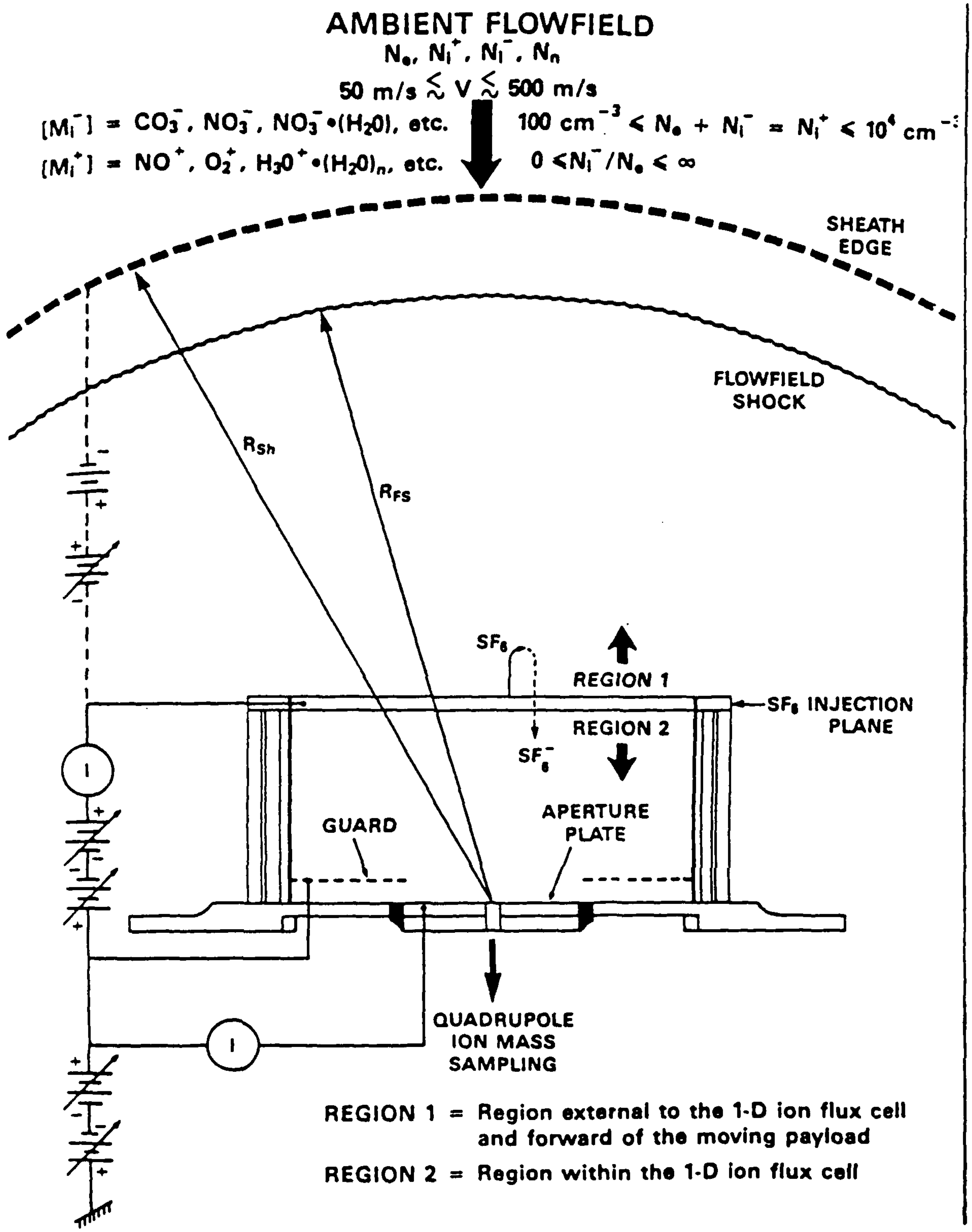


Figure 5. Phenomenological domains in the sampling process.

plate to the mass spectrometer aperture. The PIC code was designed to include flowfield collisionality and electric field effects.

3. Laboratory Simulations and Innovative Approaches to Direct Measurements of N_e

Parallel to the design of the mass spectrometer experiment was an effort that focused on the development of laboratory capabilities to conduct simulation experiments for verification of the in-flight observations and the attendant theoretical/numerical models. This effort was complemented by the development of design considerations focused on new approaches to the direct measurement of the N_e population. The approach was directed at devices that required no modification of the ambient environment (as in the SF_6 injection), and devices that could be readily tested under laboratory simulations and developed for the next flight for complementary diagnostics with the mass spectrometer. The results pointed toward the promising application of a new device, a plasma-potential, particle-density and distribution detector (referred to as a $(PD)^3$), which would provide direct measurements of the integrated negative ion population, the integrated positive ion population, the free electron density and the energy distributions of each of the three major charge species. This instrument would also provide direct measurement of the local plasma and vehicle potentials, and irregularity distributions in the ambient charged particle distributions with minimum effects of unknown and uncontrolled offset voltages due to charging on "contaminated" surfaces. The $(PD)^3$ device and the 1-D Ion Flux Cell could be tested under simulated flight conditions in the SAIC plasma laboratory facility.

J. FEASIBILITY OF RADIO BLACKOUT MITIGATION IN THE BRAKING PHASE OF AOTV OPERATIONS

Performing organization: SAIC
Dates: 20 April through 30 September 1987
Personnel: E. Szuszczewicz (P.I.), D. Rault, and C.-L. Chang

This section summarizes the work performed under TRN 0003005. The objective of this TRN is to develop a computer modelling code which will enable calculation of chemical modification techniques on phenomena of radio blackout during re-entry of orbiting spacecraft.

1. Brief Description of the Problem

Communication with hypersonic vehicles in an Earth re-entry mode can be severely hampered by intense plasma created by the vehicle's interactions with the ambient neutral particle populations. The intense plasma, with densities in excess of 10^{15} cm^{-3}, is formed primarily at surfaces perpendicular to the direction of motion, and can envelop the entire vehicle. The resulting plasma will flow around the vehicle form the stagnation region and envelop the vehicle with complex configurations of excited atoms and molecules, and distributions of ions and electrons. The plasma state and its attendant spatial distributions are critically dependent on the reentry velocity, ambient particle populations, vehicle geometry, outgassing characteristics, and turbulence. From the standpoint of communications, the free electrons are the most important constituent since their attendant plasma frequency characteristically represents the cut-off frequency below which no electromagnetic waves can propagate. The critical frequency at a number density of $10^{15}\ cm^{-3}$ is 270 GHz.

The projected Aero-assisted Orbital Transfer Vehicle (AOTV), with its high energy dissipative velocities at altitudes near 90 km, will generate very intense reentry-type plasmas and threaten command and control functions during its perigee maneuvers. While there has been considerable modeling and measurement activity on reentry plasmas, the domain of AOTV interactions (see Figure 6) are substantially unique to warrant an especially careful and critically unique approach to analyzing the problem. In contrast with the Shuttle, for example, there is virtually no flight data relevant to the AOTV entry problem (see top panel Figure 6) and there are a number of factors that significantly increase the difficulty of the analytical/numerical task. The chemistry is more complex and the reaction rates are less reliable; the geometry is far from simple, and the high kinetic properties of the re-entry plasma can create magnetic field anomalies and high levels of turbulence. As a result of the complexities and uncertainties, it is expected that a carefully constructed code development program with a large number of test cases will be required. The computational task would be excessive if the geometrically precise full 3-D flowfield were calculated, but a stepwise progressive program of 1-, 2- and symmetric 3-D simulations should be expected to generate confidence in understanding the interactions and the full spectrum of processes contributing to the plasma creation and redistribution of electrons around the vehicle. While the blackout concern is focused on the wake region of the AOTV, it is clear that the wake plasma distribution and its threat can only be properly simulated if the ram plasma and flowfield calculations are properly accounted for.

The blackout problem can be mitigated by the injection of electron attaching gases which convert the free electron population in the flowfield to negative ions. The goal, of course, is the total removal of free electrons, or their reduction to attendant critical frequencies below that of the command and control channel. SF_6 is one such gas and has the advantage of having been applied in a number of programs, both experimental and theoretical.

The task focused on the development of a theoretical/numerical computer model which will assist in the evaluation of the chemical modification technique, with specific objectives to identify the critical placement of injection ports, the chemical species most appropriate to the problem,and the rates of chemical injection (Szuszczewicz and Rault, September 1987).

2. Simulations of the Flowfield and SF_6 Injection

The approach adopted for the first year's activity pivoted about a simplified representation of the AOTV geometry. This approach made it possible to develop very early in the program some physical insight into the ram/wake flowfields and a quantitative perspective on the location of SF_6 injectors, the attendant mass injection requirements and mixing ratios in the wake.

The simplification of geometry is illustrated in Figure 7, where the bold-faced object is a cross-section of a R-Z symmetric body of rotation (in this case a cylindrical slab). This cylindrical slab was adopted as a representation of the AOTV, and allowed a fully three-dimensional flowfield calculation. Results for a 9 km/s vehicle velocity near the 90 km regime are presented in Figure 8. Attention to the

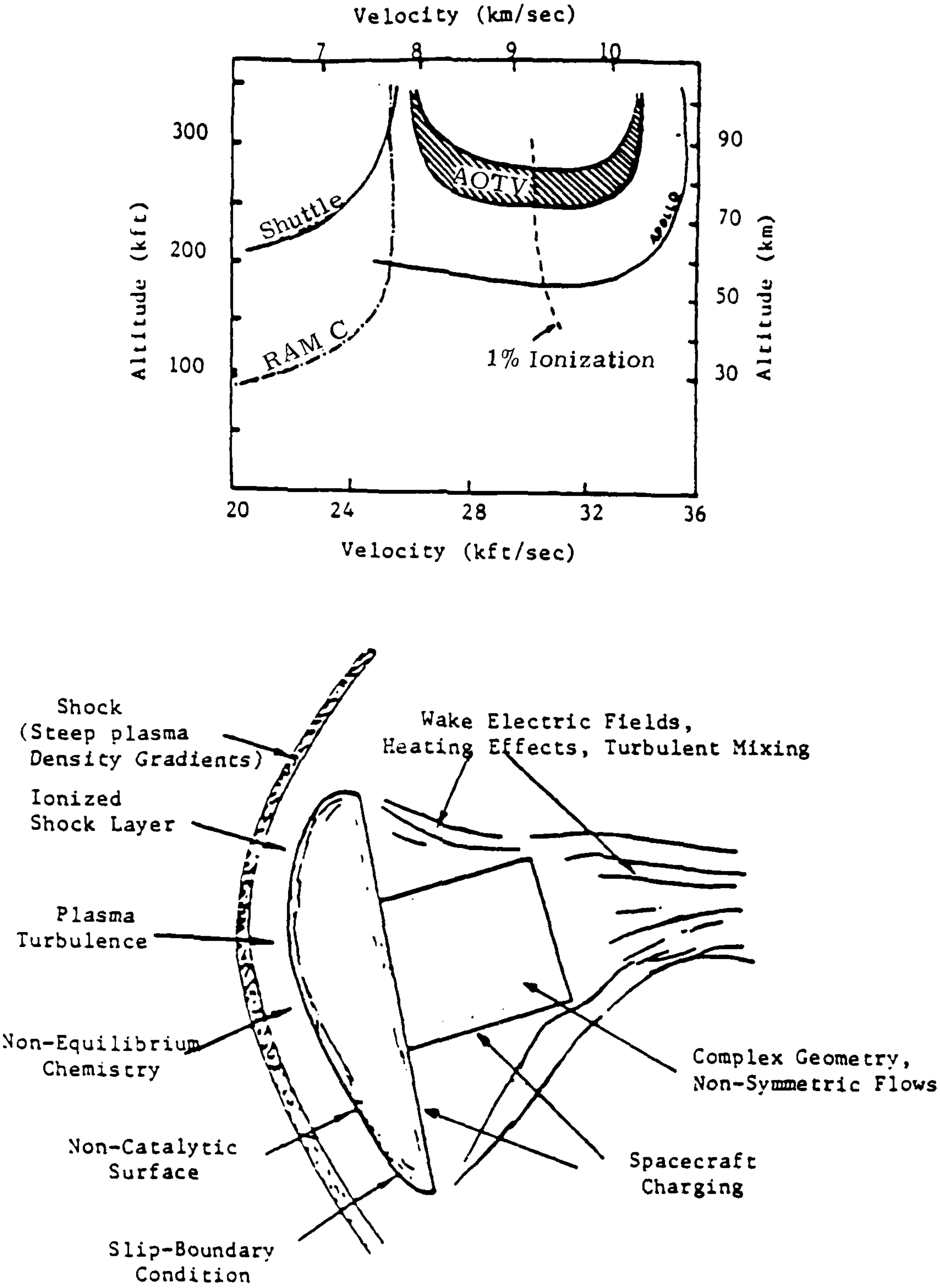


Figure 6. Top panel: Comparison of flight regimes in the AOTV, Apollo and RAM-C Re-entry Programs. Bottom panel: Illustration of Elements contributing to the complexity in developing model predictions for AOTV re-entry plasma distributions. (Figures are adaptations of results in the NASA AOTV and RAM-C programs.)

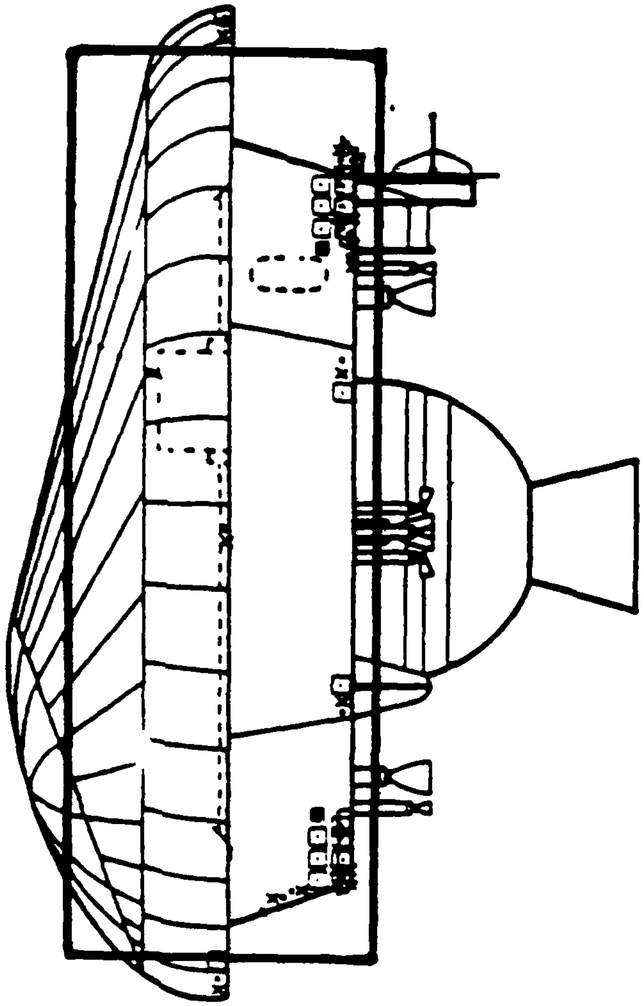


Figure 7. The AOTV (AFE) shown in cross section with an R-Z symmetric body of rotation (the bold-faced object), which in this case is a cylindrical slab used in the re-entry simulations.

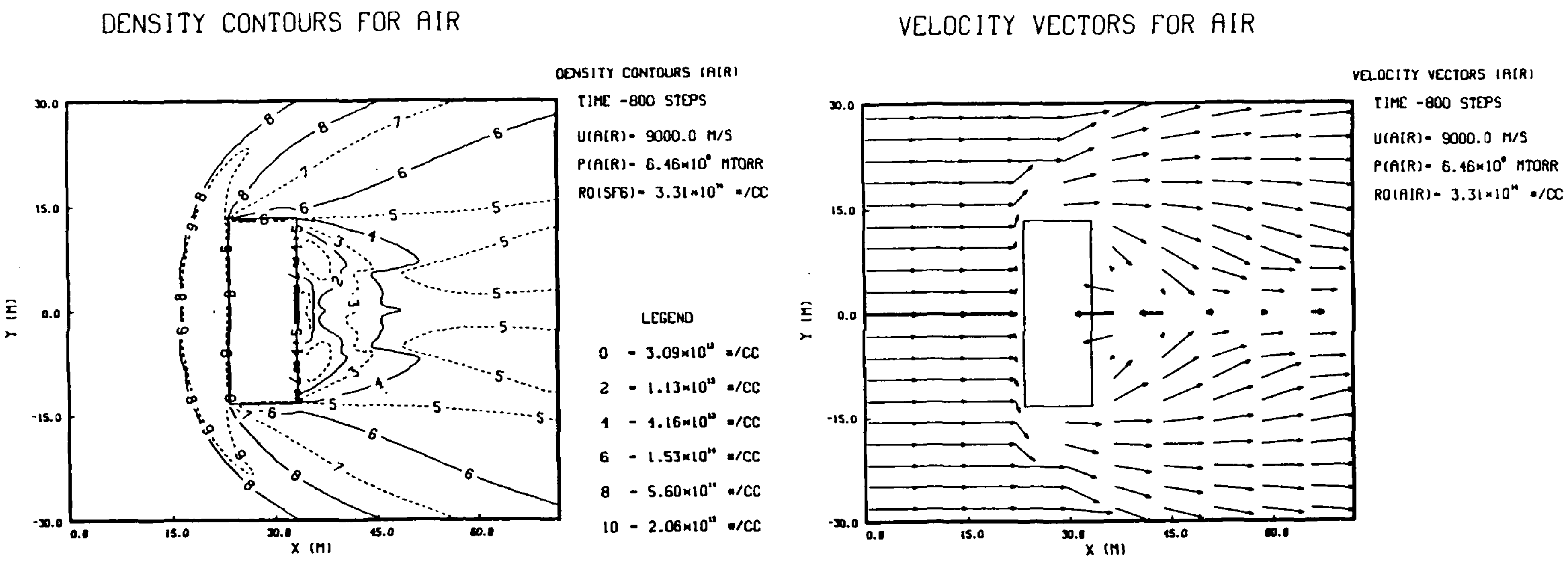


Figure 8. Simulated AOTV flowfield at a velocity of 9 km/sec near an altitude of 90 km.

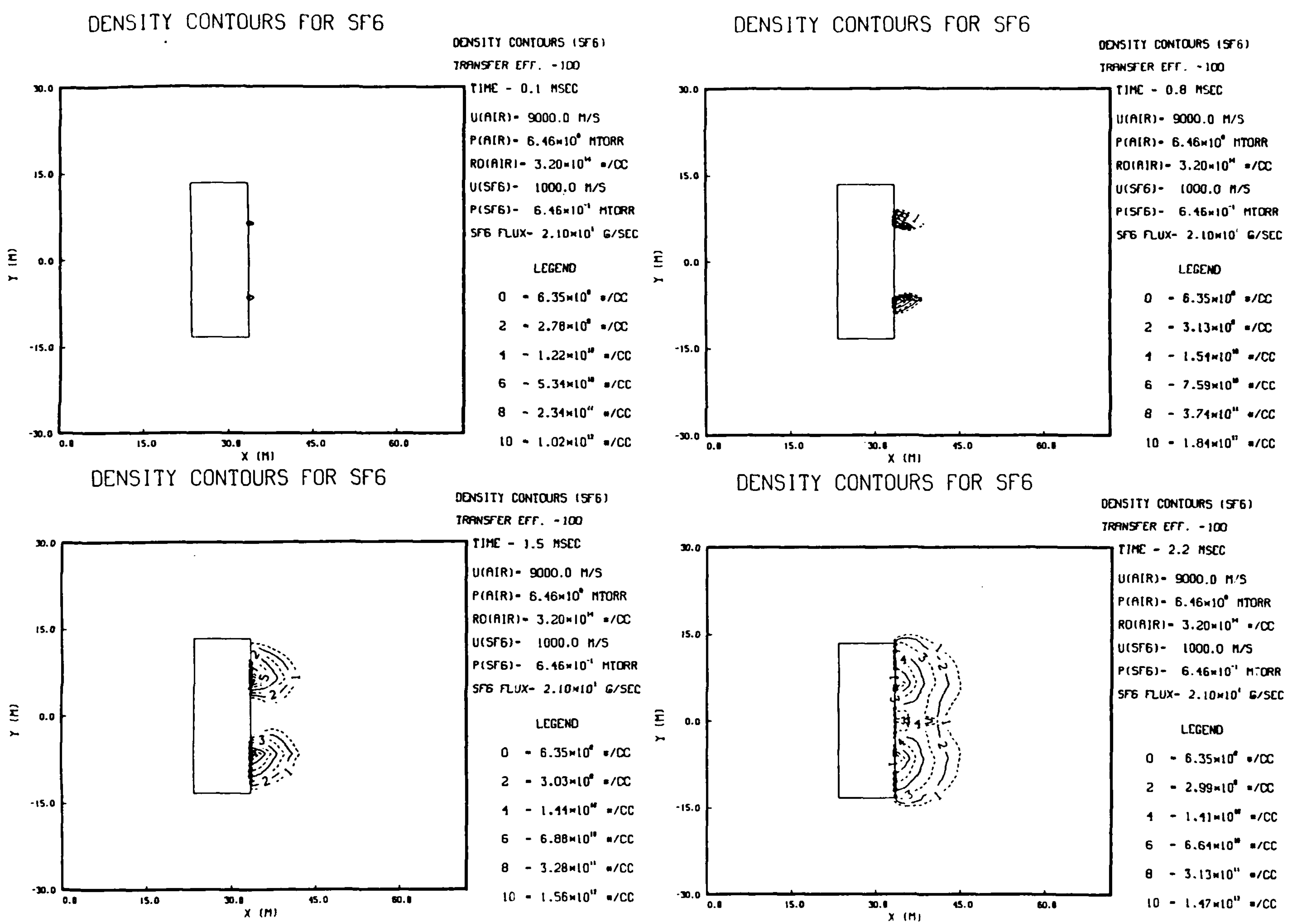


Figure 9. Density contours of SF_6 injection into the AOTV wake shown as a function of time after valve

velocity vectors and the density contours of the ambient flowfield (in Figure 8) suggest appropriate locations of injectors in the wake region that are most likely to provide maximum mixing. With the guidance from these results, we initiated a number of numerical experiments involving SF_6 injection at two points in the wake region with sample results shown in Figure 9. The vehicle conditions correspond to those in Figure 8, while the SF_6 flow has been specified by injection velocity at 1 km/s at a pressure of .65 mTorr. This corresponds to a flux of 21 gm/s. Other cases were run with additional outputs specifying the resultant SF_6 mixing ratio integrated over the wake volume. If one assumes a 1% ionization level in the wake regime, the associated requirement for full free electron gettering would be an associated mixing ratio of 1%. Numerical experiments focusing on that assumption were detailed in our FY-87 report.

3. Perspectives on the Problem and the Approach

The results introduced in the preceding section and detailed in the FY-87 report represented an important first step in establishing a comprehensive numerical model capable of fulfilling the Task goals. However, there are several important aspects in the future of the code development that should be identified. The first is geometry. As discussed earlier, the AOTV/AFE geometry is itself a challenge to the construction of a computational grid that is compatible with the changing shapes that define the body and is amenable to the boundary conditions that apply to each cell in the entire grid. Our first approach was the simplified scheme described above, but in parallel we have been pursuing a more appropriate geometry and associated computational grid that will improve confidence in the flowfield calculations and establish a basis for ever-increasing realism in the predictions of mixing ratios for the injected species in the AOTV wake regime. We see this as one of the important subtasks in our follow-on activities.

Other important aspects that require increased attention include: (1) the chemistry that contributes to the charged-particle production and ion-mass distributions, (2) the plasma particle and field issues that dominate the levels of turbulence, particle energization processes, diffusion and transport and, (3) a Monte Carlo approach to the flowfield calculations. Chemistry has been a long-standing element in codes developed to date, with the major hurdle not being the number of reactions that an investigator can include in the code, but rather the integrity of the reaction rates appropriate to the system. To a large extent the rates in current use are mostly conjecture. They are either values specified at temperatures near $300^{O}\ K$, or speculative extrapolation of those values to the temperature regime appropriate to the AOTV problem ($5{,}000$-$20{,}000^{O}\ K$). While this is a serious problem, there is not much that can be done until concerted laboratory programs are initiated to determine the rate coefficients that match the AOTV conditions.

A problem area that is at least as important as that of chemistry involves plasma processes and interactive effects with electric and magnetic fields. To date there has not been any effective development of AOTV-oriented computer codes that include plasma processes which impact the spatial distribution of charged-particles. Typical omissions include the effects of vehicle charging, the ambient magnetic field, and plasma turbulence . . . all of which can affect the energy distributions of the charged species, their reactions rates, transport, and diffusion. These are terms, that if they are not properly accounted for in the ram and/or streamline regime, will not provide accurate predictions. We have identified the plasma issue as an important subtask element for our follow-on activities, with a projected approach that will focus on specified phenomenological domains. In this way we expect to be able to quantify the relative importance of plasma effects relative to the hydrodynamic effects of the neutral flowfield. This will provide a building block for insertion into the geometrically-accurate 3-D aspects of the entire flowfield.

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