FINAL REPORT

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of Work Performed

Under Contract #NAS 8-37109:

Co-Investigator for Study Entitled

"Research On Orbital Plasma Electrodynamics (ROPE)"

by

Dr. Devrie S. Intriligator, Director
Space Plasma Laboratory
Carmel Research Center
Post Office Box 1732
Santa Monica, CA 90406

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I. ABSTRACT

This final report summarizes some of the important scientific contributions to the Research on Orbital Plasma Electrodynamics (ROPE) investigation, to the Tethered Satellite System (TSS) mission, and to NASA that resulted from the work carried out under this contract at Carmel Research Center. These include Dr. Intriligator's participation in the PIT for the TSS-1R simulations and flight, her participation in ROPE team meetings and IWG meetings, her scientific analyses, and her writing and submitting technical papers to scientific journals. The scientific analyses concentrated on the characterization of energetic ions and their possible relation to pickup ion effects, correlation of particle and other effects (e.g., magnetic field, satellite surface), and collaboration with theorists including with ROPE co-investigators. In addition, scientific analyses were carried out of the effects due to satellite gas releases.

II. INTRODUCTION

The next section, HIGHLIGHTS OF CARMEL RESEARCH CENTER PERFORMANCE, documents and summarizes some of the significant scientific contributions to the TSS-1R mission and to the NASA space science and technology programs accomplished under Contract NAS 8-37109 at Carmel Research Center (CRC). The period of performance of this contract was August 1987 to September 30, 1998. This final report and the scientific publications are the end product of this contract.

The TSS-1 mission was originally launched in August 1992. The satellite was deployed to 6 km from the shuttle. On February 22, 1996 the TSS-1R mission was launched on STS-75 into a 300-km circular orbit at 28.5° inclination. The satellite was deployed to 19.6 km from the shuttle when the tether broke. Subsequently the satellite was tracked as a "free-flyer". This tracking of the satellite as a free-flyer allowed measurements of the ambient ionosphere in the vicinity of 300 km. The sending and receiving of commands and data retrieval during this time was somewhat complicated since the NASA orbital trajectory software assumed that the center of mass (cm) of the satellite system was the center of mass of the satellite itself. This was not the case since the satellite had a 19.6 km tether hanging vertical down from it so that the center of mass of the satellite/tether system was considerably below the cm of the satellite. This led to tracking difficulties and complications with the sending of commands and the downloading of data to and from the satellite. In spite of these system problems, excellent ionospheric data were obtained during this unexpected phase of the mission.

III. HIGHLIGHTS OF CARMEL RESEARCH CENTER PERFORMANCE

Many significant contributions to the TSS-1R mission and to the NASA space science and engineering goals were made under this contract at CRC. These included:

1. "Energetic Ion Characteristics in the TSS-1R Satellite Environment" by D.S. Intriligator, N.H. Stone, J.D. Winningham, K.H. Wright, R.A. Frahm, C.A. Gurgiolo, S. Orsini, F. Marcucci, and F. Mariani, preprint, to be submitted for publication, 1998.

Analysis of TSS-1R ROPE (Stone, et al., 1994) plasma observations provides new evidence for the presence of energetic ions in the vicinity of the satellite ram direction. These data were obtained during the TSS-1R satellite flight when the satellite was floating at the local ionospheric plasma potential both before the tether break and after the tether break when the satellite was a "free-flyer". The energies of the energetic ions can extend up to $\geq$ 150 eV. There is an asymmetry with respect to the ram direction in the flux contours of the energetic ions and this asymmetry tends to be controlled by the Bz component of the ambient magnetic field as measured by TEMAG (Mariani et al., 1998). The origin of the energetic ions is unclear and several possible sources are discussed including if the ions are pickup ions, a monolayer on the satellite surface from atmospheric NO. The sputtering of the ions from the antimony and tin paint that was painted on the satellite surface is also a possibility, but it appears to be less likely.

2. "Characteristics of a Satellite Gas Release Event in the TSS-1R Satellite Environment" by D.S. Intriligator, N.H. Stone, et al., paper in preparation, 1998.

Following the satellite thruster firing the satellite potential which had been charged up to ~1 kV, dropped down to a few volts and the tether current surged to ~600 mA and then remained elevated at ~500 mA. So during the gas release at the TSS-1R satellite the satellite current increased while the voltage decreased. Also the collection efficiency increased by a factor of ten. Before the thruster firing the DIFP ion intensity was zero and after the thruster firing it saturated (at a voltage greater than 100 volts). The source of these particles is either the ionosphere or ionization products. Before the thruster fired the current path was over the surface of the satellite. After thruster firing the path was through the thruster nozzle, indicating a change in the current path. The BMSP voltage before the thruster firing was in the range of 580 to 1000 volts. After the firing there was a sharp drop to 500 volts followed by stairstepping down to 100 volts. Before the thruster firing the DCDV was at -1600 to -1700 volts; after the firing there was a sharp drop to -2400 volts. This event is particularly interesting for comparison with the tether break situation when an unintended gas discharge from the tether led to voltage and current surges.

3. Characterization of pickup ion effects; correlation of particle and other effects (e.g., magnetic field), and collaboration with theorists including ROPE co-investigators.

These tasks were an intrinsic part of the analyses performed for items 1 and 2 above. The characterization of the energetic ions discussed in item 1 includes specific discussions of the characterization of pickup ion effects and the correlation of particles and magnetic fields. We are grateful to the ROPE and TSS-1R theorists for so generously sharing their ideas with us and for their comments on the energetic ion manuscript.

4. Evaluation of spacecraft paint and other characteristics on the scientific results of this contract.

It appears that it was unfortunate that the TSS-1R satellite had an antimony (Sb)-tin(Sn)-epoxy paint on its outside surface. The primary reason for this statement is that the work function of this Sb-Sn-epoxy paint is ~5 eV which is approximately the same energy as the ram O^+ ions, i.e., the ambient ionospheric oxygen ions that are "rammed" into the front of the satellite as it plows through the ambient ionosphere at a speed of ~8 km/s. Thus these ram O^+ ions colliding with the Sb-Sn-epoxy paint can give rise to electrons which can severely alter the satellite environment. This affects the observations being made by the various instruments on the satellite and on the boom and probably also on the shuttle. Vanderbilt University has investigated some of the surface effects for the TSS-1R mission. Their results (which were faxed to us on November 16, 1998) indicate the efficiency of photoemission from the Sb-Sn-epoxy paint. They identify 5.2 eV as the work junction of the paint. The efficiency curve has an exponential shape with increasing efficiency at higher eV. The secondary electron yield of the paint is exceedingly peaked in the low energy region below 100 eV.

Another aspect of the Sb-Sn-epoxy paint complications is whether or not the paint could be a source of ions through sputtering (of the paint) by bombardment analogous to that which occurs, for example, at the surface of the moons of Jupiter. To investigate this possibility Dr. Intriligator conferred with Professor Judge and Dr. Wu of the University of Southern California Space Science Center. Since they believed this was a serious possibility, a literature search was performed. It was found that Sb-Sn sputtering can be enhanced in a reactive atmosphere such as the TSS-1R environment where oxygen is present. Also that oxide films can form on these surfaces and that composition gradients can be present. We concluded that in order to more clearly ascertain the sputtering properties of the Sb-Sn-epoxy for the TSS-1R environment, laboratory experiments would have to be carried out, similar to those conducted by Professor Judge and Dr. Wu for other materials.

5. Participation in TSS-1R SIMS, IWG's, ROPE team meetings, and other support of the TSS-1R mission.

Dr. Intriligator participated in and supported the TSS-1R mission in order to enhance the overall space science, mission, and NASA results. She was an active member of the PIT throughout the TSS-1R SIMS and mission (both pre-tether break and post-tether break). During the TSS-1R pre-mission phase she extensively participated in the SIMS and other project activities at MSFC. In the PIT she actively supported not only the ROPE science goals and operations but also the overall TSS-1R goals and operations by assisting the other scientists and the project as various issues and alternatives arose. During the post-tether break activities she worked closely with the project to ensure that the ROPE instrument configurations and other satellite and shuttle instrument configurations were correct in spite of the tracking and command problems due to the use of an incorrect cm for the satellite/tether system. After the mission, during the analysis phase, she participated in ROPE team meetings and IWG's For example, at the March 1996 IWG in Washington, DC, she prepared several charts for the TSS-1R briefing at NASA Headquarters. These included not only the TSS-1R Electrodynamics Gas Release at Satellite briefing chart but also the TSS-1R Dynamics chart that the astronaut Franklin-Diaz then used in his briefing. Later in the analysis phase she actively participated in data and information exchanges with ROPE co-investigators and with those from other teams (e.g., TEMAG).

IV. CONCLUSIONS

The TSS-1R mission was an important and successful NASA mission. The results of this mission, including those supported by this contract, indicate that tethers in space can provide unique opportunities both in terms of technology and science. NASA, and its international partners, should build on the TSS-1R results so as to enhance our knowledge and utilization of space in the vicinity of earth and other planets.

V. REFERENCES

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Stone, N.H., K.H. Wright, J.D. Winningham, J. Biard, and C. Gurgiolo, A Technical Description of the TSS-1 ROPE Investigation, Il Nuovo Cimento, 17, 85-99, 1994.

APPENDIX

SYMBOLS AND ABBREVIATIONS

AMU	Atomic mass units
BMSP	Boom-Mounted Sensor Package
CRC	Carmel Research Center
DIFP	Differential Ion Flux Probe
eV	Electron Volts
H^+	Atomic Hydrogen Ions
IWG	Investigator Working Group
K	Kelvin Temperature
KeV	Kilovolt
KM	Kilometer
MSFC	Marshall Space Flight Center (NASA)
NASA	National Aeronautics and Space Administration
NO	Nitrous Oxide
O^+	Atomic Oxygen Ions
PIT	Principal Investigator Table
ROPE	Research on Orbital Plasma-Electrodynamics
S	Seconds
Sb	Antimony
SIMS	Simulations
Sn	Tin
SPES	Soft-Particle Energy Spectrometers
TEMAG	Magnetometer Experiment on TSS
TSS-1R	Tethered Satellite System - Reflight
V	Volts