NASA/CR—2003-212005/PART12

Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites

Express/T-160 Project Express A2 and A3 Sensors Operations Procedures Document

N. Sitnikova, D. Volkov, I. Maximov, and V. Petrusevich
Nauchno-Proizvodstvennoe Obiedinenie Prikladnoi Mekhaniki, Krasnoyarsk region, Russia

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June 2003

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Preface

This 12-part report documents the data obtained from various sensor measurements taken aboard the Russian Express-A2 and Express-A3 spacecraft in Geosynchronous Earth Orbit (GEO). These GEO communications satellites, which were designed and built by NPO Prikladnoy Mekhaniki (NPO PM) of Zheleznogorsk, Russia, utilize Hall thruster propulsion systems for north-south and east-west station-keeping and as of June 2002, were still operating at 80° E. and 11° W., respectively. Express-A2 was launched on March 12, 2000, while Express-A3 was launched on June 24, 2000. The diagnostic equipment from which these data were taken includes electric field strength sensors, ion current and energy sensors, and pressure sensors. The diagnostics and the Hall thruster propulsion systems are described in detail along with lists of tabular data from those diagnostics and propulsion system and other satellite systems.

Space Power, Inc., now part of Pratt & Whitney's Chemical Systems Division, under contract NAS3–99151 to the NASA Glenn Research Center, obtained these data over several periods from March 12, 2000, through September 30, 2001. Each of the 12 individual reports describe, in detail, the propulsion systems as well as the diagnostic sensors utilized.

Finally, parts 11 and 12 include the requirements to which NPO PM prepared and delivered these data.

Filename	Title
CR-2003-212005-PART1.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A2 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of March 12, 2000 to and Including June 15, 2000, Task 29
CR-2003-212005-PART2.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type B Sensors for "Express-A" Number 2 Satellite for the Period of March 12, 2000 to and Including June 15, 2000, Task 25
CR-2003-212005-PART3.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A3 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of June 24, 2000 to and Including September 30, 2000, Task 30
CR-2003-212005-PART4.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type A and Type B Sensors for "Express-A" Number 3 Satellite for the Period of June 24, 2000 to and Including September 30, 2000, Task 27A

Filename	Title
CR-2003-212005-PART5.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A3 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of October 1, 2000 to and Including December 31, 2000, Task 31
CR-2003-212005-PART6.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type A and Type B Sensors for "Express-A" Number 3 Satellite for the Period of October 1, 2000 to and Including December 31, 2000, Task 27B
CR-2003-212005-PART7.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A3 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of January 1, 2001 to and Including March 31, 2001, Task 32
CR-2003-212005-PART8.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type A and Type B Sensors for "Express-A" Number 3 Satellite for the Period of January 1, 2001 to and Including March 31, 2001, Task 27C
CR-2003-212005-PART9.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire Express-A3 SPT–100 Based Propulsion Subsystem and Other Subsystem Flight Operation TM-Data for the Period of July 1, 2001 to and Including September 30, 2001, Task 33
CR-2003-212005-PART10.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Acquire TM-Data for Type A and Type B Sensors for "Express-A" Number 3 Satellite for the Period of July 1, 2001 to and Including September 30, 2001, Task 27D
CR-2003-212005-PART11.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Express/T-160E Project Express A2 and A3 Data Agreement Document
CR-2003-212005-PART12.pdf	Hall Effect Thruster Interactions Data From the Russian Express-A2 and Express-A3 Satellites Express/T-160E Project Express A2 and A3 Sensors Operations Procedures Document

SIGNATURE PAGE

This is a controlled document. Any changes require the concurrence of the two Approving Officials listed below.

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D. Allen/Schafer Corp. Date

Reviewed by: *Signature on file*
V. Petrusevich/NPO-PM Date

Approved by: *Signature on file*
A. Romashko/NPO-PM Date

Approved by: *Signature on file*
F. Elliott/GRC Date

DOCUMENTATION CHANGE PAGE

Document Title: Express/T160E Project Interface Control Document			
Change	**Description of Change**	**Date**	**Concurrence**
1	Initial Release	11/6/00	

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

ARCAN	Express spacecraft software subprogram to write sensor data to RAM once per hour
DIERA	Express spacecraft software subprogram to write sensor data to RAM every 6 minutes
DEP	Electric field sensor
DRT	Plasma sensors used to measure current density on Express A2 and A3 and ion energy on Express A3
DRT3	Plasma sensors used to measure current density and ion energy on Express A3
GCS	Ground Control Segment
GRC	Glenn Research Center
HETS	Hall Effect Thruster System
IMDD	Magnetron-inversion pressure sensor
MLI	Multi-Layer Insulation
MPZ	"Plasma Zone Module" (Express spacecraft software subprogram to write sensor data to RAM once per minute)
NASA	National Aeronautics and Space Administration
NSSK	North-South Station keeping
PPU	Power Processing Unit
PTC	Programmable Time-tagged Control
RAM	Random Access Memory
SPI	Space Power, Incorporated
U.S.	United States

1.0 Purpose

The Express A2 and A3 Sensors Operations Procedures Document describes and jointly approves the procedures to be used to operate the plasma sensors being used on the Express A2 and A3 spacecraft as part of the Express/T-160E project. This document includes experiment flight test objectives, a definition of each organization's roles and responsibilities for the flight operations, the operations procedures for the flight experiment, and the approach to be used to evaluate and distribute the data generated by the flight experiment.

1.1 Background

The Express/T-160E project was initiated in March 1997 to develop a scaled-up, enhanced version of existing HETS technology in a North-South Station keeping (NSSK) role on the Russian Express A3 communications satellite. The Express A satellites use SPT-100 thrusters for NSSK as well as for a East-West station keeping. On Express A3, we were going to use the T-160E HETS from this project instead of one of the onboard SPT-100 thrusters for part of the mission.

The majority of activity on the project was directed at developing, qualifying, and flight testing a 5.3 kW HETS including the T-160E Hall effect thruster and a modular Power Processing Unit (PPU). One of the primary goals of the project is to correlate thruster system performance testing on the ground with results obtained in space operations. In order to achieve this goal, the data collected during ground testing of HETS can be compared to data collected during the flight of that system on the Express A2 and A3 spacecraft.

The project also includes flight data collection from onboard sensors to measure plasma characteristics around the spacecraft. These sensors will be used on both the Express-A2 and A3 flights, complemented by ground tests of the sensors with Hall thrusters. The sensors will collect data periodically during the flights, when the thrusters are operating and when they are not being used. Data from the sensors will be provided by NPO-PM to the project team for analysis and comparisons with ground-based test results.

1.2 Mission Objectives

Joint US/Russian flight test operations objectives for the Express A2 and A3 flights are to successfully integrate the flight sensors with the Express-A2 and A3 spacecraft, launch the system, activate and checkout the sensors on-orbit, and operate the sensors to collect the required data from the flight.

Overall project objectives/goals for flight test operations with the sensors installed on Express A2 and A3 can be summarized as follows:

- Develop a data base to compare ground test plasma data with plasma data generated by Hall thrusters during orbital operations
- Acquire and analyze sensor data measuring plasma parameters at key locations near the spacecraft
- Acquire and analyze relevant SPT-100 propulsion system and other spacecraft subsystem data from Express A2 and A3 to help evaluate and interpret the sensor flight data.

2.0 Reference Documentation

Task 21 Completion Report, “Issue documentation on integration of sensors Type B into “Express-A” No. 2 satellite, dated 1999

Task 22 Completion Report, “Purchase type B sensors on “Express-A” #2 satellite”, dated 1999

Task 23 Completion Report, “Mount and test type B sensors on “Express-A” #2 satellite”, dated 2000

Task 20 & 24 Completion Report, “Develop procedures and techniques to dump and process tm-data from type A and type B sensors on “Express-A” #2 satellite” and “Develop procedures and techniques to dump and process tm-data from type B sensors on “Express-A” #3 satellite”, dated 2000

Express A2 and A3 Data Agreement Document, dated October 29, 2000

SPI subcontract No. 97-1088-02 for the Express/T160E Project with NPO-PM, through Mod 13, dated 2000

3.0 Joint Operations and Flight Test Team Definition

This section is intended to describe the roles and responsibilities of each organization participating in the operation of the Express A2 and A3 sensors space experiment. The lead organization for the experiment is GRC. Both SPI and Schafer Corp. are under contract to GRC and will support mission operations. NPO-PM is under contract to SPI (subcontracts under SPI's contracts with GRC) and will also support mission operations. NPO-PM is also the Express A2 and A3 spacecraft integrator and is responsible for operating the spacecraft.

3.1 NASA Glenn Research Center

GRC is the lead organization for the project. All work required to fulfill the requirements of this document will be performed by GRC personnel or by the other organizations listed below under contract to GRC. GRC will be the lead organization for the ground test portion of the project and will be responsible for comparing the flight data with the ground test data. GRC will also be responsible for distribution of data to organizations and people other than the project participants. Fred Elliott will be the GRC point of contact for flight operations.

3.2 Space Power, Inc./Pratt and Whitney

SPI is the prime contractor for the Express/T-160E project and is now part of Pratt and Whitney. All work performed by NPO-PM to accomplish the operations described in this document will be performed as part of NPO-PM's subcontract with SPI. SPI will forward the data provided from the Express A2 and A3 spacecraft to GRC and Schafer. Kent Koester will be the SPI point of contact for flight operations.

3.3 NPO-PM

NPO-PM will collect the required sensor data from the Express A2 and A3 spacecraft and reduce it to engineering units. NPO-PM will perform analysis to provide measured or inferred physical parameters, such as ion energy. They will provide this data to the U.S. project participants through SPI in accordance with the terms of their subcontract from SPI. Victor Petrusevich will be the NPO-PM point of contact for flight operations.

3.4 Schafer Corp.

Schafer will review and analyze the NPO-PM data for NASA and highlight any discrepancies requiring clarification from SPI and NPO-PM. Schafer will provide GRC with the results of the data review, which will include data plots, identification of trends or anomalies, and timeline integration of the sensor data with spacecraft subsystem data on plots to help understand any anomalies. Doug Allen will be the Schafer point of contact for flight operations.

4.0 Mission Operations

Sensors will be operated on both the Express A2 and the A3 mission to collect the relevant data both during operation of the SPT-100 thrusters and to monitor the condition of the plasma around the spacecraft before and following operations of the thrusters.

4.1 Command and Control

Control of the plasma sensors is performed using commands uplinked by the Ground Control Segment (GCS) or by using commands loaded in advance into a Programmable Time-tagged Control (PTC – a program of time settings) schedule.

4.1.1 Express A3 Plasma Sensors

There are two Type A sensors and two Type B plasma sensors (also called DRT-3) on Express A3. The telecommands listed in Table 4-I are used to command the sensors and to acquire data from them. In standard mode, telemetry data is written to onboard spacecraft computer RAM by the DIERA subprogram once per 6 minutes (240 data points per day) for up to 4 days. If more data than 4 days is collected before the RAM is read, the oldest data is overwritten. Data can also be collected once every 12 minutes, once every 24 minutes, or once every 48 minutes to allow longer time intervals before the data is overwritten. This is explained in detail in NPO-PM's "Task 20 & 24 Completion Report", including an additional set of commands to change the mode for different data collection rates.

Table 4-I Type A Sensor Telecommands

Command	Command Description
2416	Switch on all sensors
2417	Switch off all sensors
0110	Switch on the DIERA subprogram
0113	Cancel the DIERA subprogram
2420	Acquire data from RAM

4.1.2 Express A2 Plasma Sensors

There are two Type B sensors on Express A2, DRT-1 and DRT-2. The telecommands listed in Table 4-II are used to command the sensors and to acquire the data from them. The same data acquisition commands listed in section 4.1.1 above are used to acquire sensor data. Telemetry data is written to onboard spacecraft computer RAM for up to 72 hours. If more data than 72 hours is collected before the RAM is read, the oldest data is overwritten. When command 2202 is issued, a subprogram to read the RAM is also initiated.

Table 4-II. Type B Sensor Telecommands

Command	Command Description
2202	switch on the MPZ
2204	switch off the MPZ

4.1.3 Pressure Sensors (Express A2 and A3)

There are two pressure sensors on Express A2 and A3, IMDD1 and IMDD2. The telecommands listed in Table 4-III are used to command the sensors and to acquire the data from them. Telemetry data is written to onboard spacecraft computer RAM by the ARCAN subprogram once per hour for up to 24 hours. If more data than 24 hours is collected before the RAM is read, the oldest data is overwritten.

Table 4-III. Pressure Sensor Telecommands

Command	Command Description
2407	switch on the IMDD
2410	switch off the IMDD
2411	setup IMDD1
2412	setup IMDD2
1645	Switch on the ARCAN program
1646	Switch off the ARCAN program
1647	Acquire the IMDD report

4.1.4 Electric Field Intensity Sensors (Express A2 and A3)

There are three electric field sensors on Express A2 and A3, DEP1, DEP2, and DEP3. The telecommands listed in Table 4-IV are used to command the sensors and to acquire the data from them. Telemetry data is written to onboard spacecraft computer RAM by the DIERA subprogram once per 6 minutes (240 data points per day) for up to 10 days. If more data than 10 days is collected before the RAM is read, the oldest data is overwritten.

Table 4-IV. Electric Field Intensity Sensor Telecommands

Command	Command Description
2200	switch on the DEP sensors
2201	switch off the DEP sensors
0110	Switch on the DIERA subprogram
0113	Cancel the DIERA subprogram
2413	Read the RAM

4.2 Telemetry Data Delivery Method

Telemetry data from the sensors on the Express-A2 and A3 spacecraft shall be provided to the Express/T-160E project. NPO-PM will provide all of the applicable telemetry data by sending reports to SPI (in accordance with terms of that contract). At the same time NPO-PM will provide with electronic files of the reports to SPI, GRC, and Schafer. NPO-PM will provide this data in accordance with the Sections 4.3.1 and 4.3.2 of this document.

4.3 Express A2 and A3 Data and Reporting Formats

Data is collected from the onboard sensors and reported for the period of 12 March 2000 to and including 15 June 2000 for Express A2 and the following time periods for Express A3:

- 24 June 2000 to and Including 30 September 2000
- 01 October 2000 to and Including 31 December 2000
- 01 January 2001 to and Including 31 March 2001
- 01 July 2001 to and Including 30 September 2001

NPO-PM will prepare this data and deliver it to the US program participants in accordance Section 4.2 above.

4.3.1 On-board measurements of plasma/plume induced environment on Express A2

NPO-PM has installed sensors to measure electrical and plasma environmental parameters in the vicinity of the spacecraft before, during, and after the SPT-100 thruster firings. NPO-PM will provide the specific geometry of each thruster, DRT and DEP sensors locations. NPO-PM will provide the method used to convert the raw TM-data measured for the current density and ion energy probes in to the final calculated value. NPO-PM will report the measurement uncertainty for each sensor type (DRT and DEP).

4.3.1.1 Current Density measurements

Two plasma current density probes (DRT-1 and DRT-2) are placed on the Express A2 spacecraft. Both are on the antenna unit truss near the payload. One is under the spacecraft MLI (DRT-1) and the other is above the MLI (DRT-2). The probe area in cm^2 will be reported and the probe data will be reported in the following format:

Time (hh:mm:ss)	DRT-1 Current (μA)	DRT-2 Current (μA)

Notes: 1) The data from the DRT-1 and DRT-2 probes will be provided before, during and after SPT-100 firings.
2) Information should contain the data from the probes at least for 10 thruster operating sessions through every month for the reporting period.

4.3.1.2 Electric Field measurements

Three electric field sensors are used on the Express A2 spacecraft. Two of these measure the field strength on the thermal control system radiator along the –Y axis (DEP-1 and DEP-2). These two sensors are oriented at an angle of 180° relative to each other. The other electric field sensor (DEP-3) measures charge build-up on the "astroplate". The data will be reported in the following format:

Time (hh:mm:ss)	DEP-1 Calculated Field (V/m)	DEP-2 Calculated Field (V/m)	DEP-3 Calculated Field (V/m)

Notes: 1) The electric field sensors will provide a direct measurement of electric field strength and so no any conversion of measured data is required.
2) Information from the sensors should contain data at least for 10 days through every month for the reporting period.

4.3.1.3 Pressure measurements

Two pressure sensors (IMDD-1 and IMDD-2) measure the atmosphere pressure outside the Express A2 spacecraft. These sensors are located on the payload antenna truss. One of them is located under the MLI (IMDD-1), and the other over the MLI (IMDD-2). Regrettably, an ignition of plasma charge did not occur in an operating space of the sensors on the Express-A #2 satellite. A reason (as per a conclusion of the sensor supplier) is a later enabling of the equipment outside the sensor ignition areas. Therefore, a pressure is not measured. The sensors are on continuously and their supplier hopes that they will possible operate (e.g., when taking a hit of high-energy particle into the operating area), in addition, NPO-PM periodically performs particular operations with the sensors in order to actuate them.

4.3.2 On-board measurements of plasma/plume induced environment on Express A3

NPO-PM installed sensors to measure electrical and plasma environmental parameters in the vicinity of the spacecraft during and after the SPT-100 thruster firings. NPO-PM will provide the specific geometry of each thruster, DEP and DRT sensors locations. NPO-PM will provide the method used to convert the raw data measured for the current density and ion energy probes in to the final calculated value. NPO-PM will report the measurement uncertainty for each sensor type (DEP and DRT).

4.3.2.1 Current Density and Ion Energy measurements

Two Type A and two Type B plasma probes have been placed on the Express A3 spacecraft to measure current density and ion energy.

The two Type A sensors (DRT-1 and DRT-2) are located on the edges of the two spacecraft solar array wings. The probe area in cm^2 will be reported and the Type A probe data will be reported in the following format:

Raw Data from the spacecraft:

Time (hh:mm:ss)	DRT-1 Current (μA)	DRT-1 Bias Voltage (V)	DRT-2 Current (μA)	DRT-2 Bias Voltage (V)	Solar Array Angle (deg.)

Calculated results:

Time (hh:mm:ss)	DRT-1 Current Density (A/m^2)	DRT-2 Current Density (A/m^2)	DRT-1 Ion Energy (eV)	DRT-2 Ion Energy (eV)

Both Type B sensors (DRT3-1 and DRT3-2) are on the antenna unit truss near the payload. One will be under the spacecraft MLI (DRT3-1) and the other will be above the MLI (DRT3-2). The probe area in cm^2 will be reported and the Type B probe data will be reported in the following format:

Raw Data from the spacecraft:

Time (hh:mm:ss)	DRT3-1 Current (μA)	DRT3-1 Bias Voltage (V)	DRT3-2 Current (μA)	DRT3-2 Bias Voltage (V)

Calculated results:

Time (hh:mm:ss)	DRT3-1 Current Density (A/m^2)	DRT3-2 Current Density (A/m^2)	DRT3-1 Ion Energy (eV)	DRT3-2 Ion Energy (eV)

Notes: 1) The data from the DRT-1, DRT-2, DRT3-1 and DRT3-2 probes will be provided before, during and after SPT-100 firings.
2) Information should contain the data from the probes at least for 10 thruster operating sessions through every month for the reporting period.

4.3.2.2 Electric Field measurements

Three electric field sensors are used on the Express A3 spacecraft. Two of these measure the field strength on the thermal control system radiator along the –Y axis (DEP-1 and DEP-2). These two sensors are oriented at an angle of 180° relative to each other. The other electric field sensor (DEP-3) measures charge build-up on the "astroplate". The data will be reported in the following format:

Time (hh:mm:ss)	DEP-1 Calculated Field (V/m)	DEP-2 Calculated Field (V/m)	DEP-3 Calculated Field (V/m)

Notes: 1) The electric field sensors will provide a direct measurement of electric field strength and so no any conversion of measured data is required.
2) Information from the sensors should contain data at least for 10 days through every month for the reporting period.

4.3.2.3 Pressure measurements

Two pressure sensors (IMDD-1 and IMDD-2) measure the atmosphere pressure outside the Express A3 spacecraft. These sensors are located on the payload antenna truss. One of them

is located under the MLI (IMDD-1), and the other over the MLI (IMDD-2). The data will be reported in the following format:

Time (hh:mm:ss)	IMDD-1 Raw Measurement (number density)	IMDD-1 Calculated Pressure (Torr)	IMDD-1 Raw Measurement (number density)	IMDD-2 Calculated Pressure (Torr)

Note: The data from the sensors will be provided for 7 hours of the sensors operating. On the Express-A #3 satellite, the sensors were on in 5 hours from a spacecraft separation event, and the pressure under the MLI was very high (a measured current was maximum). As per a conclusion of the sensor supplier a long high current has called forth burning-out the power supply unit.

4.3.3 Data Reporting Exception

The sensor data tables for Sections 4.3.1 and 4.3.2 shall include all relevant data points downloaded from the Express A2 and A3 satellites, unless there is no change in any of the measured values for that table over a sequence of five or more consecutive data points. If five or more consecutive table entries are the same, NPO-PM shall report the data in the table only one time and include the following items with that entry:

- The time of the first measurement in the sequence
- The time of the last measurement in the sequence
- The total number of measurements during the sequence

4.4 Ground Test Data

NPO-PM will provide the data from the acceptance tests performed at KeRC and the University of Novosibirsk for the sensors used on Express A2 and A3. This will include the calibration data for the sensors being used on Express A2 and A3. This includes the data used for calibrating the Type A sensors at KeRC, the data used to calibrate the Type B sensors at the University of Novosibirsk, the calibration curves for each sensor, and calibration data for the electric field sensors and pressure gauges.

4.5 Contingency Operations

NPO-PM is responsible for operating passive sensors on the Express A2 and A3 flights. Operation of these sensors is not critical to the missions. Therefore, no specific contingency plans have been generated for participation in the Express A2 and A3 flights. In the event an anomaly is observed, NPO-PM will have the authority to shut the sensor operation off. All Express/T-160E project team members will then determine an appropriate course of action and recommend what steps should be taken to resolve the anomaly. GRC and NPO-PM shall both approve these procedures before they are submitted to the Express A2 or A3 operations team to be implemented on the spacecraft.

5.0 Express A2 and A3 Mission Assessments

5.1 Express A2 and A3 Mission Analyses

Analyses to support real-time operations and mission replanning for the plasma sensors may be done by the project participants. Both GRC and NPO-PM must approve any changes to planned normal operations of the sensors.

5.2 Reports

NPO-PM will provide five reports with all of the required data, as specified in Sections 4.3.1 and 4.3.2 of this document, in accordance with Tasks #25 and #27 of the subcontract with SPI. One report will be delivered following completion of each of the time periods listed in Section 4.3 above.

Schafer will provide five interim reports and one final report to GRC. The interim reports will be prepared following receipt of each of the five NPO-PM sensor data reports. Schafer will be responsible for reviewing the data provided by NPO-PM as it applies to US requirements and will provide a report on this review to GRC. Schafer will prepare a final report that summarizes all of the data from Express A2 and A3.

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11. SUPPLEMENTARY NOTES

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13. ABSTRACT ***(Maximum 200 words)***

This 12-part report documents the data obtained from various sensor measurements taken aboard the Russian Express-A2 and Express-A3 spacecraft in Geosynchronous Earth Orbit (GEO). These GEO communications satellites, which were designed and built by NPO Prikladnoy Mekhaniki (NPO PM) of Zheleznogorsk, Russia, utilize Hall thruster propulsion systems for north-south and east-west stationkeeping and as of June 2002, were still operating at 80° E. and 11° W., respectively. Express-A2 was launched on March 12, 2000, while Express-A3 was launched on June 24, 2000. The diagnostic equipment from which these data were taken includes electric field strength sensors, ion current and energy sensors, and pressure sensors. The diagnostics and the Hall thruster propulsion systems are described in detail along with lists of tabular data from those diagnostics and propulsion system and other satellite systems. Space Power, Inc., now part of Pratt & Whitney's Chemical Systems Division, under contract NAS3–99151 to the NASA Glenn Research Center, obtained these data over several periods from March 12, 2000, through September 30, 2001. Each of the 12 individual reports describe, in detail, the propulsion systems as well as the diagnostic sensors utilized. Finally, parts 11 and 12 include the requirements to which NPO PM prepared and delivered these data.

14. SUBJECT TERMS

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