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A Data Acquisition and Storage System for the Ion Auxiliary Propulsion System Cyclic Thruster Test

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E-4583

SUMMARY

A nine track tape drive interfaced to a standard personal computer was used to transport data from a remote test site to the NASA Lewis mainframe computer for analysis. The Cyclic Ground Test of the Ion Auxiliary Propulsion System (IAPS), which successfully achieved its goal of 2557 cycles and 7057 hr of thrusting beam on time generated several megabytes of test data over many months of continuous testing. A flight-like controller and power supply were used to control the thruster and acquire data. Thruster data was converted to RS232 format and transmitted to a personal computer, which stored the raw digital data on the nine track tape. The tape format was such that with minor modifications, mainframe flight data analysis software could be used to analyze the Cyclic Ground Test data. The personal computer also converted the digital data to engineering units and displayed real time thruster parameters. Hardcopy data was printed at a rate dependent on thruster operating conditions. The tape drive provided a convenient means to transport the data to the mainframe for analysis, and avoided a development effort for new data analysis software for the Cyclic test. The following paper describes the data system, interfacing and software requirements.

INTRODUCTION

The goal of the Ion Auxiliary Propulsion System (IAPS) Cyclic Thruster Ground Test was 2557 on/off cycles and 7057 hr of beam on time. This simulates a typical 7 yr station keeping mission for a 1000 kg class communications satellite. In flight applications the thruster is nominally cycled once daily. For the purposes of the cyclic test, the thruster was cycled five times daily, to reduce the time required for the completion of the simulated flight test.

The test began May 1982 and was suspended for programmatic reasons in October 1983. 1399 cycles and 3593 beam on hours had been completed. During this time period, the thruster was powered with several laboratory type supplies. A custom discrete state controller was used to operate the thruster. Data was stored on a combination of strip chart recorders and the NASA Lewis central data system. The thruster itself was mounted in a 0.89-m (35 in.) diameter 1.96-m (77 in.) high vacuum chamber. The chamber was capable of automatic operation (ref. 1.)

A breadboard of the flight thruster controller, the Digital Control and Interface Unit (DCIU) and the engineering model of the Power Electronics Unit (PEU) became available prior to the resumption of the test in February 1987. It was decided to use these components to operate the thruster for the remainder of the test. This provided a better simulation of the mission and training for future IAPS flight operations.

An Automatic Command Generator (ACG) was fabricated to command the DCIU to cycle the thruster on and off at the proper intervals. The DCIU acquired and temporarily stored thruster data and controlled the PEU. A DCIU tester was used to extract data from the DCIU and convert the data to RS232 format. This data was transmitted to an IBM PC[1] which was interfaced to an IBM 3420 mainframe compatible tape drive. The data received from the DCIU tester was stored on tape in a format compatible with that of existing mainframe software for flight data analysis.

FACILITY

The thruster was mounted in a 0.89-m (35-in.) diameter by 1.96-m (77-in.) high vacuum chamber. An integral 0.31-m (12-in.) bell jar was provided for thruster isolation. A 0.91-m (36-in.) diameter oil diffusion pump and LN_2 cold trap facilitated pumping of noncondensible gases. A frozen mercury target was provided to ensure that beam sputtered material was predominantly mercury. Beam pressures of 1.3×10^{-4} Pa (1×10^{-6} torr) were typical. The facility is capable of unattended operation (ref. 1).

Ion gauges were used to monitor chamber pressure at three locations. The gauges provided a set of normally closed contacts which opened when chamber pressure exceeded a preset limit. These contacts were used to remove power from the Power Electronics Unit (PEU), shutting down the thruster. No direct connection between the facility and the data acquisition computer was made as the data system computer was not required to alter the facility operation. A facility shutdown was indicated by a zero reading on PEU supply voltage data, which is a standard thruster data parameter. A block diagram of the cyclic test facility and electronics is shown in figure 1.

HARDWARE OVERVIEW

The Ion Auxiliary Propulsion System (IAPS) is an 8-cm (3.15-in.) diameter electron bombardment ion thruster. Mercury is used as the propellant. IAPS consists of a Thruster Gimbal Beam Shield Unit (TGBSU), Power Electronics Unit (PEU), a Digital Controller Interface Unit (DCIU) and a propellant tank. The IAPS components are illustrated in figure 2 and a general description of each device follows (ref. 2).

Thruster Gimbal Beam Shield Unit (TGBSU)

The IAPS TGBSU consists of an 8 cm electron bombardment ion thruster using mercury as a propellant. The nominal thrust of an IAPS thruster is 5-mN (1-mlb). The thruster is mounted on a gimbal unit which facilitates thrust vectoring. The gimbal unit was not operated during the cyclic test. A beam shield made of a graphite fiber polyimide composite provides for directional shielding from thruster efflux.

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[1]IBM, IBM PC, and PC/XT are trademarks of the International Business Machines Corporation.

Power Electronics Unit (PEU)

The IAPS PEU converts power from a 70 VDC bus into the voltages required for thruster operation. The PEU contains 5 direct current and 4 alternating current supplies, each of which is independently controlled by the Digital Controller Interface Unit (DCIU). Each supply is provided with a proportional 0-5 VDC reference from the DCIU or a discrete on/off command. The PEU also contains signal conditioning circuitry which monitors the output of each supply and provides the DCIU with a proportional 0-5 VDC output for control feedback and digitization for telemetry output.

Digital Controller Interface Unit (DCIU)

The DCIU controls thruster operation based on commands input from the spacecraft computer. The DCIU is capable of automatic startup and shutdown of the thruster on command (ref. 3). Several thruster maintenance routines such as cathode conditioning are available. Manual on/off and setpoint commands for each supply are supported where applicable. The DCIU converts the analog 0 to 5 VDC feedback signals into 8 bit digital words. There are a total of thirty-two 8 bit telemetry parameters sampled once every 32 sec. One parameter per second is available for transmission to the spacecraft interface which must actively extract the data from the DCIU. Therefore, a complete data frame is transmitted once every 32 sec. Each thruster parameter constitutes one subframe. A breadboard DCIU with flight software installed was used for the resumption of the Cyclic Thruster Test.

DCIU Tester

The DCIU tester is part of the Ground Support Equipment (GSE) originally used for testing and software verification of the DCIU. The DCIU tester simulates the spacecraft interface, clocking the telemetry data from the DCIU at the rate of one parameter per second. An eight bit telemetry word or subframe number is added to each parameter. The subframe number and parameter are then displayed on the front panel in hexadecimal format. The parameter and its associated subframe number are also converted to RS 232 serial data which is simultaneously transmitted over a two wire link. Baud rate is selectable by a back panel switch. 300 Bd was selected due to the length of the cabling from the thruster control rack to the control room. A hexadecimal keypad is provided for the manual input of thruster commands.

Automatic Command Generator (ACG)

A means for unattended input of thruster commands was necessary for continuous operation of the test. A device was fabricated to store two commands and transmit each to the DCIU at a programmable time interval. In the case of normal test operation, the full beam and thruster off commands were stored. Each 16 bit command word is programmed via DIP switches, along with the interval at which it is to be transmitted. Time to transmission of each command is displayed on the front panel in minutes. The DCIU tester front panel command input was used during system checkout for brief periods of manual thruster operation.

IBM PC

A standard IBM PC/XT was used to receive the RS232 telemetry stream from the DCIU tester and process the data. A 3420 compatible nine track tape drive was interfaced to the computer. Raw thruster data was output to tape while engineering unit data was displayed on the monitor and selectively printed on a standard dot matrix printer.

SOFTWARE

Software Requirements

Data display. - All thruster data was displayed on the computer monitor in engineering units in real time. A complete frame of data was displayed with the individual parameters updated once per second as they were received. Incoming data was also continuously displayed in hex.

Hardcopy data. - Hardcopy data was printed continuously during thruster mode transitions, i.e., beam off to full beam and during thruster maintenance modes. Any changes in the thruster would be indicated in the continuous data during mode transitions. The hardcopy data facilitated quick look data capability without dismounting and processing a data tape. During beam on mode, data was printed at 2.5 min intervals. An 11 min interval was selected for beam off mode. This is due to the steady state nature of thruster parameters during beam on/off modes.

Data archival. - All thruster data was stored on magnetic tape in a format compatible with the flight data analysis software. This facilitated the plotting and trend analysis of data. Also, the tapes were stored after the completion of the test to provide a data archive for future use. A time tag for each data frame containing the year, month, day and time of day was recorded with the data.

Mainframe software. - The flight data analysis software required some minor modifications. The calibration curves used for conversion of raw data into engineering unit data varied slightly between each PEU. The calibration curves for the Engineering Model PEU were inserted into the software.

Also, the flight data tapes contained certain spacecraft parameters which did not apply to the operation of the cyclic test. This data did not appear in the test data tapes. The mainframe software was modified to deal with the absence of this data.

OPERATING ENVIRONMENT

Hardware Configuration

The hardware used for the data system was an IBM PC/XT with 640K of RAM, a battery-backed real time clock, parallel printer port and two serial ports. Only one of the serial ports was active during the testing. A Digi-data Series

2000[2] streaming tape drive was interfaced to the PC. The PC/Tape Drive interface card provided contained a 64K data buffer and tape drive controller circuitry. The tape drive was supplied with an MS-DOS[3] device driver. The operating system used was MS-DOS version 3.20. The software was written in "C".

SOFTWARE IMPLEMENTATION

RS232 Input

The data output by the DCIU tester was transmitted over a twisted shielded pair of wires from the test area to the central control room. The line length was approximately 175 ft. Due to the length of the cabling and the slow data rate (2 B/sec) 300 Bd was chosen as the data transmission rate. Documentation of the output format for the DCIU tester was unavailable. A storage oscilloscope was used in conjunction with the data display on the DCIU tester front panel to determine the word length and parity. The word length was 8 bits with no parity. The serial port on the PC was initialized to receive the data using the MS-DOS MODE command in an autoexec.bat file which also called the data acquisition software at boot-up. This was acceptable since the PC was to be dedicated to the data acquisition task and no other software would utilize the serial port. However, the serial port could have been initialized in the main software with no problem.

Data was input by continuously polling the serial port status register. When the data ready bit was set, the data was input from the serial port receive buffer (ref. 4). This technique was quite successful. No handshaking between the DCIU tester and the computer was available.

The two byte output of the DCIU tester consisted of an 8 bit subframe number and an 8 bit data word. The data was transmitted sequentially, subframe 0 through 31 (32 total words). The 8 bit subframe number preceded the data word. The data input module returned both bytes of data to the acquisition program simultaneously. The input module kept track of the order in which the data was being received. If subframe number 1 was just received the input module specifically expected subframe number 2 to appear next. If a data dropout occurred, that is subframe number 2 did not appear, the module would return no data and wait until proper synchronization was achieved again. This essentially caused the loss of a complete data frame in the event of a dropout. Due to the steady state characteristics of an operating thruster, it was decided that the potential loss of an occasional data frame was acceptable. A detailed flow diagram of this module is shown in figure 3.

Engineering unit conversion. - The real time data display, hardcopy and mainframe data analysis software were required to convert the raw integer thruster data to engineering units. This required calibration or conversion polynomials which input the integer data and output the appropriate floating point data. The DCIU tester and a DVM were used to compare the output of each of the PEU power supplies with the returned digital data. The PEU was

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[2]Series 2000 is a trademark of the Digi-Data Corporation, Jessup Md.
[3]MS-DOS is a trademark of the Microsoft Corporation.

connected to a dummy load during this procedure. In the cases of the variable setpoint supplies, each setpoint was tested and the data recorded. The on/off only supplies yielded two data points. The data was tabulated and least squares methods were used to generate first or second order polynomials where applicable. The vaporizer temperature data could not be measured in this fashion, so manufacturer's calibration data for the platinum RTD's was used.

Real time data display. - The thruster data was displayed on the PC screen in real time. A static screen format containing the mnemonic for each telemetry parameter was implemented. The data field for each parameter was updated each time new data was received. As a result, new data appeared in each field every 32 sec. The static format prevented annoying data scrolling and screen flicker. The screen format is shown in figure 4

Hardcopy data. - Thruster data was printed continuously during transitions from one mode to the next, for example during the transition from off to full beam. During full beam operation the data was printed only once every 5 data frames (approximately 2.5 min). During beam off operation, the data rate was further reduced to once every 20 data frames (approximately 11 min). If the thruster was operated in a maintenance mode, the data was continuously printed. The thruster mode was determined by the mode parameter output by the DCIU. A print flag was initialized to turn on the printer at the beginning of data acquisition. When the thruster mode was received, the flag was left on if a mode transition or maintenance mode was indicated in the data. If a beam on or off mode was indicated the flag was toggled off for a fixed number of data frames. The flag was toggled on when a counter indicated that the proper number of complete data frames was received. Printing resumed with the next data frame, and the flag toggled off again. When a mode transition was detected, the printer flag was toggled on and left on. The format of the hardcopy output is shown in figure 5.

The paper out indicator on the printer was disabled in the event of a paper jam or depletion of the paper supply. This prevented the printer from interrupting the data acquisition computer during unattended operation.

Magnetic tape storage. - All raw thruster data was stored on magnetic tape. The Digi-Data Series 2000 tape drive is an IBM 3420 compatible nine track tape drive capable of 1200 bpi storage. The drive is supplied with an MS-DOS device driver which is loaded into memory during computer boot up. This allows the tape drive to be controlled by software in a manner similar to that of a line printer of any other "standard" MS-DOS device. The controller card for the tape drive is equipped with a 64 Kb data buffer. Data written to the tape drive is stored in the buffer until the buffer is full or is loaded to a limit set by the user. When the buffer is loaded, the data is written to the tape.

The format of the data tape is outlined in figure 6. This format is identical to that of the flight data with the exception of flight spacecraft data not associated with the ground test. The spacecraft data was omitted to simplify the format of the data blocks and increase the amount of data stored on each tape. The thruster data was written to tape in physical records containing 22 logical records each. A logical record contains 1 complete data frame or 32 sec of thruster data. A time stamp containing the year, month, day and time of day was added to the data frame. Each tape contained one file made up of an arbitrary number of physical records. The number of physical records was dependent on the amount of time the tape remained mounted during the data acquisition process. Subframe numbers are designated as <SFNN>. Analog thruster parameters are designated by measurement numbers PNNN, digital or discrete parameters D#NN. (N is an integer number).

<u>Tape drive programming</u>. - The tape drive is initialized using the standard "open();" statement available in the C language. At this point the tape drive is available as an ASCII device, the default mode for MS-DOS. A unique integer number or file handle is assigned to the tape drive which is used as an address for future reads or writes to the device. Since the data must be stored on the tape as binary data, the drive must be toggled to the binary mode using the standard MS-DOS function for this purpose. The function is called by loading the CPU's AX register with the function number and issuing software interrupt 21h (ref. 5). Sample code is shown in table I.

Thruster data was stored in a buffer set up within the main code. This buffer was set to a 1760 B length which corresponds to 22 IAPS data frames plus a time tag for each. The time tag preceded the data in each frame. The thruster data and corresponding word numbers were written to this buffer until it was full, at which time the data was written to the tape buffer on the controller card. The standard C "write();" function was used to perform this operation. This resulted in a write to the tape drive buffer once every 11.5 min. The tape drive is configured such that each write is treated as a physical record. The controller card was configured to a full 64 Kb buffer size. The data was retained in this buffer until it was full. This resulted in a physical write to tape every 7.5 hr. Unfortunately, the writing of data to tape resulted in a data dropout at the RS232 port. The write took several seconds to execute, not allowing the CPU to input data from the RS232 port. This resulted in the loss of one data frame or 32 sec of data for every 7.5 hr which was deemed acceptable. In more critical applications RS232 data could be handled using an interrupt routine which interrupts the CPU when data is input.

Tapes were generally left online for a one or two week period. No method for automatic closing of a tape drive file was implemented. This required operator intervention to close a tape file, dismount a tape and load a new tape. The tapes were dismounted only during thruster off periods. There were two reasons for this. Dismounting a tape results in data loss during the time interval required to mount a new tape. Also, any data in the buffer in the main code is lost upon exiting the main software. Loss of data during an off period was not critical. A tape was dismounted using the following procedure. The main software was terminated using "control C" (^C) keyboard input. Data in the temporary 1760 B buffer is immediately lost. This represents up to approximately 11 min of data. The data written to the tape drive buffer is immediately written to tape. At this point, the MS-DOS prompt appears on the computer monitor. The tape drive vendor supplies a number of MS-DOS routines used for diagnostic purposes. The routine which writes a double EOF is then called and a double EOF written. The tape was then dismounted and sent to the central computing facility for input to the mainframe. A new tape was then mounted and the data acquisition software restarted. A logic flow diagram of the software is shown in figure 7.

SYSTEM PERFORMANCE

The overall performance of the data system was excellent. The occasional lost data during the physical tape writes did not adversely effect the research and were essentially transparent. Again, an interrupt driven data input scheme could have prevented any data dropouts. On one occasion a facility power failure resulted in the loss of the contents of the 64 Kb data buffer. An uninterruptable power supply for the computer and tape drives would have prevented this. There were no tapes produced by the tape drive which could not be read by the mainframe and all data was successfully processed. The system continuously operated without a hardware failure for the duration of the Cyclic Test, a time period of 14 months.

CONCLUSION

The nine track tape drive interfaced to the personal computer provided a cost effective means of transporting large amounts of data from a remote test site to a mainframe for analysis. The system proved to be quite reliable and easy to operate. The data tapes also provide an excellent means for archival of test data.

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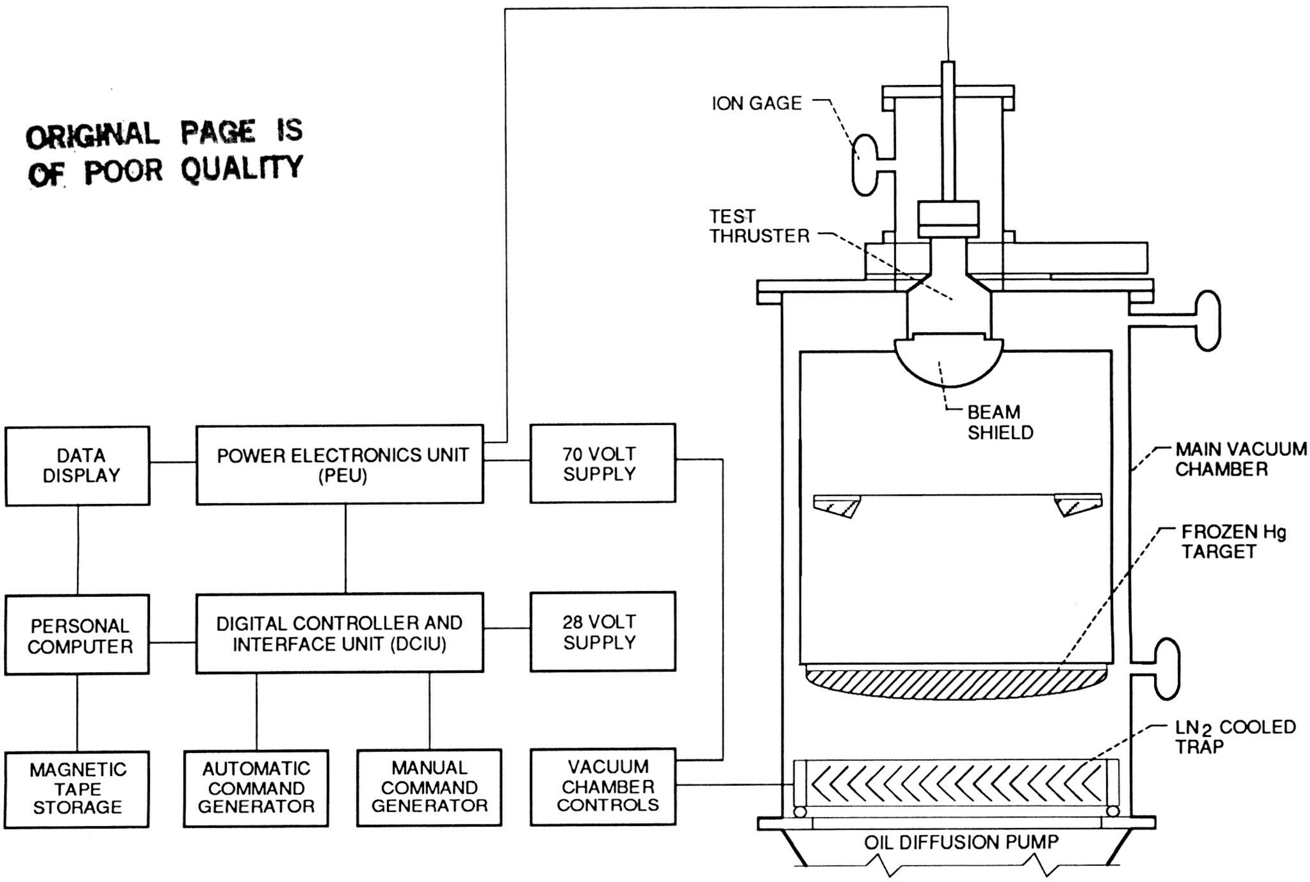

Figure 1. - Ground test facility and electronics block diagram.

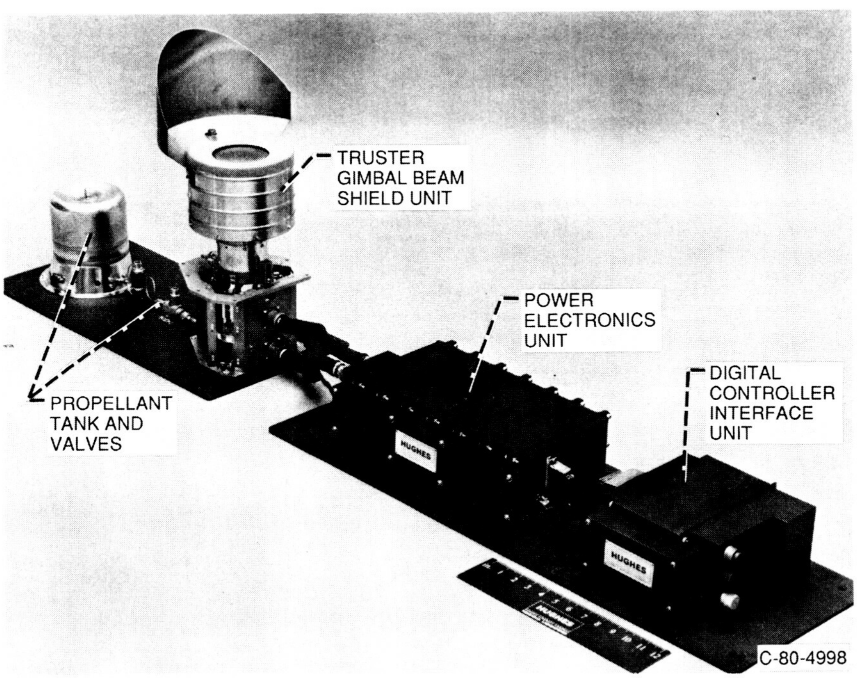

Figure 2. - IAPS components.

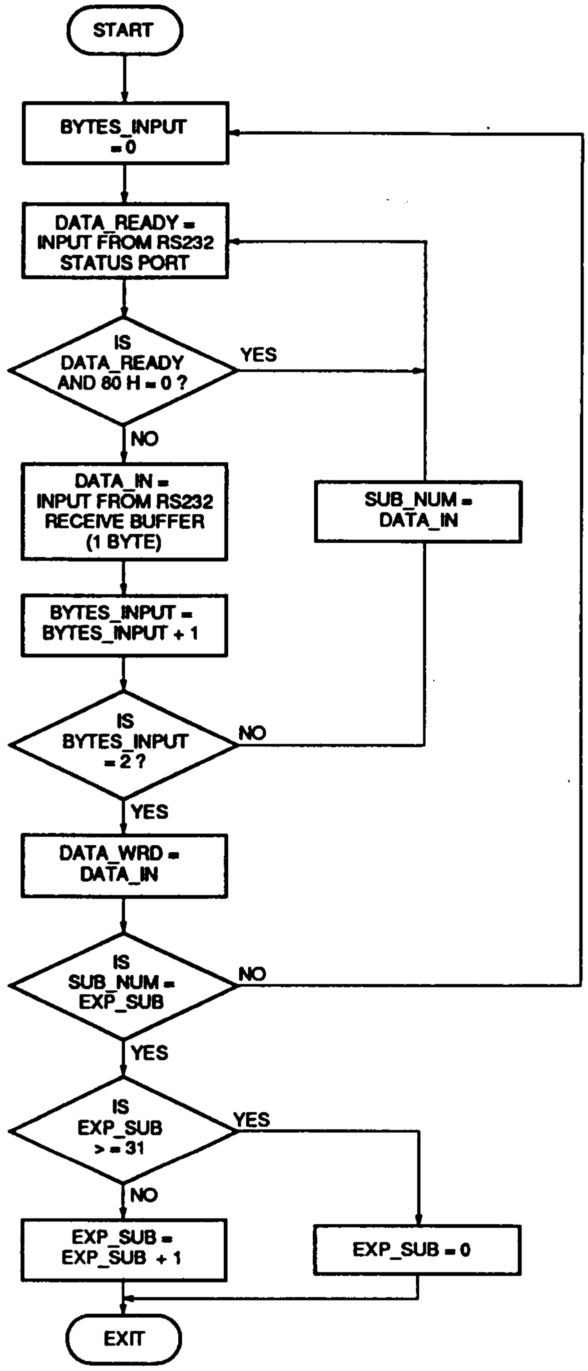

Figure 3. - RS232 input module.

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```
                         IAPS Cyclic Thruster Test

                         Tue June 2 11:09:00 1987

BOTI - ####.## HRS  SI   - ####.## mA   SV   - ####.## VDC  DI   - ####.## mA

DV   - ####.## VDC  NFPV - ####.## VDC  ACCI - ####.## mA   NKV  - ####.## VDC

PRES -      ##      ACCV - ####.## VDC  NKI  - ####.## mA   70V  - ####.## VDC

70VI - ####.## ADC  DVT  - ####.## Cel  NVT  - ####.## Cel  INKT -      ##

DKI  - ####.## mA   DKV  - ####.## VDC  NHTI - ####.## AAC  DHTI - ####.## AAC

FLAG20 -    ## HEX  FLAG21 -    ## HEX  SYSMODE -   ## HEX  HISTORY -   ## HEX

OVERRIDE -  ## HEX  BITFLIPS - ###      RECYCLES -  ###     COMMAND - ####



INCOMING DATA: ## ##
```

Figure 4. - Cyclic test real time data display.

```
SI   - ####.## mA   SV   - ####.## VDC  DI   - ####.## mA   DV   - ####.## VDC
NFPV - ####.## VDC  ACCI - ####.## mA   NKV  - ####.## VDC  PRES -      ##
ACCV - ####.## VDC  NKI  - ####.## mA   70V  - ####.## VDC  70VI - ####.## ADC
DVT  - ####.## Cel  NVT  - ####.## Cel  INKT -     ### Cel  DKI  - ####.## mA
DKV  - ####.## VDC  NHTI - ####.## AAC  DHTI - ####.## AAC  FL20 -      ## HEX
FL21 -      ## HEX  MODE -      ## HEX  HIST -      ## HEX  RECO -      ## HEX
FLIP -     ###      RECY -     ###      GIMA -     ###      GIMB -     ###
CMD  -    ####      BOTI -    ####
Tue June 2 11:09:00 1987
```

Figure 5. - Hardcopy data format.

< BEGINNING OF RECORD >

Byte No.								
0	YEAR	YEAR	MODA	MODA	HRMN	HRMN	SECS	SECS
8	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
16	<SF00>	P701	<SF01>	P507	<SF02>	P505	<SF03>	P517
24	<SF04>	P515	<SF05>	P529	<SF06>	P511	<SF07>	P525
32	<SF08>	P202	<SF09>	P509	<SF10>	P527	<SF11>	P503
40	<SF12>	P501	<SF13>	P103	<SF14>	P105	<SF15>	P101
48	<SF16>	P521	<SF17>	P520	<SF18>	P531	<SF19>	P523
56	<SF20>	D#12	<SF21>	D#16	<SF22>	P801	<SF23>	P811
64	<SF24>	D#18	<SF25>	P809	<SF26>	P803	<SF27>	P301
72	<SF28>	P303	<SF29>	P807	<SF30>	P805	<SF31>	P703

< END OF RECORD >

Each logical record contains 80 eight bit words

22 Logical records will make one physical record

One (1) Logical record equals 32 seconds of data and 80 words

One (1) Physical record equals 704 seconds of data and 1760 words

The tape will contain only one file with a double end of file (EOF) marker at the end of the tape

Figure 6. - Tape format.

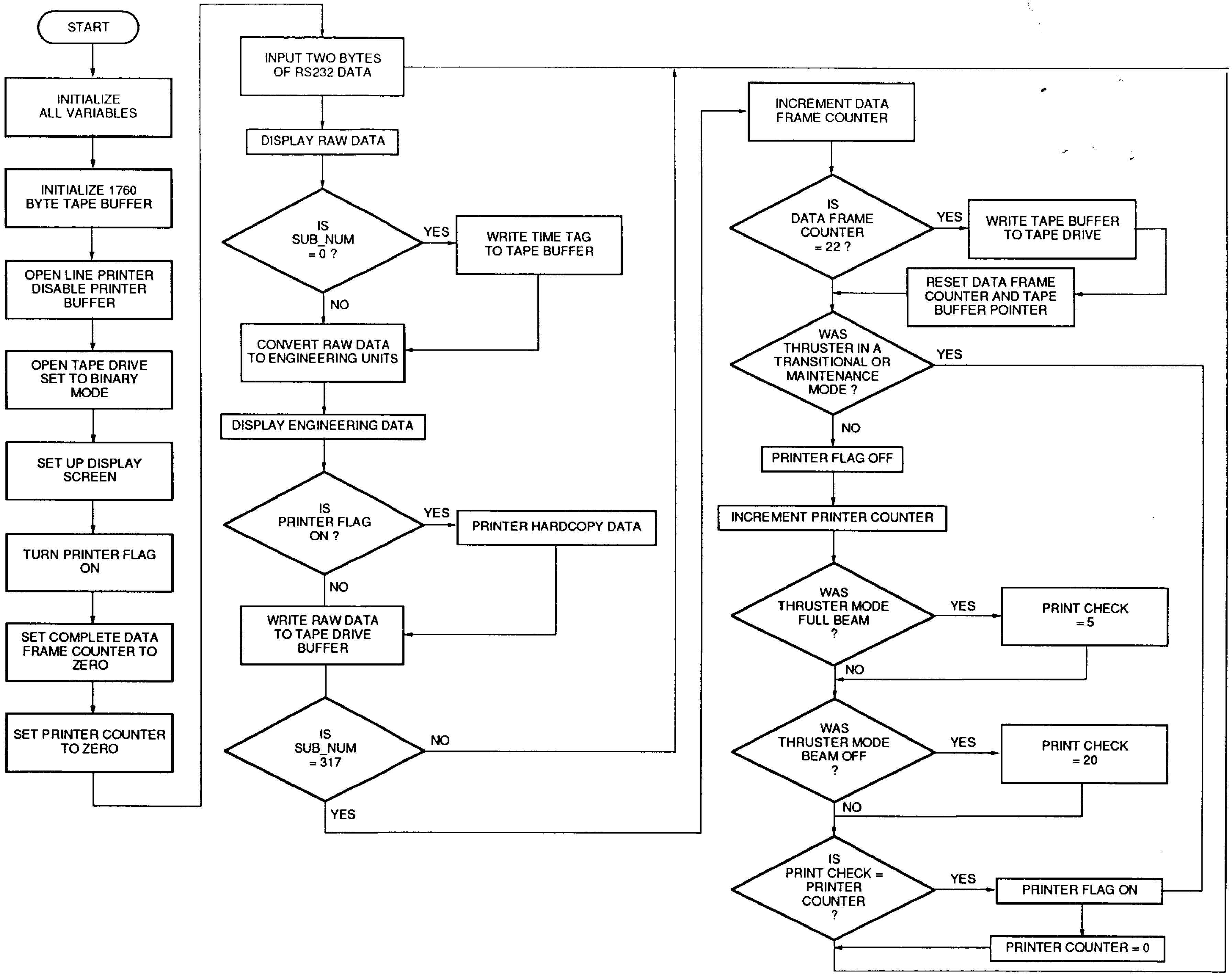

Figure 7. - Software logic flow diagram.

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15. Supplementary Notes

16. Abstract

A nine track tape drive interfaced to a standard personal computer was used to transport data from a remote test site to the NASA Lewis mainframe computer for analysis. The Cyclic Ground Test of the Ion Auxiliary Propulsion System (IAPS), which successfully achieved its goal of 2557 cycles and 7057 hr of thrusting beam on time generated several megabytes of test data over many months of continuous testing. A flight-like controller and power supply were used to control the thruster and acquire data. Thruster data was converted to RS232 format and transmitted to a personal computer, which stored the raw digital data on the nine track tape. The tape format was such that with minor modifications, mainframe flight data analysis software could be used to analyze the Cyclic Ground Test data. The personal computer also converted the digital data to engineering units and displayed real time thruster parameters. Hardcopy data was printed at a rate dependent on thruster operating conditions. The tape drive provided a convenient means to transport the data to the mainframe for analysis, and avoided a development effort for new data analysis software for the Cyclic test. The following paper describes the data system, interfacing and software requirements.

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