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RADIATION TEST REPORT

AMS Hard Drives: 500GB Hitachi, 640GB Seagate, and 750GB Western Digital

ENGINEERING DIRECTORATE

AVIONIC SYSTEMS DIVISION

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1.0 INTRODUCTION

Three models of hard drives were evaluated for potential use in supporting the AMS Project: 500GB Hitachi, 640GB Seagate, and 750GB Western Digital. The hard drive is used to record and playback data. It will be housed in the DVD bay drive of a T61p laptop computer, or stored in a Nomex Bag on front of Express Rack. The hard drive is classified as a non-critical hardware (Crit 3) used in the ISS crew cabin environment. The purpose of this test was for engineering evaluation, with the primary intent on determining the single-event effect (SEE) susceptibility of the device to high-energy proton radiation.

None of the drives had fatal error. Files pre-loaded for the static test were not compromised. There were functional interrupts during the dynamic portion of the tests with accumulated MTBF varied from 43 days to 95 days

The hard drives were tested at the Indiana University Cyclotron Facility (IUCF), on September 21st and 22nd, 2010, and consumed 11 hours of beam time.

The members of the test team were:

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2.0 TEST PHILOSOPHY

2.1 Space Radiation Environment Assumptions

The objectives of this testing were to determine the hardware susceptibility and calculate a mean-time-between-failure (MTBF) rate due to exposure in the space radiation environment. The environment is for a typical space shuttle or space station orbit (51.6 – 57 degree inclination, 270 nmi altitude) consisting of Galactic Cosmic Rays and trapped protons and electrons. Orbit average solar minimum conditions with 0.1" thick spherical aluminum shielding for quiet conditions and no earth shadow were assumed. Based on SSP30512 [8], hardware operating inside an ISS pressurized module can be expected to receive less than 20 rads (Si) per year. Appendix A provides the ionizing radiation testing philosophy and more details on the environment definition applied toward this test and the results.

2.2 Standard Test Protocol

All testing was done with a proton beam energy of 198 mega-electron-volts (MeV). At this energy it takes 2.5 inches of solid copper to stop the beam. The normal beam diameter of approximately 6 cm was collimated with various copper vignettes to adjust the size of the final beam allowed to radiate the test article. Prior to the test, the hardware was inspected to create a sequence of beam positions, with each position consisting of isolated groups of integrated circuits based on similar function or spatial proximity. The size of each copper vignette was also determined, so that only the position of interest was irradiated, blocking off any surrounding components. Each beam position was irradiated separately and an intermediate failure rate was established.

Each beam position was exposed to a minimum fluence of 1E+10 protons/cm^2, which equates to 600 rads (Si). This is the standard radiation exposure for hardware destined for inside a pressurized module at the ISS orbit. The MTBFs calculated are due to contributions expected from both protons and heavy ions in the space environment.

The devices-under-test (DUT) were located in the test cave, about 80 feet away from the control room. A typical test run involved aligning the hardware with the beam centerline for each beam position, positioned exactly 12 inches from the end of the beam collimator. The software was started and normal operation verified. The beam was then applied to begin the test. The run would stop either when: (a) an anomalous event was detected; or (b) when the fluence of 1E+10 protons/cm^2 was reached (usually 3-4 minutes).

To analyze the data, the first step was to group the errors by type, number and severity. This information was then entered into a NASA/EV-developed software program called "PRO-TEST" [10]. The resulting output is the MTBF rate for each beam position, and the composite MTBF rate for the entire assembly. These MTBF predictions are based on the conservative assumption that the device is continually operating in space during its mission, which is usually not the case. **For those beam positions that did not exhibit any anomalies or failures, the MTBF rate is assumed to be greater than 10 years.**

Any deviations or modifications to this test protocol will be described in the following sections.

3.0 HARDWARE CONFIGURATION & TEST PROCEDURES

Three models of hard drives – 500GB Hitachi, 640GB Seagate, and 750GB Western Digital – were evaluated with Protons at Indiana University Cyclotron Facility (IUCF) on September 21st and 22nd, 2010. The hard drive is used to record and playback data to support the AMS Project. It will be housed in the DVD bay drive of a T61p laptop computer, or stored in a Nomex Bag on front of Express Rack.

The hard drive was irradiated in a stand-alone setup – mounted onto a post – and was exercised remotely via cables that connected it to a laptop (a ThinkPad T61p laptop) in the test room which was accessed remotely from the control room using the KVM Extender system. The hard drive was exercised using Passmark's Burn In Test and custom software written by NASA/JSC EV2 Branch. Passmark's Burn In Test software was originally written to exercise the full capabilities of the T61p laptop and external hardware of the laptop. This software ran a continuous loopback test on the express card port of the laptop and logged any errors if they occurred. A multimeter was used to monitor current from the USB/SATA power Adapter; any significant increase in current would be noted and could be interpreted as a latchup condition.

Each drive was pre-loaded with five 2GB files. These were to be part of the static test mode. The integrity of these files would be verified when drives were received back at JSC after the test. For the dynamic portion of the test, the custom software, RWTEST.EXE, was used. An $A5 data pattern was written during irradiation then the pattern was read for errors.

Each hard drive was covered with 4 beam positions. Each position was irradiated to a minimum fluence of 1E+10 protons/cm^2, which equates to about 600 rads (Si).

The block diagram below showed the typical test setup that was used for all three hard drives.

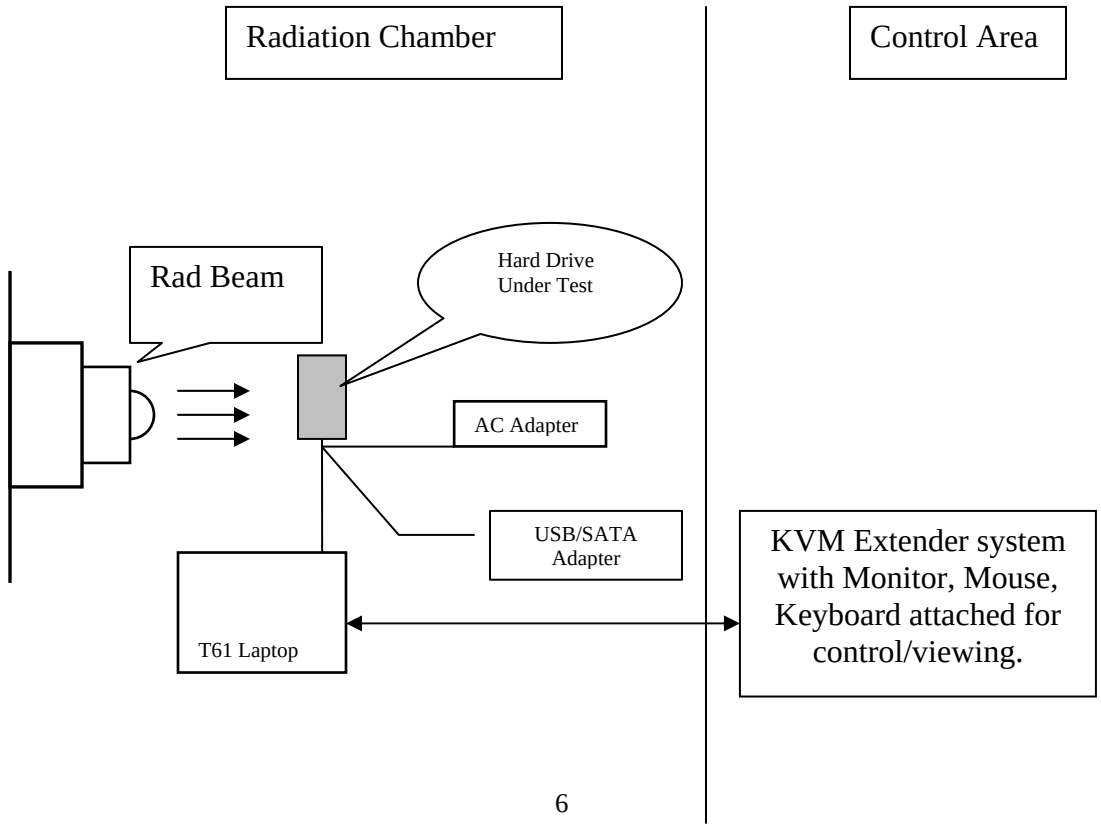

Figure 1. Test setup – hard drive mounted onto a post

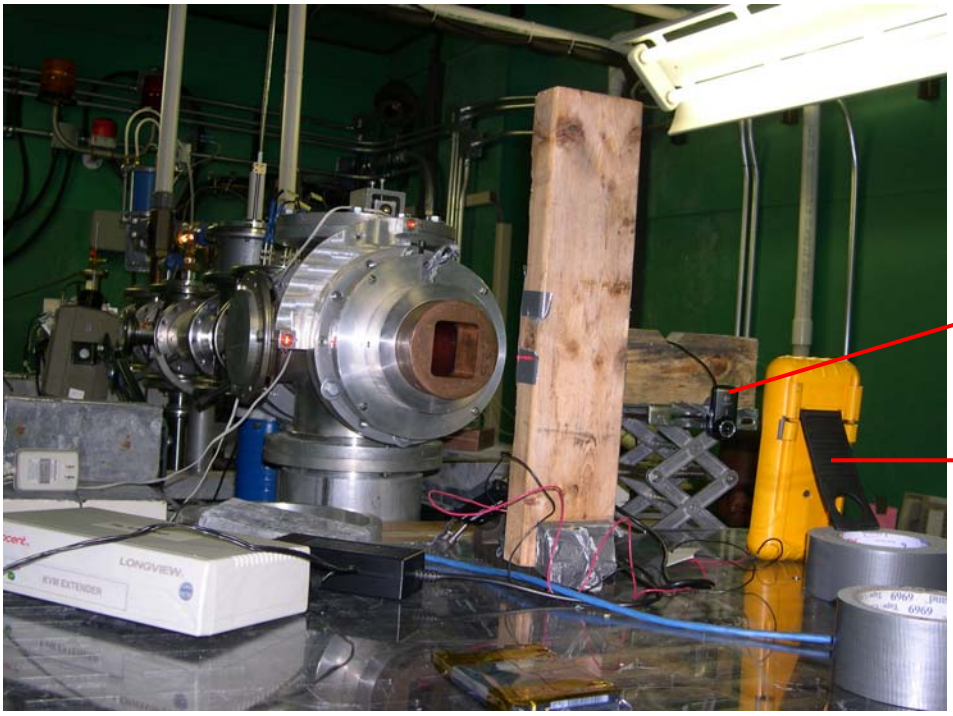

Figure 2. Hard drive placed in front of the beam

4.0 TEST SUMMARY & RESULTS

Three hard drives were tested: 500GB Hitachi, 640GB Seagate, and 750GB Western Digital. Each hard drive was covered in 4 beam positions, and each position was irradiated to a minimum fluence of 1E+10 protons/cm^2, which equates to about 600 rads (Si).

Figure 3. Hitachi - 500GB

Figure 4. Seagate – 640GB

Figure 5. Western Digital - 750GB

Table 1. Summary of Test Results

Drive Model	Position	Error Mode	Fluence (protons/cm^2)	MTBF (day)
Western Digital WD7500BPVT, S/N WX81A30R8405, Date: 29 Mar 2010				
750GB	1	None	1E10	
	2	5F1	2.48E9	88
	3	None	1E10	
	4	5F1	2.64E9	94
Cumulated MTBF: 45 days				
Hitachi HTS725050A9A364, S/N VLGTWR4C, Date: Mar 10				
500GB	1	None	1E10	
	2	1F1	6.02E8	107
	3	5F1	2.04E9	72
	4	None	1E10	
Cumulated MTBF: 43 days				

Seagate 5000C5001F710824, S/N 5WXoL86C, Date: 10322				
640GB	1	None	1E10	
	2	None	1E10	
	3	None	1E10	
	4	5F1	2.66E9	95
Cumulated MTBF: 95 days				

Note: F1 – Read cycle error

Files that were loaded prior to irradiating the unit were read at the conclusion of the test: No error was found.

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4. Adams Jr., J. H., "Cosmic Ray Effects on Microelectronics, Part IV", Naval Research Laboratory Memorandum Report 5901, December 31, 1986.

5. O'Neill, P. M., G. D. Badhwar, and W. X. Culpepper, "Internuclear Cascade - Evaporation Model for LET Spectra of 200 MeV Protons Used for Parts Testing," IEEE Trans. Nuclear Science, (Dec. 1998).

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8. Space Station Ionizing Radiation Design Environment, Rev C: International Space Station Alpha, NASA SSP30512 Revision C, (June 1994).

9. NSTS 07700, Volume X, Book 1 and Book 2.

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11. Test Plan from Project

APPENDIX A
Ionizing Radiation Testing Philosophy & Environment Definition

BACKGROUND

A definition of the test philosophy and the radiation environment model used is presented in this section.

Radiation Test Philosophy – Hardware elements must be able to operate in the environment for the duration of their missions. The two major elements of the ionizing radiation environment are the deposition of energy from Total Ionizing Dose (TID) and the Single Event Effects (SEE) produced by high energy particles like protons and atomically heavier ions. The TID experienced by any hardware element is a function of its location on the vehicle. Shielding values are available for various locations within the spacecraft. The SEE's experienced on orbit are not substantially mitigated by shielding because of the high energy of the particles producing the effects.

Radiation testing for SEE's with high energy protons is designed to establish the susceptibility of a given test article to trapped protons in the South Atlantic Anomaly (SAA) and heavy ions due to Galactic and Solar Cosmic Rays. A SEE can be detected as:

- **Single Event Upset (SEU)** – an event like a bit flip resulting in a data error only.
- **Functional Interrupt (FI)** – an event requiring a software reboot or a power cycle.
- **Single Event Latchup (SEL)** – an event where the device has an abnormal conduction path established by the ionizing radiation and as indicated by a primary power supply current change. Power must be recycled to regain control and/or to save the device from destruction.
- **Single Event Burnout (SEB)** – an event where the device has an abnormal conduction path established by the ionizing radiation and is destroyed almost immediately.

The occurrence of a SEE is a single sample observed from a random process. The more samples (in this case SEE's detected) observed, the better the estimate of the Mean Time Between Failures (MTBF) for that specific type of SEE. The goals of this testing are to establish estimates of the MTBF's for each type of SEE detected for a given test article or electronic component.

The probability of an SEE occurring within a test article is related to the number of particles per square centimeter (called fluence) allowed to impinge on the device. The general criterion used in testing with protons is to expose each beam position or test article to a fluence of 10 billion (1E10) protons/cm2.

Even though the SEE susceptibilities measured during testing were only from proton testing, the MTBF's cited in this report are the composite MTBF's due to the nominal proton (primarily SAA trapped protons) and the nominal heavy ion (Galactic Cosmic Rays) environments. The procedures for deriving the MTBF's were determined using the software tool PROTEST [10]. The proton SEE MTBF's from proton test results were determined using the Bendel A method and are described in [6]. The heavy ion SEE MTBF from proton test results was calculated as described in [5] and [7], using the formula:

MTBF = 6 years/Number of SEE's in 1E10 protons/cm^2

Radiation Environment Definition For typical orbits for the space shuttle or the space station considered here (51.6 - 57 degree inclination, 270 nmi altitude), the nominal ionizing radiation environment consists of Galactic Cosmic Rays and trapped protons and electrons. The Galactic Cosmic Ray flux was modeled with a solar modulation algorithm [1], [2] whose accuracy has been demonstrated over four solar cycles. The trapped proton and electron radiation spectrum was generated using the AP8 model with solar minimum conditions (1964 epoch, 1965 International Geomagnetic Reference Field (IGRF)) [3]. Orbit average environments were determined for solar minimum conditions with 0.1" thick spherical aluminum shielding for quiet conditions and no earth shadow. Transport and geomagnetic shielding models can be found in [4]. The trapped electron spectrum was only used for TID calculations. These environments are consistent with those defined in [8] and [9].

APPENDIX B
Test Plan for the AMS Hard Drives

Radiation Test Procedure for

500GB Hitachi, 640GB Seagate, and 750GB Western Digital

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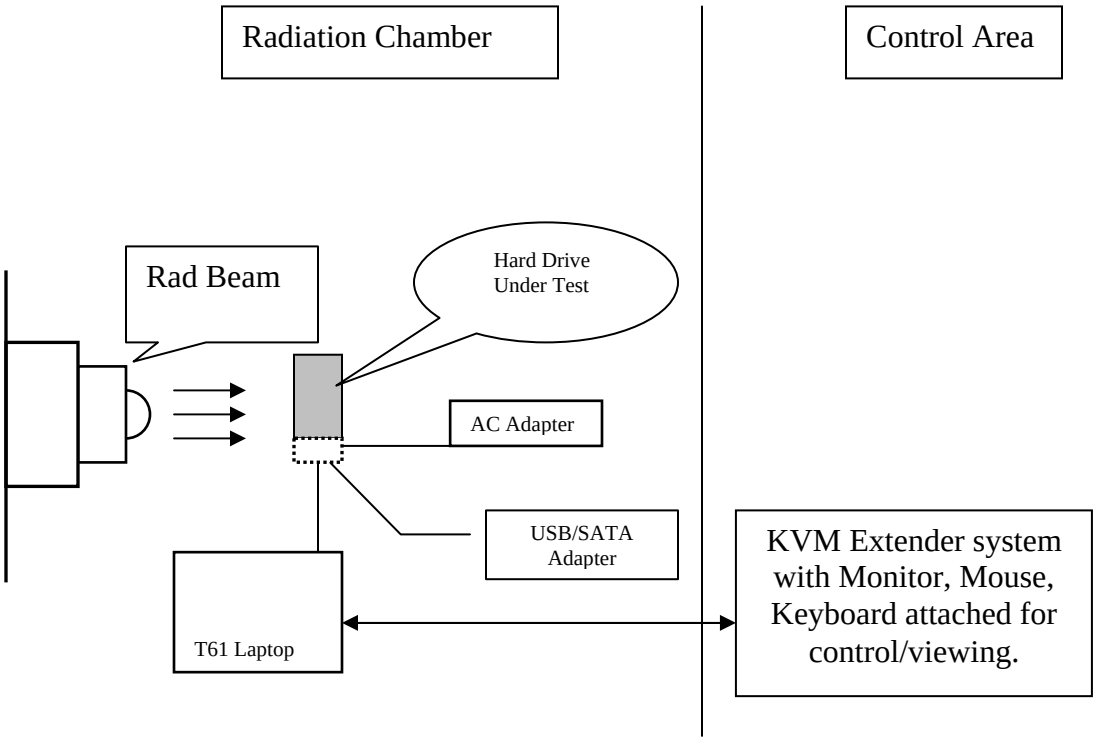


IMPORTANT NOTE: Be sure to isolate laptop and other test support equipment from direct radiation beam using lead block shielding.

List of Hard Drive :

1. 500GB Hitachi PN HTS725050A9A364, SN_____
2. 640GB Seagate PN ST9640320AS, SN _____
3. 750GB Western Digital PN WD7500BPVT, SN _____

Support Equipment :

1. USB / SATA Adapter & Power PN_____, SN _____
2. Fluke Model 87 III Multimeter, NASA CAL_____ Date_____
3. KVM Extender system PN_____, SN _____
4. T61 IBM Laptop, PN 6457-HU1, SN LK-AFFNF
5. T61 AC Adapter, PN 93P5026, SN N/A

Test Procedure:

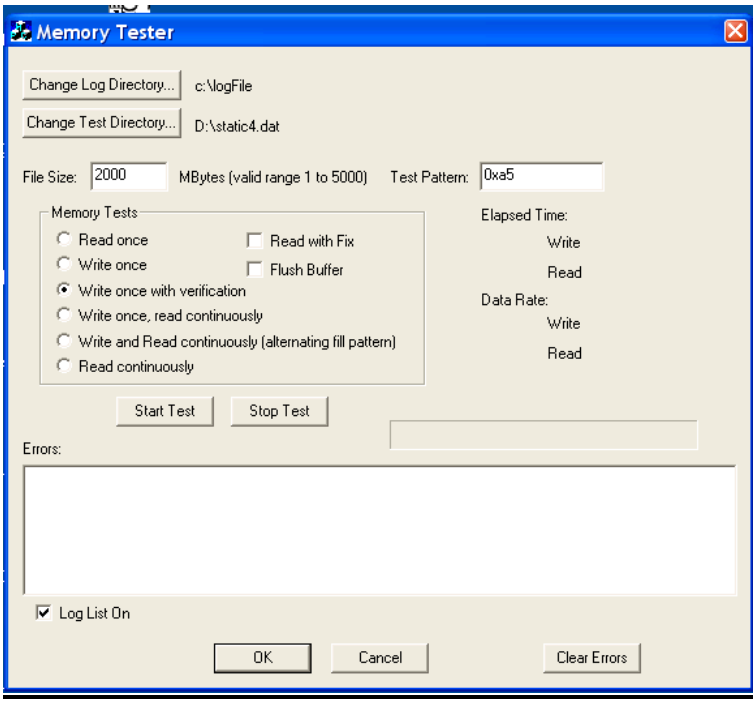
- Boot up T61 Laptop
- Setup Multimeter to read current from the USB/SATA power Adapter (do not connect AC Adapter)
- Switch multimeter to current mode (While turning multimeter on Press and Hold HOLD button – this will disable auto off mode)
- Install USB/SATA Adapter & Power into Hard Drive
- Connect AC Adapter to power up the Hard Drive
- Verify that some current is showing (in mA)
- Insert USB/SATA Adapter into laptop USB Port
- Verify that USB amber led is lit
- Check My Computer and verify Hard Drive is recognized by the laptop
- Set up laptop and put Hard Drive in the beam
- Isolate laptop from stray radiation as much as possible using shielding
- Set up external camera to look at multimeter
- Verify that current measurement can be seen in monitor at control station
- In My Computer, double click on drive D:\
- Verify that Five (5) 2GB static test files (static1 – static5) are on each Hard Drive
- Open **RWTest** program (See Print Screen in Appendix A)
- Initialize **RWTest** to perform read/write continuous (Alternating Fill Pattern)
- Check box with Flush Buffer
- Click on Change Test Directory, type Test RWtest in file name in Removable Disk (D), Enter
- Verify D:\RWtest.dat is next to *Change Test Directory* icon.

- Click on Start Test to start the radiation test
- Start beam slow and gradually increase until 600 rads
- Wait for upset to occur or run to complete
- Repeat for all for other Hard Drives

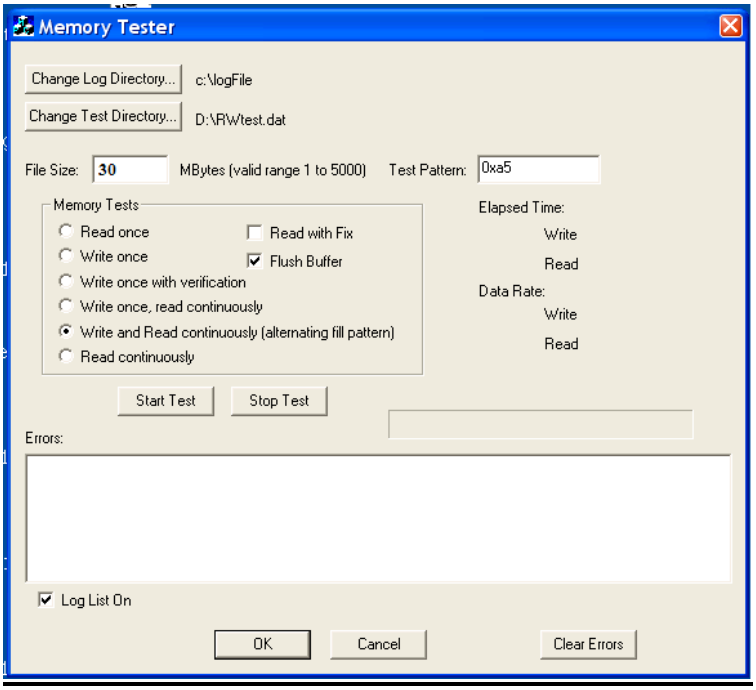
Note: Do not delete any files on Hard Drives or C drive after test completion. Static Files on Hard Drive will be analyzed when return to JSC.

Appendix B

Creating of Static Files:



Peform Read-Write during Radiation Testing


Memory Tester
Change Log Directory...
c:\logFile
Change Test Directory...
D:\RWtest.dat
File Size:
30
MBytes (valid range 1 to 5000)
Test Pattern:
0xa5
Memory Tests
Read once
Write once
Write once with verification
Write once, read continuously
Write and Read continuously (alternating fill pattern)
Read continuously
Read with Fix
Flush Buffer
Elapsed Time:
Write
Read
Data Rate:
Write
Read
Start Test
Stop Test
Errors:
Log List On
OK
Cancel
Clear Errors

Hard Drive _____GB Manuf_____

Run #	Dose	Current (mA)	Time	Upset/Event/Notes (Read ? - Write?)