DATA STORAGE SUITED TO FLIGHT DATA RECORDERS

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Introduction

Flight data recorders must operate in the most demanding environments. Data storage technologies have advanced beyond magnetic media used in tape and disk drives to the functional storage equivalents built using flash memory. Flash-based storage delivers high immunity to shock, vibration and wear out. Additionally, flash exceeds the performance and security found in disks and tapes.

This broad topic covers many applications, each sharing the basic components of a processor, storage, I/O, and system interface as shown in the figure below.

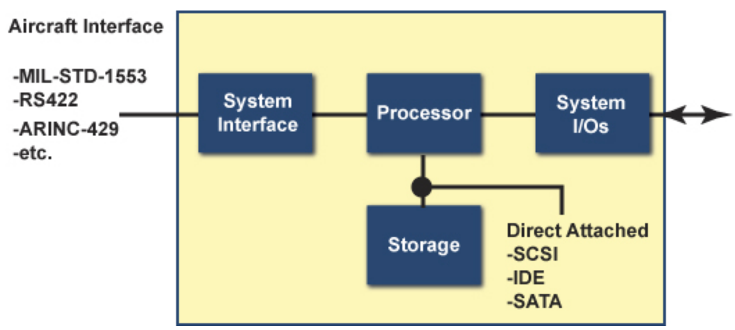

Figure 1 Basic components

This paper focuses on the storage element as required by several fundamental applications. These applications include:

- Health and Usage Monitoring Systems (HUMS)
- Airframe monitoring
- Mapping and mission data transfer
- Voice and video data recording
- Electronic countermeasures
- Surveillance recording

Each of these applications place different demands on the storage device used for recording and information retrieval. Quantitative differences include:

- Storage capacity
- Read and write performance
- Environmental durability
- Fixed or removable operation
- System interface

Fundamental to all of these applications is the need to employ a cost effective storage medium. To achieve cost effectiveness requires leveraging industry-standard component technology and a successful transition from commercial to military level COTS reliability.

Environmental hardening of commercial computer disk and tape drives has been attempted and accomplished in the past through the use of:

- Dampeners to absorb shock and vibration
- Heaters to ensure operation of the media above freezing
- Atmospheric sealing to eliminate vacuum and contamination of the media chamber

The design and cost of mechanical systems to absorb shock and vibration and to heat and cool disk and tape drives adds significantly to the cost, weight and size of the original commercial storage device as shown in the table below.

Flight Hardened Storage			
Storage Device	**Volume**	**Weight**	**Power**
3.5-inch hard disk 10GBytes	680 cc	8 kg	41 W (with heater)
DAT drive – 5GBytes	2540 cc	12 kg	25 W (with heater)
3.5-inch flash disk – 10GBytes	380 cc	2.5 kg	12 W (no heater required)

Table 1 Storage device comparison

SOLID STATE ALTERNATIVE

A recent trend of employing solid state technology in the form of flash memory has proven to be successful in reaching high capacity densities in small volumes, with low power and decreasing costs. The solid state nature of flash memory allows full environmental durability without the extra mechanical support hardware required for tape and disk media.

When implemented as a disk or tape replacement, flash memory has proven to offer improved performance, higher reliability, significantly higher data integrity, and lower power operation than its magnetic counterpart.

Technology of system interface management

The interface technology designed for traditional media of disk and tape is now being adapted to storage systems built with flash memory. Advancements in the management of flash memory now allow the rapid implementation of practically any computer interface now used in standard tape and disk storage systems.

In the same way that the ISO seven-layer communication standard opened the architecture for reusable communications elements, the standardization of storage interfaces allows cross platform and application implementation of storage.

A well behaved system stratifies to these storage system elements:

- Application
- Operating system storage management
- Storage command and status protocol
- Electrical interface
- Mechanical connection

By adhering to these layers and standards, it is possible to integrate flash media to a number of standard storage interfaces and to incorporate a wide range of emulations to match application requirements.

The layers diagram below illustrates the fundamental layers of a storage implementation that allows interface, emulation and media to be tailored to the application requirements.

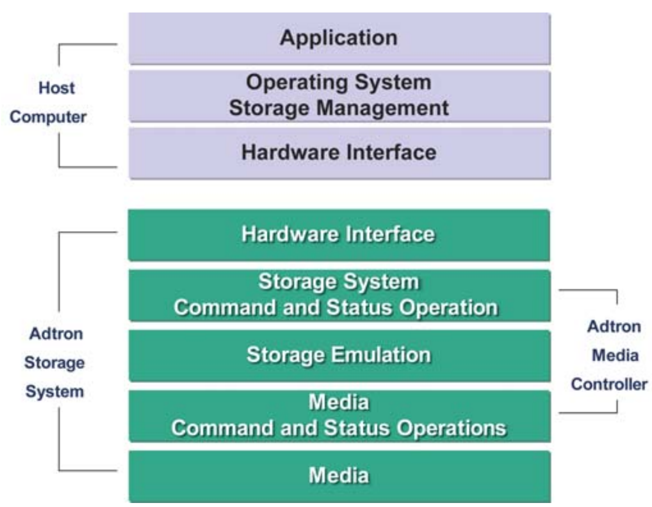

Figure 2 Storage layers

Flash-based storage systems are available today with the following characteristics:

- Emulation
  - Fixed disk
  - Removable disk
  - Tape

- Direct attached interfaces
  - SCSI
  - IDE / ATAPI
  - USB
  - Firewire

- Network attached
  - Ethernet TCP/IP
  - NAS / NFS
  - SAN / iSCSI

Traditionally storage has connected as direct attached to the processor through SCSI, IDE, and serial interfaces. Many versions of these interfaces exist as illustrated by the timeline chart below.

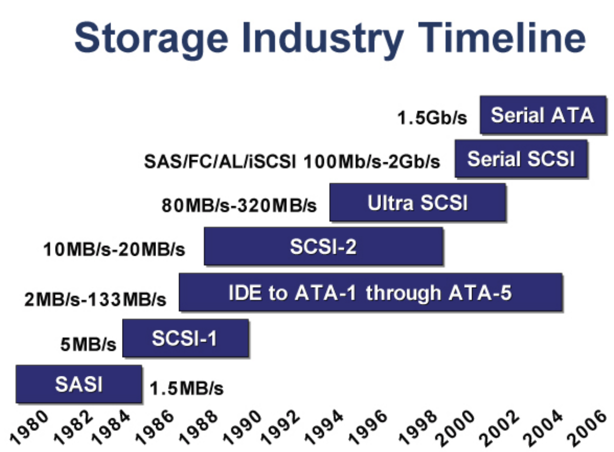

Figure 3 Timeline

Managing these interfaces for installed equipment through spares has proven to be very difficult. Commercial product life cycles are too fast to meet the long term defense and aerospace requirements.

Flash disks available today have targeted the legacy SCSI and newer IDE interfaces, and are looking forward to the next generation interfaces of high speed SATA, Ethernet and Firewire.

Following commercial standards, enhanced to airborne requirements, the next generation aircraft systems will implement data networks based on Ethernet. This allows for distributed storage and supports high availability operation to overcome failures within the network. The nature of direct attached storage does not allow sharing or failover in case of a CPU failure. High availability network management, built into the operating system or as a separate middleware layer, allows redundant storage across a network with failover capability.

As shown below, the flight data recorder can now share the storage elements in a distributed system.

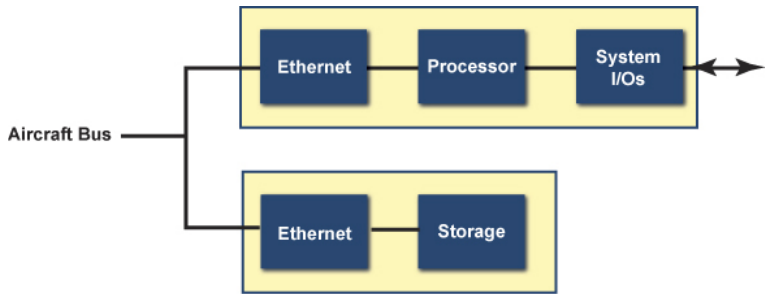

Figure 4 Storage in a distributed system

FLASH PERFORMANCE

Flash storage systems can exceed the performance of magnetic media principally through the elimination of the time-wasting mechanical motion required to find the data. The sequential or track oriented nature of tape and disk data requires seek operations to find the information. Flash is a random access technology and does not add latency overhead to data transfers.

The true performance of a storage system is not indicated by the bandwidth of the data payload bus as often sold by the disk industry. Interface modes such as Ultra-160 or UDMA-100 only indicate the transfer rate and not the end-to-end rate. The overall effective throughput depends on the random nature of data access and the data transfer block size. The following table shows an example of a random access benchmark using small file transfers, which shows how seek operations slows down a higher-rated hard disk drive when compared to a flash disk.

Random access Small file transfers	Flash Disk Ultra-20 Wide S35FB Sequential rate up to 40MB/s	Hard Disk Ultra-80 Wide Quantum Sequential rate up to 160MB/s
Sustained read	8.8 MB/s	1 MB/s
Sustained write	9.5 MB/s	1.5 MB/s
Burst read Avg / Peak	36 / 37 MB/s	10 / 152 MB/s
Burst write Avg / Peak	34 / 37 MB/s	65 / 91 MB/s
Track to track seek max	0.5 ms	16 ms
Track to track seek avg	0.5 ms	8 ms
Rotational latency	0 ms	4.17 ms

Table 2 Flash versus Disk

Flash tape drives offer a similar speed advantage over magnetic tape-based tape drives. As files are transferred the tape must frequently relocate to find and write file markers. A rewind operation can add more than five minutes to a tape data transfer, whereas a flash-based tape drive can rewind in about 500 microseconds.

Higher performance flash memory will enable applications that have found transfer rate limitations in applications such as electronic countermeasures, threat tracking and recognition, surveillance and video recording.

TECHNOLOGY OF FLASH MANAGEMENT

With flash maturing to achieve storage grade operation, it is now feasible to characterize flash as a truly advanced version of tape and disk media. This new understanding means systems designers can move forward with solid state flash implementation, taking advantage of disk and tape storage technology that is appropriate for the application.

Decreasing cell geometry, change over from single- to multi-level cells, and more dense control architectures, make flash-based storage systems more dependent on defect management. The flash disk manufacturer qualifies the flash and verifies the effectiveness of the controller-based algorithms to validate write endurance, data disturb and data retention.

With modern write endurance and defect management techniques there are very few applications that are limited by write endurance. The two most important management techniques to extend the write endurance life of flash are wear leveling and spare sectors. Spare sectors are just like spare tires, they are replacements for failed sectors. When a sector fails during a write or has a correctable read error, it is retired and the data is written to the spare sector. This technique is also used in hard disk drives to overcome similar failures.

The inherent write endurance is effectively increased through the use of wear leveling techniques that even out the write cycles across a flash array used in a solid-state disk. The controller that manages the flash keeps track of the write usage within the flash array and moves the writing around the array to prevent concentrated write areas. Even static or read-only areas are moved to accommodate the leveling of writes.

To combat data disturb errors, the defect management in the flash controller detects data errors and corrects data errors on the fly using error correction codes (ECC). Just like magnetic media, ECC is used to manage random bit errors to significantly increase the data integrity above the inherent media quality.

The archive quality of flash data, i.e. the time that data can be stored without power, is the retention time. A typical value is 10 years at 25 degC, and is significantly better than magnetic media.

SECURITY

While all tape and disk magnetic media-based drives have erase capabilities, flash-based storage offers significantly faster erase and sanitize operations, as well as erase operations that do not require processor activity.

One special feature of a flash disk or tape is the auto resume operation, active during intermittent power conditions, that automatically restarts the secure erase function when power is restored to the drive. Progress indication is available during each secure erase command operation. Erase operation progress, including both the sequence step and step percent completion, is available through the drive interface. An option is available to connect a push button or other actuator to manually initiate a configured secure erase operation.

Flash Characteristics for Securing Sensitive Data		
Feature	**Technique**	**Available in Disk or Tape**
Fast erase	Bulk erase memory	No
Sanitize erase	Overwrite erased memory	Yes, 10x to 100x longer
Write protect	Disable writing to all or portions of the memory array	Limited
Read protect	Password protect areas for read back with varying access for writing	Limited

Table 3 Security features

Several standards exist that define the secure erase operations. There is ongoing activity to standardize these for flash memory.

	Specification	Device	Clear	Sanitize
DoD	NISPOM 8-306 DoD 5220.22-M 1995 Original	FEPROM	Performs a full chip erase as per manufacturer's data sheets.	Overwrite all addressable locations with a single character then perform a full chip erase as per manufacturer's data sheets.
DoD	DoD 5220.22-M NISPOM Supplement 1	FEPROM & EEPROM	Not Specified.	Overwrite all locations with a character, its complement, then a random character.
NSA	NSA 130-2	EEPROM	Same as sanitize operation.	Overwrite all locations with a pseudo-random pattern twice and then overwrite all locations with a known pattern.
Army	AR 380-19	FEPROM & EEPROM	Perform a full chip erase as per manufacturer's data sheets.	Overwrite all locations with a random character, a specified character, then its complement.
Navy	NAVSO P-5239-26	EEPROM	Erase per manufacturer's specifications.	Erase, program all locations with a random pattern, wait 2 minutes, erase, program all locations with another random pattern, verify the random pattern.
Air Force	AFSSI-5020	FEPROM & EEPROM	Erase, verify then overwrite all bit locations with arbitrary unclassified data.	Erase, verify then overwrite all bit locations with arbitrary unclassified data. Declassify the media after observing the respective organizations verification and review procedures.
RCC-TG	IRIG 106-03	FEPROM & EEPROM	Not specified.	Erase; Write 55h: Erase; Write AAh; Erase; Write single file containing string "SecureErase" repeated to fill all available space.

Table 4 Security standards

CONCLUSION

Solid state flash disks are a drop-in replacement for traditional disk and tape storage devices. Flash disks function like hard disk and tape drives with many of the same features, using the same industry-standard interfaces and connectors. Unlike disk and tape, flash disks provide extreme ruggedness under the conditions that are demanded of flight data recording applications. Flash exceeds the durability requirements, improves wear-out rate and performance without the additional mechanical apparatus for dampening and environmental controls required by hard disk and tape drives.

APPLICATION EXAMPLES

Helicopter Health and Usage Monitoring System

In this HUMS application, the storage device must provide a small amount of storage with the ability to remove the data via a transfer to a PCMCIA card. This megabit RS422 interface incorporates a robust protocol between the host and storage device using CRC to validate the data stream for both reading and writing.

During flight, up to 128Mbytes of flight information is written to flash memory. Once on the ground, a large PCMCIA card is inserted by the ground crew to extract the recorded information. One of the many flexible features of this design includes the fast expansion from 128Mbytes up to 2GBytes by changing one plug-in module.

UAV flight recorder

This is an example of a non-removable flash tape that replaces a DAT tape drive for recording airframe and systems operations in an Unmanned Airborne Vehicle (UAV). The two problems with the initial DAT system were: 1) the operating temperature range required special heaters for environments below freezing; 2) and despite mechanical dampeners and environmental harden packaging, the overall vibration and shock caused unpredictable failures.

Flash tape, operating with the command set and storage capacity of a DAT drive, provides an operating range beyond the envelope of the UAV operating environment. This allows the elimination of the heaters and their respective controls, and the reduction in weight and volume through the elimination of special packaging required for the DAT.

With the benefits of size, weight and reliability, and no system modifications required the flash tape drive functioned as a drop-in replacement for the commercial DAT drive within the UAV computer system.

Map and mission transfer

Loading the flight mission and maps into an aircraft is accomplished through a data transfer unit to a removable disk cassette. In this system a ground based station transfers mission information and maps to a flash disk cassette which is transported to the waiting aircraft. These time-critical operations require high speed writing and reading.

The durability of flash provides two types of protection, first the disk must survive the handling when transporting the cassette across the flight line to the aircraft, and second the durability must exceed the mission environment for shock, vibration, altitude, and temperature.

A flash disk replaced the original design that used a hard disk. With this implementation the additional features of heaters and mechanical dampeners were eliminated.