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STRATEGIC/TACTICAL OPTICAL DISK SYSTEM S/TODS JUKEBOX

Lockheed Martin Communications Systems

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13. ABSTRACT *(Maximum 200 words)*
Rewritable optical disk technology affords the promise of larger storage capacity storage for many military applications. The original objective was to develop and deliver two advanced development model (ADM) optical disk storage systems for scientific and technical (S&T) reconnaissance aircraft and ground-based intelligence collection stations. The first ADM consisted of a single disk device capable of performing high-speed write, read and erase operations on a 14-inch diameter, rewritable optical disk. Each optical disk stores 12 gigabytes of user data. Key technical developments included the optical head assembly, optical disk media and high speed electronics design. The second ADM consisted of a fully automated optical disk jukebox storing 120 gigabytes. Key technical features include rugged, modular design for quick deployment set-up and tear-down, dual picker robotics for faster cycle time and an easily interchangeable disk cache for rapid data access in very large capacity applications. Both ADMS were designed, built and tested to comply with anticipated airborne and tactical environments.

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SECTION 1

INTRODUCTION

1.1 SUMMARY

This volume describes the development of the Strategic/Tactical Optical Disk System Jukebox (S/TODS Jukebox) by Lockheed Martin Communications Systems for the Air Force Materiel Command's Rome Laboratory, under Phase 2 of contract F30602–89–C–008. The purpose of Phase 2 was to design, build, and test a 10 disk ruggedized deployable Jukebox based on the S/TODS Airborne Optical Disk Recorder and Media previously developed under Phase 1.

The single disk S/TODS Advanced Development Model (ADM) Airborne Recorder and the Media development (Phase 1) is covered in Volume 1 of this report. The equipment developed in Phase 1 was utilized in Phase 2. The modifications required to convert the Airborne disk drive for Jukebox operation are covered in this volume.

The Jukebox incorporates features such as a rugged, modular design for quick easy deployment set-up and tear down, dual picker robotics for fast cycle time, and an easily interchangeable disk cache for rapid data access in very large capacity applications. System capacity is 120 GBytes per 10 disk cache. Control and data interface is standard SCSI 2.

The Jukebox was integrated and tested with a Sun Workstation and with the Air Force Mission Support System (AFMSS) at the Lockheed Martin facility. At the Air Force's Special Operations Command (AFSOC) the Jukebox was integrated and demonstrated running as a standard SCSI peripheral on the Special Operations Forces Planning and Rehearsal (SOFPARS) mission planner.

Hierarchical Storage Management (HSM) software running on a Sun workstation was integrated with the S/TODS Jukebox, providing automatic, transparent management of the 10 disk cache.

1.2 SCOPE

This volume covers the analysis, design, fabrication, integration, and test results of the development of the S/TODS Jukebox.

1.3 BACKGROUND

1.4 PROGRAM OVERVIEW

This program was performed in two consecutive phases. Phase 1, covered in Volume 1 of this report, developed the airborne single disk S/TODS Advanced Development Model (S/TODS ADM) and the custom 14" media. Phase 2, covered in this volume, developed a 10 disk deployable Jukebox based on the recorder and media from the previous phase. The airborne recorder development built on the results of the Durable I and Durable II optical disk programs (see RADC–TR–86–82 and RADC–TR–88–209), where key risk areas were evaluated and system trade–off studies were performed.

1.4.1 Airborne Phase

A high performance optical disk recorder for use in Scientific and Technical (S&T) Aircraft was designed, built and tested in Phase 1 of this program. Custom, 14 inch diameter, rewritable magneto–optic media was developed under subcontract by 3M. Analysis and design began in December, 1988. The recorder demonstrated successful operation under stressful conditions during September 1993 flight tests on an RC–135 aircraft. The disk drive operated without error through aircraft maneuvers including 60 degree bank turns, takeoff and landings, and tactical descents. Acceptance test was completed in February 1994. Volume 1 of this report covers all these efforts in detail.

1.4.2 Jukebox Phase

Following the Airborne phase, a 10 disk Jukebox version of the S/TODS recorder was designed, built, and tested. Design was begun in September 1993, PDR was held in December of that year. CDR of the mechanical, electrical and software designs was held in May, 1994. Build began with the frames and robot mechanism in early 1994, and continued with the electronics in mid year. Electronic modules and software integration began in November 1994, along with the necessary modifications to the S/TODS disk drive for Jukebox operation.

A major interim demonstration milestone in February 1995 showed operation of the Jukebox robot mechanism with the S/TODS disk drive assembled on a lab bench. Following the demonstration, Jukebox system integration was completed in May 1995. Integration and testing with a Sun workstation, the AFMSS mission planning system, and Metior Hierarchical Storage Manager was done through summer and fall 1995, cumulating in a demonstration of the Jukebox system at the Air Force Special Operations Command (AFSOC) in January, 1996.

1.5 GENERAL DESCRIPTION OF THE EQUIPMENT

The S/TODS Jukebox is shown in Figure 1.5–1.

1.5.1 General Performance Specifications

The specifications of the S/TODS Jukebox are summarized in Table 1.5.1–1.

TABLE 1.5.1–1 S/TODS Jukebox Performance Specifications

SPECIFICATION:	VALUE
Interface :	SCSI 2
Mounting:	Stand Alone
Size:	57" length, 32" width, 45" height
Weight:	485 lbs (deployed)
Power:	120 VAC, 50/60 Hz, 1Φ, 4 A avg, 6 A max
Recording Media:	Qty 10, 14 inch erasable disks, (expandable)
Individual Disk Capacity:	6.0 Gigabytes/side, 2 sided disk
Data Transfer Rate (Burst):	10 Mbytes/s
Data Transfer Rate (Continuous):	0 to 25 Mbits/s
Bit Error Rate (BER):	$< 1 \times 10^{-11}$
Disk Storage:	in standard disk carriers in cache
Temperature:	0 C to +40 C operational –40 C to +68 C Transit and Storage
Shock:	15 inch drop

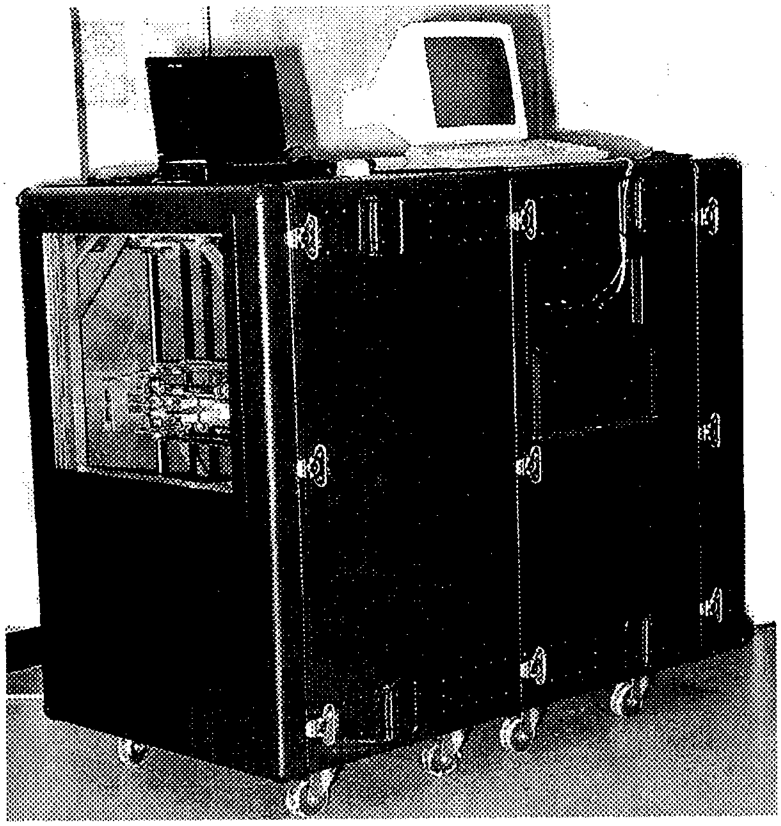

Figure 1.5–1 S/TODS Jukebox

1.5.2 The S/TODS Jukebox Equipment

The Jukebox is comprised of the Robotics Unit (RU) and the Support Rack (SR) cases. The two cases are detached for deployment in easily managed pieces. The RU contains the disk accessing mechanism providing movement of the optical disks between the disk storage Cache and the disk drive. The disk drive is composed of the Disk Drive Unit (DDU) and the Electronics Unit (EU), both of which are housed in the SR along with the Disk Cache and Jukebox control electronics. The equipment in the operational configuration is shown in Figure 1.5.2–1.

1.5.3 The Optical Disk Drive Equipment

The S/TODS ADM airborne optical disk drive was developed in Phase 1 and covered in Volume 1 of this report. This high performance rewritable recorder incorporated many advanced features such as dual write lasers with separate read beams for fast data transfer and real time verification; 25 Mbit/s continuous transfer rate; and very small written feature size for 12 GByte capacity per double sided disk. Required modifications for Jukebox operation are covered in this volume.

1.5.3.1 Modifications for Jukebox Operation

Modifications to the disk drive were necessary for Jukebox operation. Both the DDU and the EU mounting was changed from the airborne configuration rack mount to a drawer mount configuration. The DDU required changes to the disk loading mechanism to allow use with the robotics mech-

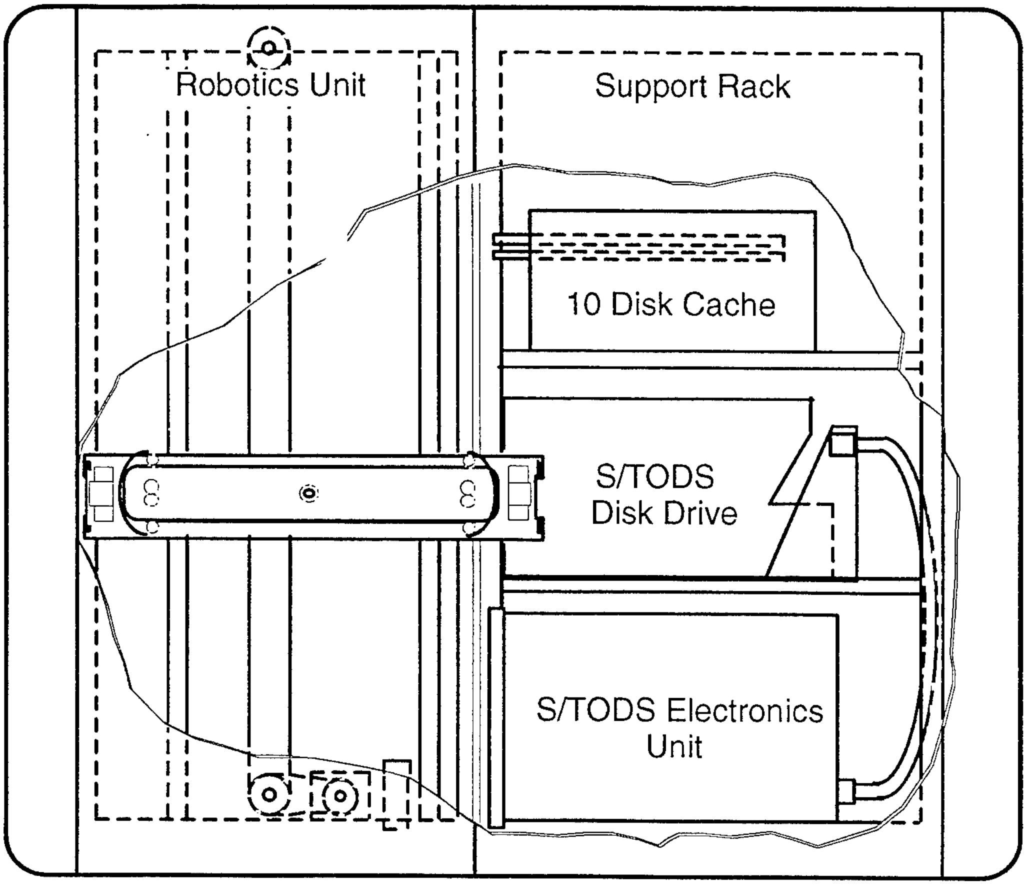

Fig. 1.5.2–1 S/TODS Jukebox Front View (with Cutaway)

anism of the Jukebox. Software changes were made to the EU for coordinating operations with the robotics controller, and the drive was converted from SCSI 1 to SCSI 2 interface.

1.5.4 Media

14 inch diameter custom magneto–optic media was developed under subcontract by 3M in Phase 1 of this program, and is described in Volume 1 of this report. Additional work on media performance and utilization was done in Phase 2 and is covered here. Ten disks are housed in standard 14" carriers in the Disk Cache of the Jukebox. The double sided disks store 6 GByte per side and are rewritable.

1.6 HOST INTEGRATION

The Jukebox was interfaced via SCSI 2 as a storage peripheral to a number of Host system configurations and software packages.

1.6.1 SCSI 2 Interface

The Jukebox command and data interface is via SCSI 2. Modifications were made to the disk drive to convert from SCSI 1, used in the airborne configuration. A standard VME SCSI 2 controller module was purchased and installed in the EU. Custom software for the Jukebox was written for this module.

The Jukebox conforms with the SCSI 2 specifications for a direct access device and for a medium changer device. All mandatory commands are supported. In addition, a number of optional commands necessary for compatibility with the Sun Workstation and purchased software packages are also supported. Refer to the Jukebox ICD for details of this interface and supported commands.

1.6.2 Sun Workstation

Interface with a Sun SPARC10 Workstation was accomplished under both SunOS and Solaris operating systems. File systems were created on selected disk sides. The Jukebox was then mounted as a normal UNIX file system, appearing as a standard hard drive to the filesystem software and the operator. A software tool was developed for use with the Sun Workstation. This tool permits the operator to issue Jukebox disk movement commands. Disk load and store commands are entered using the mouse in the graphical user interface (GUI) version or from a command tool in the command line version.

1.6.3 Air Force Mission Planning Systems

A SCSI external hard drive was loaded with the Air Force Mission Support System (AFMSS) software by Lockheed Sanders, the vendor. This system runs on a Sun workstation and is used by pilots for planning flights. The large, random access, map database required for planner operation is a typical Air Force application of the S/TODS Jukebox. In the Camden facility, the Jukebox was integrated with AFMSS in a standalone demonstration system consisting of the Jukebox, external hard drive, and a Sun Sparc10 workstation.

Following integration of the stand alone system, the Jukebox was shipped to the Air Force Special Operations Command (AFSOC) at Hurlburt Field, Florida and integrated with the Special Operations Forces Planning and Rehearsal System (SOFPARS). SOFPARS is a deployable mission planner running the AFMSS software.

1.6.4 Metior HSM

The S/TODS Jukebox was integrated with the Metior – Hierarchical Storage Management (HSM) software. The Metior software is a commercial package, supplied by ANT Inc.. The Metior software is run on a Sun Workstation and interfaces the associated Unix file system with the Jukebox in such a way that disk move management, file migration from the Sun hard drive to the Jukebox, and file retrieval from the Jukebox is provided transparently to the user. This system potentially makes the Jukebox appear to the user as a single 120 GByte hard drive.

SECTION 2

JUKEBOX ANALYSIS

2.1 INTRODUCTION

This section summarizes the system analysis performed prior to the detail design of the Jukebox system. System architecture rational and preliminary design choices are included. Design was based on the *Statement of Work for Tactical Optical Disk Systems (TODS) PR NO. I–9–4266* dated December 27 1988, *Amendment to Statement of Work PR NO. I–3–4092* dated May 25 1993, and issues identified by Lockheed Martin during analysis.

2.2 SIZE

The size of the Jukebox is driven by the volume of the disk drive and disk storage cache, the size of a robot capable of translating and rotating the 14" disks, and the ruggedness and shock isolation necessary for the transit and deployment requirements.

2.2.1 Volume

The volume specification was the equivalent of one standard 19" equipment rack. This requirement was met with equipment dimensions in the deployed configuration of 57" length X 32" width X 45" height. Approximately one half of the volume is required for the robotic mechanism, which needs free space to translate and rotate disks. The second half of the volume is the disk drive Electronics Unit (EU), the Disk Drive Unit (DDU), and the disk storage cache. These three items are packaged in a stacked configuration. This dictates the minimum height of the Jukebox. The EU is located on the bottom, the DDU in the middle, and the cache is on top. The DDU and cache are adjacent so as to minimize translation distance. The remaining miscellaneous smaller components such as the control electronics, power supply, and cooling components were located in the areas left available by the described configuration.

2.2.2 Weight

Specified maximum weight was 600 lbs in the deployed configuration, with a 500 lb goal. The goal was not met, with the final weight 585 lbs. The ruggedness requirements for transport tend to drive the weight upward, see Transport, Section 2.3.1.

2.2.3 Deployment

A major design criteria was the transportability specification. The unit must be broken down into subunits suitable for two man lift. To meet this requirement the Jukebox is designed to split into two subunits, the Robotics Unit (RU) case and the Support Rack (SR) case. The disk drive EU, DDU, and the disk Cache are easily removed from the Support Rack and are packed and transported in individual shipping containers. Setup and breakdown are accomplished by 2 people in under 30 minutes, without tools. Jukebox structures are self aligning and are secured by hand operated latches. On power up, the Jukebox mechanisms perform a brief sequence of simple, automatic self–alignment operations. No manual alignment of mechanisms is required after shipment and setup.

The two man lift weight requirement was exceeded on the RU design, at 234 lbs as shipped. This is due to the ruggedness requirements of RU the structure. Casters were added to allow one or two people to easily move the RU and SR cases, separated or mated, or flip them upright from a prone transport position. Three men are recommended to lift the units if it becomes necessary to carry them across rough terrain.

2.3 ENVIRONMENT

The major environment specifications driving the design involve the ruggedness requirements for transport. Temperature, humidity, and pressure specifications were met.

2.3.1 Transport

A 15" drop shock and 0.04 G^2/Hz vibration non–operational specifications necessitated internal isolators and strong, stiff cases and frames for the SR and RU. Wire rope isolators were chosen for unchanged damping characteristics over the temperature range. The two units are designed with all components mounted on internal aluminum tube frames designed for 50G shock. The frames then mount on 8 wire rope isolators to the corners of the cases. Analysis showed an acceptable transmitted shock of 40G for a 15" drop in any axis. The size of the cases was determined by the sway space requirements of the isolators for the shock and vibration specifications, given frames holding the robot and drive components.

Transport and storage temperature range specification is –40 to +68 °C. The drive meets this specification, and all Jukebox components were selected to meet this range.

2.3.2 Operational

The Jukebox is designed for operation in a fixed location, such as a mobile shelter. The specified Temperature range is 0 to 40° C. The drive meets this specification, and all Jukebox components were selected to meet this range. To allow operation in dirty environments the cases are sealed by gaskets when mated in the deployed configuration. The cases and seals isolate the interior and keep the disks and the disk drive clean.

2.3.2.1 Cooling

The disk drive electronics unit is cooled by convection. The disk drive optics, disk drive mechanism, and robotics unit are cool by a combination of convection and radiation. The drive EU utilizes external ambient air via inlet and exhaust ducts for cooling. The ducts are provided with filters for dirt and EMI protection. Small amounts of dirt will not affect the electronics. So that the disks and mechanism would not be affected by a dirty ambient atmosphere the cooling air for the drive EU is kept separate from the cooling air for the drive and robotics unit. Fans in the sealed internal area were designed to circulate air in a controlled manner through the remaining components and along the walls of the cases, providing radiative and conductive cooling. Analysis of the heat dissipation showed an expected internal temperature rise of 5° C. This was verified by test.

2.4 INTERFACE

The system architecture assigns all data and control interface to the SCSI bus, with the minimal front panel operator control requirements for power and selftest. For maintenance control and detailed fault analysis a diagnostic port for a standard terminal is provided. A laptop PC is shipped with the Jukebox for fault diagnosis purposes.

2.4.1 Control and Data Interface

Jukebox disk movement commands and read/write data transfers are done via the SCSI 2 bus. The airborne drive used the older SCSI 1 bus, upgrading to SCSI 2 was elected for increased transfer rate and usage of the SCSI 2 Move Medium command set. A single board computer module was purchased and software written to handle this interface. All SCSI commands are parsed through this module, Read/Writes to the drive and Move Mediums to the robot. Additionally, a 16 MByte data cache is included in this module for faster user data throughput, upgraded from the 8 MByte cache used with the SCSI 1 design.

2.4.2 Operator Interface

The operator may issue commands from the Front Panel, the Maintenance Terminal, or from the Host over the SCSI bus. Typically users carry out all operations through the Host, with the exception of power cycling via a Front Panel pushbutton. Additionally the Front Panel has a Self Test pushbutton for a go–no go test. The Maintenance Terminal provides a method of direct communication with the Jukebox for integration and testing activities.

2.4.3 Power Input

The Jukebox is designed for 120 Volt AC, 50 or 60 Hz, single phase operation. The average current input to the Jukebox is approximately 4 A rms. The peak current input to the Jukebox is 6 A rms. The airborne drive previously used 400 Hz 120V aircraft power and required conversion to 50 / 60 Hz for the fans, vacuum pump, and circuit breaker.

2.5 CYCLE TIME

Maximum cycle time was specified as 15 seconds. To meet this spec a dual disk picker was designed. It can handle two disks simultaneously. This allows retrieval of a desired disk from the cache while the drive completes unload of the prior disk, saving time. Secondly, the picker mechanism weight was minimized to allow higher translation and rotation accelerations with reasonable sized motors.

2.5.1 Dual Picker Mechanism

To minimize weight the picker utilizes reinforced aluminum sheet metal construction, and carries only the small DC gear motors for disk insertion and extraction. The translation and rotation motors are hard mounted to the frame and they drive the picker through toothed belts. This ultimately reduces the weight of the entire unit by providing a lightweight picker structure and allowing selection of smaller motors.

2.5.2 Rotation and Translation Stepper Motors

Stepper motors were selected to drive the rotation and translation mechanism. This choice, instead of DC or other type motors, reduced design and integration cost. The Stepper motors selection permitted an off the shelf motor and controller with simple custom software to be used. Analysis showed open loop step operation to give sufficient position accuracy for both translation and rotation positioning, avoiding use of feedback from absolute position encoders. A "home" flag sensor marking a reference position for each motion axis was used. At power–up each stepper automatically locates the reference position and bases future motion on step counts from this location. This reference location provides a simple means of automatic power–up mechanism realignment.

2.6 JUKEBOX SYSTEM CONTROL

To control the robotics mechanism a single board computer with both VME and RS232 interfaces was selected. The existing drive system controller handles drive operations while the SCSI 2 module (see section 2.4.1) handles user data and control communication. Sensors throughout the Jukebox monitor the assembled components and the mechanism and disk positions.

2.6.1 Mechanism Control Electronics

Two electronic modules were installed to control and drive the mechanisms. They are the Disk Accessing Mechanism (DAM) Controller module and the DAM Interface module. They are located in a VME nest in the Support Rack.

2.6.1.1 DAM Controller Nest

A 6 slot VME nest with an off the shelf VME backplane was selected to house the Jukebox control electronics. This allows convenient use of an off the shelf controller, inter–module communication using existing circuit designs, and future expansion of Jukebox capabilities. Four module slots are unused, for future installation of alternate drives or components requiring additional electronic modules.

For the DAM Controller a standard Radstone 68020 based single board computer was purchased. This is similar to the board previously used as the drive System Controller. The VME backplane is used for communication with the DAM Interface for the purpose of motor, brake, and sensor control. The Radstone module's triple RS232 ports are used for interface with the stepper motor indexers, the disk drive electronics unit, and the diagnostic terminal interfaces. Firmware written in C coordinates all Jukebox media movement operations.

A single custom electronics module, the DAM Interface, was designed for the motor, brake, and sensor drive circuitry. Commands are received over the VME bus from the DAM Controller.

2.6.1.2 Rotation and Translation Motors and Indexers

An indexer driver was purchased for each of the two stepper motors. These units are programmed with the required motion profiles using a vendor supplied high level language. RS232 communication with the DAM Controller is used for command and status messages.

2.6.2 Safety

Several critical safety issues were addressed through a combination of position and component assembly sensors and DAM Controller firmware. Operator safety along with robotics mechanism and disk safety is provided.

2.6.2.1 Sensors

Each component requiring operator setup during deployment of the Jukebox has a sensor indicating proper installation. Sensors determine whether the Support Rack and Robotics Unit are fully mated, and whether the end caps are properly installed. The findings are acted upon during power–up in such a way as to prevent wayward fingers from entangling in a moving mechanism.

Additional sensors monitor the position of the mechanisms and the location of the valuable disks during any movement. Over travel sensors on the rotation and translation mechanism force protect against robot damage.

2.6.2.2 Firmware Abort Scenarios

On initial power–up the DAM Controller firmware checks all assembly sensors for proper and complete deployment assembly. If a discrepancy is found, the drive and robot remain unpowered, and a message describing the error is displayed on the diagnostic terminal.

Disk and mechanism positions are checked by the firmware at each step during all mechanism movement operations. Watch dog timers are operated during each sub–stage during all mechanism movement operations. Any discrepancy either position or time will cause the firmware to safely abort the operation. At the present level of software development, in some cases the fault may be recovered from fairly conveniently or automatically. In general, all motors are stopped, all breaks are applied, and a message describing the error is made available on the appropriate diagnostic ports. The Jukebox will refuse further commands until operator intervention recovers from the fault.

2.6.3 Self Test

A go–no go Self Test operation was designed to fully exercise the robotics mechanism and drive. This test loads and exchanges two cache disks, and performs an erase/write/read bit error test on the drive. A front panel pushbutton initiates the sequence, and a front panel indicator reports pass/fail status.

2.7 CAPACITY

Data storage capacity was specified at 100 GBytes. The S/TODS drive was designed for 12 GByte 14 inch double sided disks, developed in the airborne phase of the program and used for the Jukebox. A ten disk storage cache was designed, providing 120 GBytes maximum, or over 100 GBytes with an average disk defect reduced capacity of 90%.

Capacity may be increased either by manually exchanging disk caches, or by a design change extending the robot frame and enlarging the cache. The cache was designed for easy exchange. In a few minutes an operator can substitute a fresh 10 disk cache for the loaded cache. The cache slides out of the case for access, is an easy one man lift, and is equipped with alignment keys and position sensors. The mechanical design was done looking toward the possibility of extending the internal frame design upward and adding additional cache trays including up to 100 disk (1.2 TByte) capacity in 10 stacked caches. A new external case design would be required.

Disk defects had been found to be a problem in the airborne phase. Twenty–one of the custom 14" disks were built. A number of the disks provided the full 12 GByte capacity, though others were below the desired 90% capacity. Further certification effort and drive modifications were made with the goal of gaining additional capacity on the available disks, with limited success.

SECTION 3

JUKEBOX DESIGN

3.1 INTRODUCTION

This section describes the design of the S/TODS Jukebox and the required modifications to the S/TODS disk drive. System, mechanical, electrical, and firmware designs are covered.

An Operation and Maintenance (O&M) manual and an Interface Control Document (ICD) were written for the Jukebox. The O&M manual covers detailed information and instructions on the setup and operation of the Jukebox System, along with basic maintenance instructions. The ICD covers the detailed user information on the control, data, and power interfaces and physical operating environment.

3.2 SYSTEM DESIGN

The Jukebox both functionally and physically is broken down into two units, the Robotics Unit (RU) and the Support Rack (SR). The RU contains the disk movement mechanism. The SR contains the disk drive, disk storage cache, and the Jukebox control electronics nest. For shipping the RU and SR are separated, and the Electronics Unit (EU), Disk Drive Unit (DDU), and Cache are removed from the SR and placed into individual shipping containers. Figure 3.2–1 shows the major components of the system along with a Host, and diagnostic terminals for the drive and Jukebox mechanism controllers.

3.2.1 Robotics Mechanism

The RU contains the mechanical devices used to move disks between the Cache and the Disk Drive. The disk picker performs insertion and extraction operations, where disks are removed from a source (cache or drive) and loaded into a destination (cache or drive). The picker handles two disk simultaneously for faster cycle time. The translation mechanism moves the picker vertically between the Drive and Cache. The rotation mechanism inverts the picker before an insertion operation when access to the second side of a disk is requested. Stepper motors are used for the Rotation (RX) and Translation (TX) drives, driven by the RX and TX Indexers. Both the motors and indexers are mounted on the floor of the RU, moving the picker through toothed belts. DC gear motors riding with the picker are used for disk insertion and extraction, driven by the DAM Interface module in the SR.

3.2.2 Optical Disk Drive

The S/TODS ADM airborne disk drive designed and built in Phase 1 of the program was utilized in a slightly modified version for operation in the Jukebox. Design of the drive itself is covered in Volume 1 of this report, modifications are covered in this volume. The drive consists of the Electronics Unit (EU) and the Disk Drive Unit (DDU), both of which reside in the Jukebox Support Rack. Required modifications from the airborne configuration were kept to a minimum, mainly involving mounting changes, disk loader modifications, conversion to SCSI 2, and control software changes.

3.2.3 System Control

System operations are controlled by three purchased single board computers. The Disk Accessing Mechanism (DAM) Controller handles all disk movement operations between the Cache and the

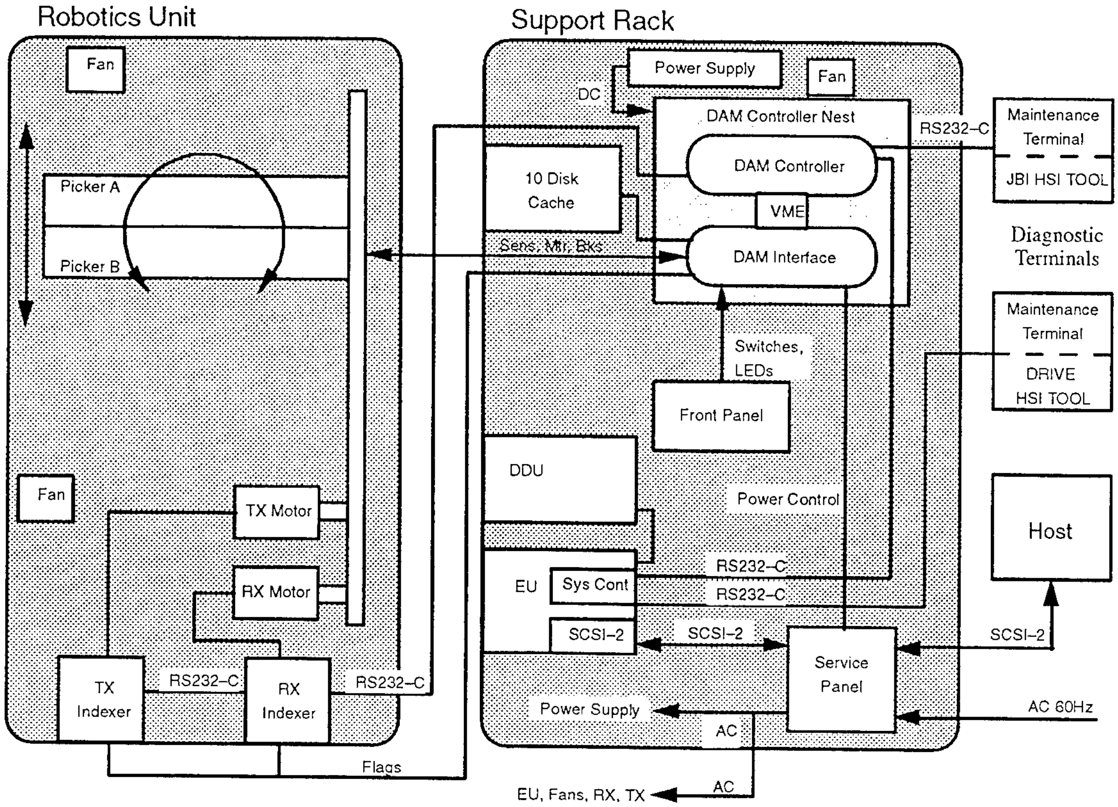

Fig. 3.2–1 Jukebox System Block Diagram

drive, Jukebox power cycle sequencing, and the Jukebox diagnostic terminal. The Drive System Controller handles read/write operations, the drive loader mechanism, and the Drive diagnostic terminal. The SCSI 2 Adapter interfaces to the Host over SCSI, parses read/write and move medium input commands, and handles the 16 MByte data cache operations. Both the System Controller and the SCSI Adapter are located in the EU. The DAM Controller is located in the DAM Controller Nest.

The Rotation (RX) and Translation (TX) stepper motors are driven by the RX and TX Indexers, located in the RU. Their motion sequences are coordinated by the DAM Controller. The Picker mechanism is controlled by the DAM Controller through the DAM Interface module. The DAM Interface module also contains the drive electronics for the small dc motors, brakes, and sensors.

3.2.4 System Communication

External Host communication is via a SCSI 2 interface. Diagnostic information and maintenance control for the drive and robot are exchanged with terminals through RS232 interfaces. Internal communication between the stepper indexers, DAM Controller, and Drive System Controller is also conducted via RS232 interface.

3.2.4.1 SCSI 2 Host Interface

One SCSI 2 port is used for all command, data, and status/error reporting to the Host. The SCSI 2 Adapter module interfaces the Host to the robotics mechanism and the disk drive.

3.2.4.2 Operator Control

Three methods of Jukebox control are available. A user in a typical operational scenario does all operational control from the Host over the SCSI bus. The Jukebox Front Panel contains power and self test buttons and status indicator lamps. Diagnostic terminals for the DAM Controller and Disk Drive may be used for the exchange of control and status information with the Jukebox and Drive respectively. These terminals provide direct access to the individual components of the system both for integration and maintenance operations and for fault diagnosis.

3.2.4.3 Jukebox Internal Communication

Communication internally between the various control components of the Jukebox is done over VME, VSB, and RS232. The SCSI Adapter communicates with the Drive System Controller via the VME bus in the EU, and transfers data to the drive track buffer over the EU's VSB bus. The DAM Controller communicates with the Drive System Controller via a dedicated RS232 connection and with the RX and TX Stepper Indexers over another dedicated RS232 port. Messages between the SCSI Adapter and DAM Controller are sent through the Drive System Controller via their VME and RS232 connections.

Control of the DAM Interface module's drive circuitry by the DAM Controller is done via a second VME bus in the Controller nest. The DAM Interface drive outputs are hardwired to the various electro–mechanical components of the Jukebox.

3.2.5 Deployment

For shipment and rapid deployment the Jukebox splits into easily manageable sub–components. The RU and SR cases separate and covers are closed over all openings. The Robotics Unit and Support Rack cases become their own shipping containers. The units may be wheeled about individually in the upright position or lain prone on their feet and then carried coffin style using the four side handles. Prior to shipment the EU, DDU, and Cache are removed from the SR and placed in individual foam lined containers. This lightens the SR and reduces the potential for shock loading on the SR frame and component tray structure. Overall, separate shipment makes it easier to meet the transport shock and vibrations specifications. Figure 3.2.5–1 shows the Jukebox in the shipping configuration.

3.3 MECHANICAL DESIGN

The Jukebox mechanical design consists of the external shipping Cases, internal component support Frames, and the Robotics Mechanism. Major design considerations were the specifications for ease and speed of deployment, disk access cycle time, and transport shock/vibration.

3.3.1 External Cases

The Robotics Unit (RU) and Support Rack (SR) external Cases contain and protect the Jukebox components. The cases become shipping containers when separated and closed by their associated covers. Construction is heavy wall aluminum with internal stiffening members. These vendor supplied cases are designed to tolerate rough handling. When the Jukebox is assembled and operating the Cases seal the interior from atmospheric dust and dirt, and provide EMI protection. Figure 3.3.1–1 shows the two cases in the mated configuration.

Each case has 4 handles, 2 along each side, for hand carrying the separated units in a prone position. When upright, casters allow rolling the units while either separated or mated.

The SR has openings for the Front Panel, Service Panel, and an EU cooling air exhaust duct. The RU has an opening for the EU cooling air inlet duct. Doors with integral gaskets are provided to cover these openings during shipment.

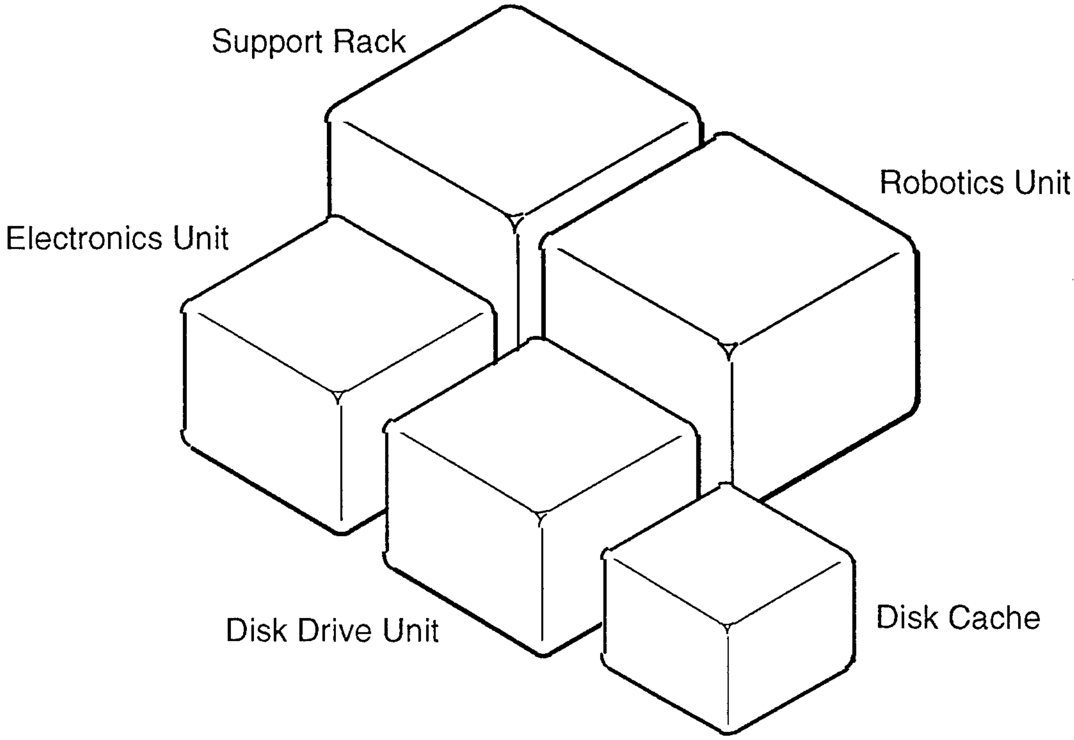

Fig. 3.2.5–1 S/TODS Jukebox Transport Cases

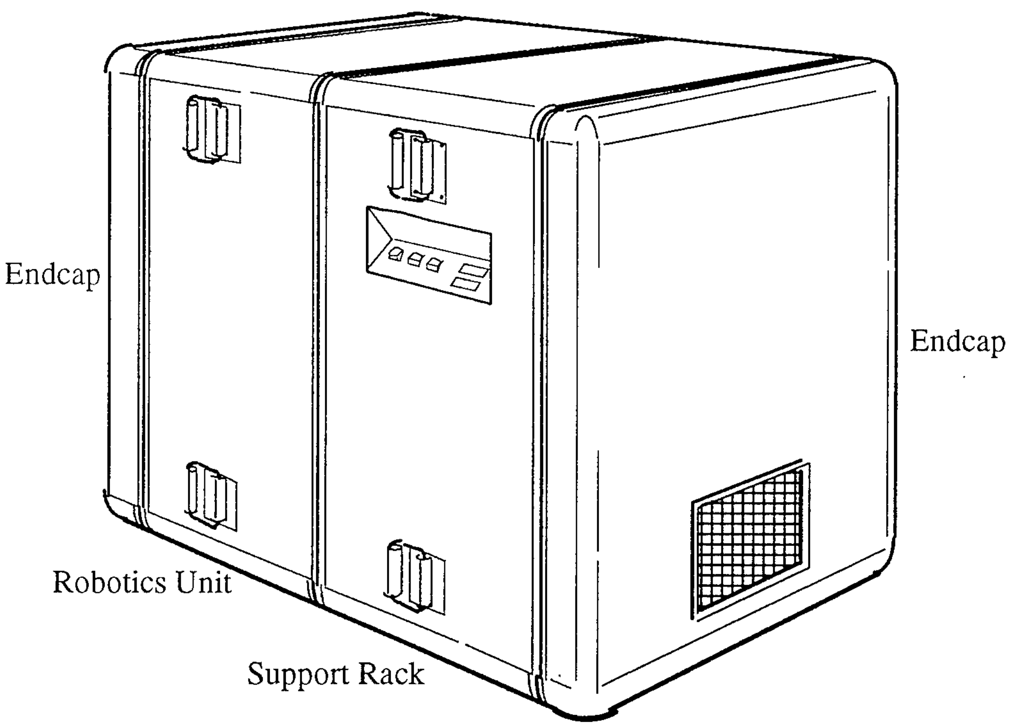

Fig. 3.3.1–1 External Cases (front view)

Two removable Endcaps cover the sides of each case for shipment. The inside Endcap on each is removed and stowed when the cases are mated for deployment. The outside Endcaps may be removed for access to the Jukebox components. For demonstration purposes, an Endcap with an observation window was built for the RU, allowing viewing of the mechanism.

3.3.2 Internal Frames

All Jukebox internal components are mounted on two frames, one for the RU and one for the SR. The frames are welded aluminum tube box frame structures, mounted in the shipping Cases on wire rope vibration isolators. When the RU and SR are mated for deployment, tapered guide pins and spring loaded hand latches along the mating ends of the frames precisely align and combine the frames into one rigid structure.

3.3.3 Robotics Unit Internal Components

The RU contains the disk movement robotics. The robotics consist of the Picker Assembly, the Translation Mechanism, and the Rotation Mechanism. The Picker is translated to a desired disk location, and rotated for access to the second side of a disk.

3.3.3.1 Disk Picker Assembly

Insertion and Extraction operations from the Drive and Cache are carried out by the Picker Assembly. This unit rides up and down on twin shafts, moving between the Cache and Drive. Two levels, Picker A and Picker B, enable the assembly to handle two disks simultaneously. Figure 3.3.3.1–1 shows the Picker Assembly top view, Figure 3.3.3.2–1 shows a side view.

The Insertion Gear Motors and Pinch Roller Motors are carried with the Picker. These DC gear motors withdraw the disk into the picker and hold it for translation and rotation. Four sensors on each Picker level feedback disk position information. At the destination the motors move the disk back out of the picker.

The Insertion Gears are mounted on the outer picker, with an upper and lower set. Insertion Gears provide the first portion of the motion on an extract, the last portion on an insert. The Pinch Rollers are mounted on the inner picker, with a side A and side B set. They move the disk to the center of the picker and hold it in place for translations and rotations. The four picker motors have integral brakes, active with power off.

Disk rotation is accomplished by a 180 degree rotation of the inner portion of the Picker Assembly about a central horizontal shaft. During a rotation the outer picker remains fixed. After a rotation the inner and outer Picker are locked together by a tapered pin.

3.3.3.2 Translation Mechanism

Vertical translation of the Picker Assembly between the Cache and Drive is driven by a stepper motor. The TX Stepper Motor is mounted to the floor of the RU frame, along with it's Indexer controller. Two gear driven toothed timing belts lift the picker to the desired location along the twin support shafts. Figure 3.3.3.2–1 is a side view of the Robotics Mechanism, showing the translation mechanism with the picker assembly.

At each power off, in preparation for potential shipment, the translation mechanism parks the picker at the top of the travel. During packing, two shipping brackets, one of each shaft, are manually locked against the mechanism to hold it in place during shock and vibration. With the picker at the top of the RU, the center of gravity coincides with the center of the unit. This makes tilting the case onto its side for hand carrying easier.

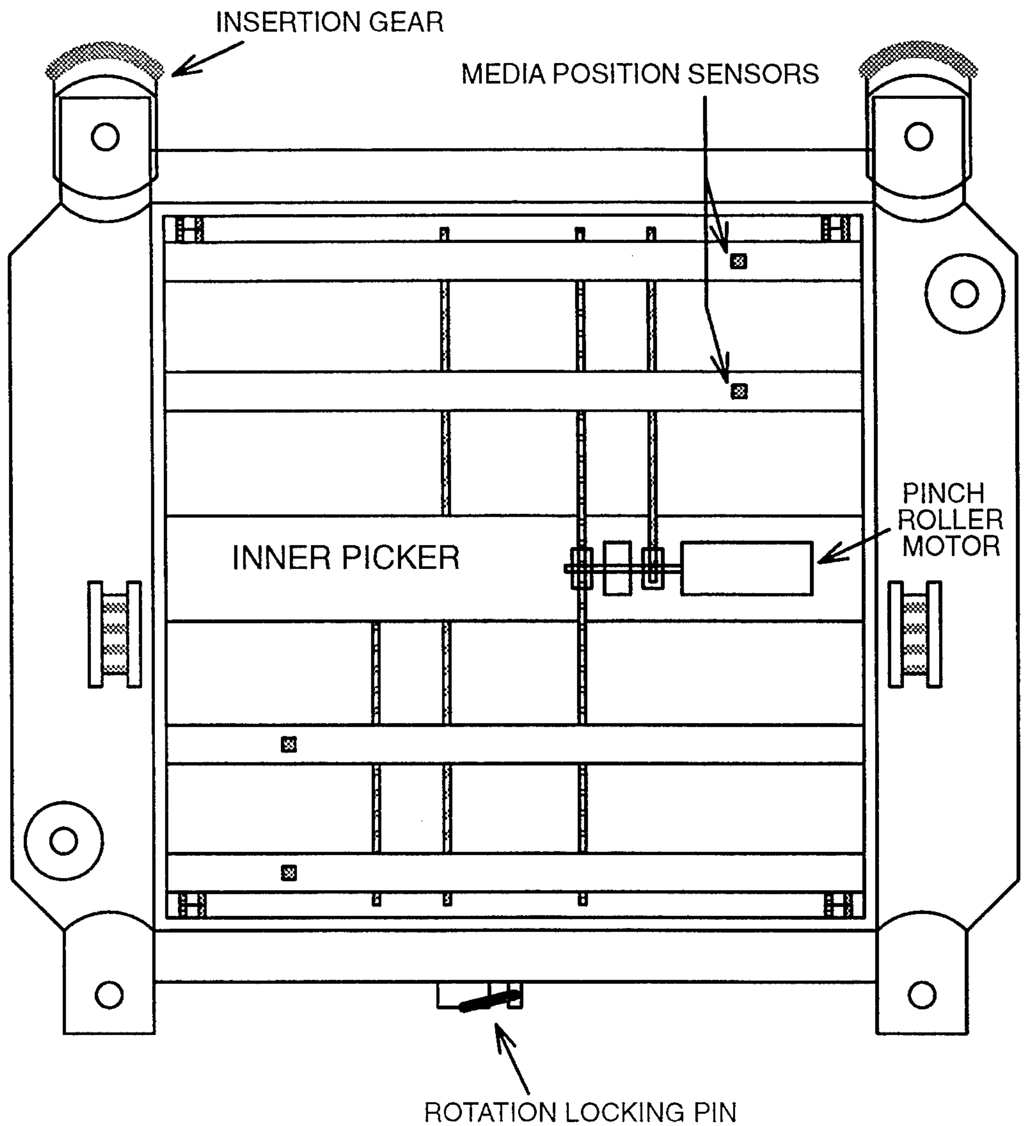

Fig. 3.3.3.1–1 Picker Assembly, Top View

3.3.3.3 Rotation Mechanism

Rotation of a disk for side 2 access is accomplished by inverting the inner portion of the Picker Assembly by a stepper motor. The RX stepper motor is mounted to the floor of the RU frame, along with it's Indexer controller. One of the two picker support shafts rotates, driven through a belt by the RX motor. A pulley in the picker, driven by a ball slide riding in a keyway on the shaft, rotates the inner picker about a central horizontal shaft.

3.3.4 Support Rack Internal Components

The Support Rack (SR) contains the Disk Drive, Cache, DAM Controller Nest, and the Front Panel and Service Panel. The Drive and Cache are mounted on sliding trays for removal for shipment. Refer to Figure 1.5.2–1 to see the location of the major components in the SR.

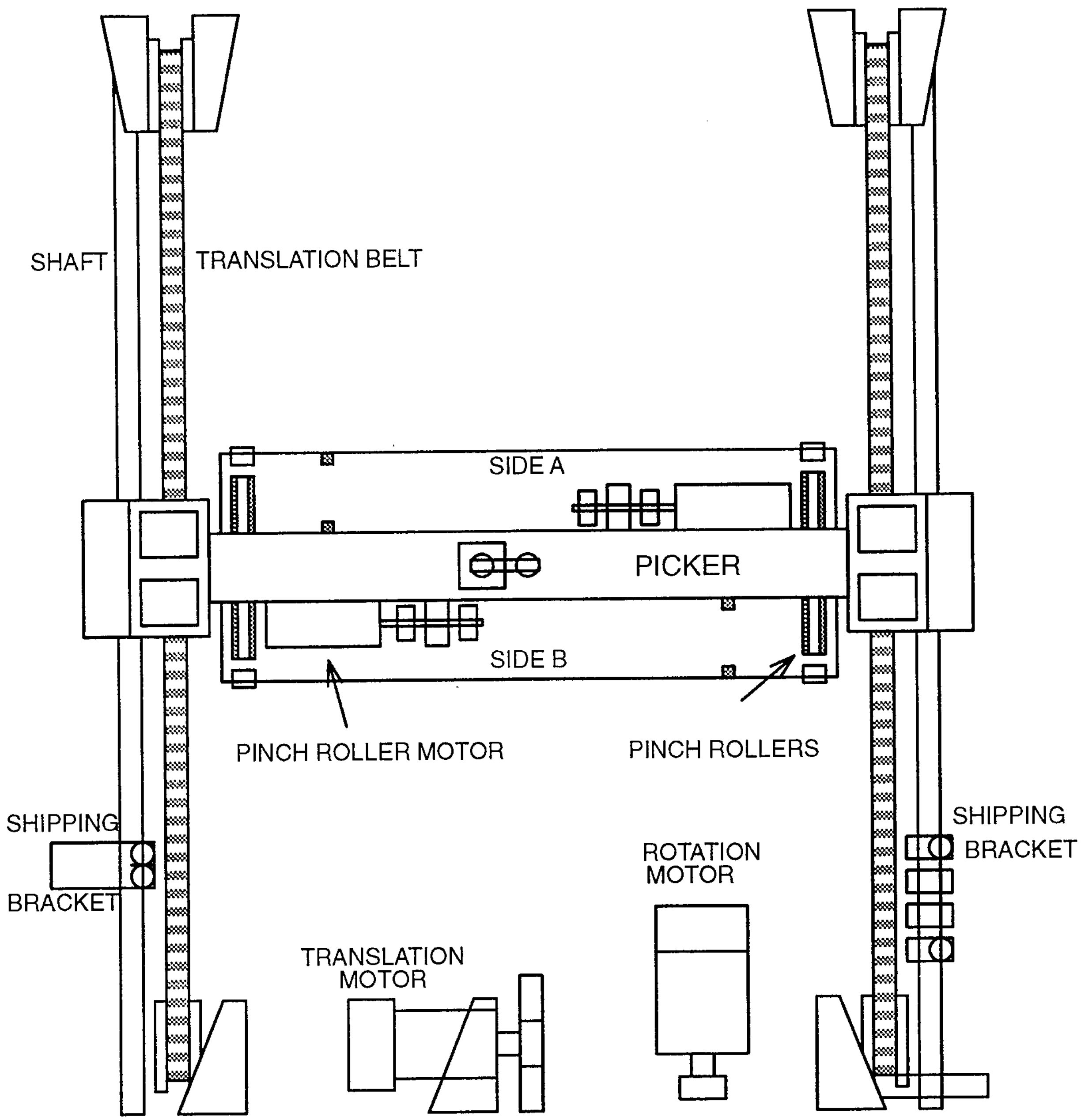

Fig. 3.3.3.2–1 Robotics Mechanism, Side View

3.3.4.1 Cache, EU, and DDU Drawers

The three removable components are mounted on sliding drawers in a stacked configuration. To remove the units, the outer Endcap is first removed. Each units is then slid out, unlatched, and lifted off. Alignment keyways and hand operated latches are used throughout; no tools are required.

Sensors on each drawer and unit detect proper assembly. This allows the Jukebox to prevent mechanism power up if the assembly process is not completed correctly.

3.3.4.2 Disk Cache

The Disk Cache holds ten disks, each in a standard commercial 14" carrier. Construction is lightweight sheet metal and plastic. The Cache includes a fail safe disk latching mechanism and top mounted handles. A keyway precisely aligns the unit onto the SR tray, allowing easy installation and removal. The Cache can rapidly be swapped with another 10 Disk Cache if an operational scenario uses very large amounts of data. An internal sensor monitors disk position and verifies that all 10 disks are properly inserted and latched. A second sensor monitors the position of the Cache on the pull–out tray, verifying proper installation and fastening of the unit. One electrical connector brings out the signals for the sensors and the latch release solenoid drive. Figure 3.3.4.2–1 shows the cache with 10 disks loaded.

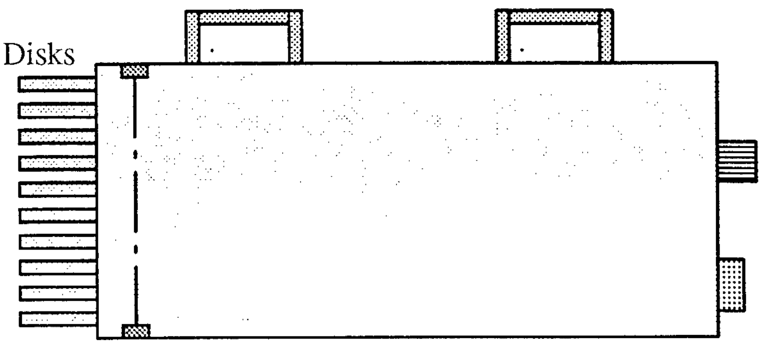

Figure 3.3.4.2–1 Disk Cache, side view

3.3.4.3 DAM Controller Nest and Power Supply

An off the shelf 6U VME card cage mounted above the cache holds the DAM Controller and DAM Interface electronics modules. The nest backplane is standard VME. The modules remove through the outside Endcap and may be installed on extender boards for service.

Although only two modules were used in the Jukebox design, a 6 card nest was installed for future expansion of capabilities.

The power supply for these modules is mounted to the top of the SR frame. The power supply is heat sunk to the frame. The supply was purchased as a semi–custom ruggedized unit with all required DAM Controller Nest power outputs in one package, and with logic control on/off capability.

3.3.4.4 Cooling

Heat is removed from the Jukebox by a combination of convection, conduction and radiation. The Drive EU is the major source of heat. The drive EU is cooled by convection using external ambient air forced through cooling ducts. The remainder of the heat is removed by convection within the case, conduction through the aluminium case skin, and by convection and radiation from the cases external surfaces.

The Drive EU contains the majority of the electronic modules and component in the Jukebox system. An inlet duct in the rear wall of the RU brings in outside air. Fans in the EU draw the air through the electronics modules. An exhaust duct carries this air out through a vent in the SR end cap. The vents contain filters for EMI and air particulate protection. This airflow path is sealed off from the rest of the Jukebox, to prevent particle infiltration of the mechanism and drive.

Fans in the RU and SR circulate the isolated internal air in a controlled manner through the heat generating components and along the inside walls of the cases. Heat is radiated away by the dark cases. Internal temperature rise is approximately 10 degrees C above ambient. The internal air is gasket sealed from the outside air, protecting the disks, drive, and mechanism from contamination. Operation in environments with large amounts of airborne dust and dirt will not harm the Jukebox.

3.3.5 Deployment

The Jukebox is designed to require less than 30 minutes for 2 men to setup or teardown without tools for shipment . The EU, DDU, and Cache mount using precise keyway alignments onto their trays. The internal frames latch together with tapered alignment pins automatically centering the components as the frames are mated. Hand operated latches are used on the external case joint, endcaps, internal frames, and component trays. Casters on the bottom of the cases allow the units to be rolled around individually during setup, and after being mated.

3.3.5.1 System Setup and Teardown

To assemble the Jukebox after shipment RU and SR cases are stood upright and mated, and the EU, DDU and Cache are installed. Figure 3.3.5.1–1 shows the deployment assembly procedure.

3.3.5.2 Ruggedness

The design incorporates heavy duty frames and cases with internal isolators for the 15 inch drop and vibration requirements in the shipping configuration. Wire rope isolators reduce transmitted force to 40G's on the internal frames. Three to four inches of sway space (dependent on the axis) is allotted for the frames to move on their isolators internal to the cases. All components are designed to survive the transmitted shock.

Gasket sealing on all openings in the shipping configuration prevents condensation from affecting the units during transit and storage. All components are designed to meet or exceed the op and non–op temperature range.

3.4 ELECTRICAL DESIGN

The Jukebox electrical design consists of the DAM Controller nest, modules, and power supply; Jukebox motors, brakes, and sensors; cabling; Front and Service Panels; and Drive EU and DDU modifications.

3.4.1 DAM Controller Nest

This 6U commercial standard VME Eurocard nest houses the DAM Controller and DAM Interface electronic modules. The backplane is standard VME on connector 1, no connections on connector 2. The modules communicate over VME. Connector 2 is used for custom Jukebox I/O signals. Four spare slots are available for future functionality upgrades.

3.4.1.1 DAM Controller Module

A Radstone 68–23 ruggedized single board computer was selected to control the Jukebox. This 6U VME Eurocard module is based on a 20 MHz 68020 microprocessor, with VME and RS232 capabilities.

3.4.1.2 DAM Interface Module

A second 6U VME module was designed to drive the motors, brakes, and sensors of the Jukebox. This mixed signal analog/digital 10 layer printed circuit board receives all control signals from the

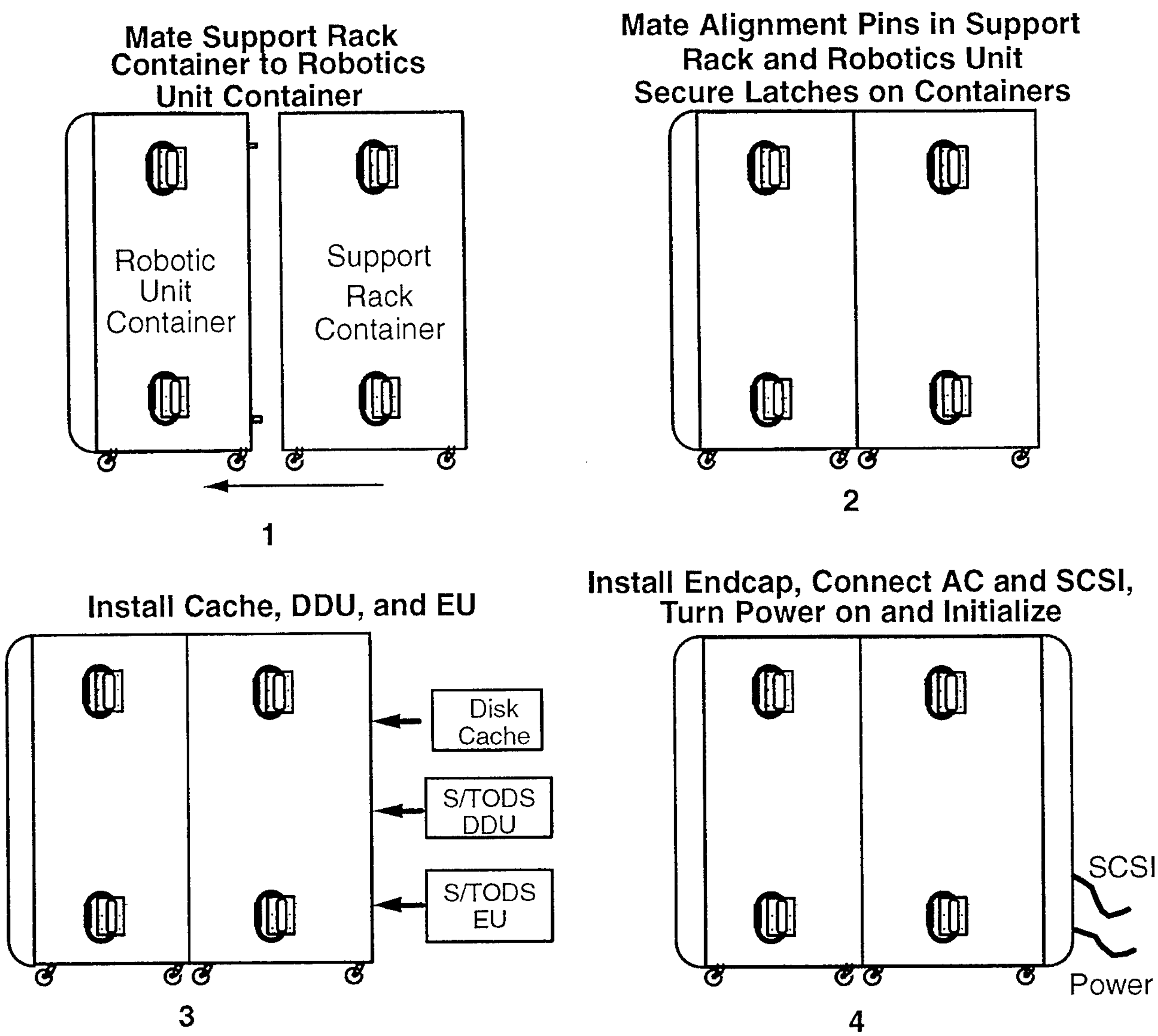

Fig. 3.3.5.1–1 S/TODS Jukebox Assembly Procedure

DAM Controller. The digital circuitry is implemented in two Xilinx 3090 field programmable gate arrays (FPGAs). Figure 3.4.1.2–1 shows the DAM Interface basic block diagram.

3.4.1.3 DAM Controller Power Supply

An Arnold Magnetics semi–custom power supply was purchased to provide all DC power used for the DAM Controller nest, and the electro–mechanical components driven by the DAM Interface module. A logic power up/down control enables the DAM Interface to take over control once the Jukebox is powered up, allowing software control of the power down sequence. The following voltages are provided +/– 5V, +/–12V, and +28V.

3.4.2 Sensors

All Jukebox sensors are driven by the DAM Interface module. Infrared optical and mechanical sensors are used where appropriate. Circuitry on the DAM Interface filters noise and determines make/

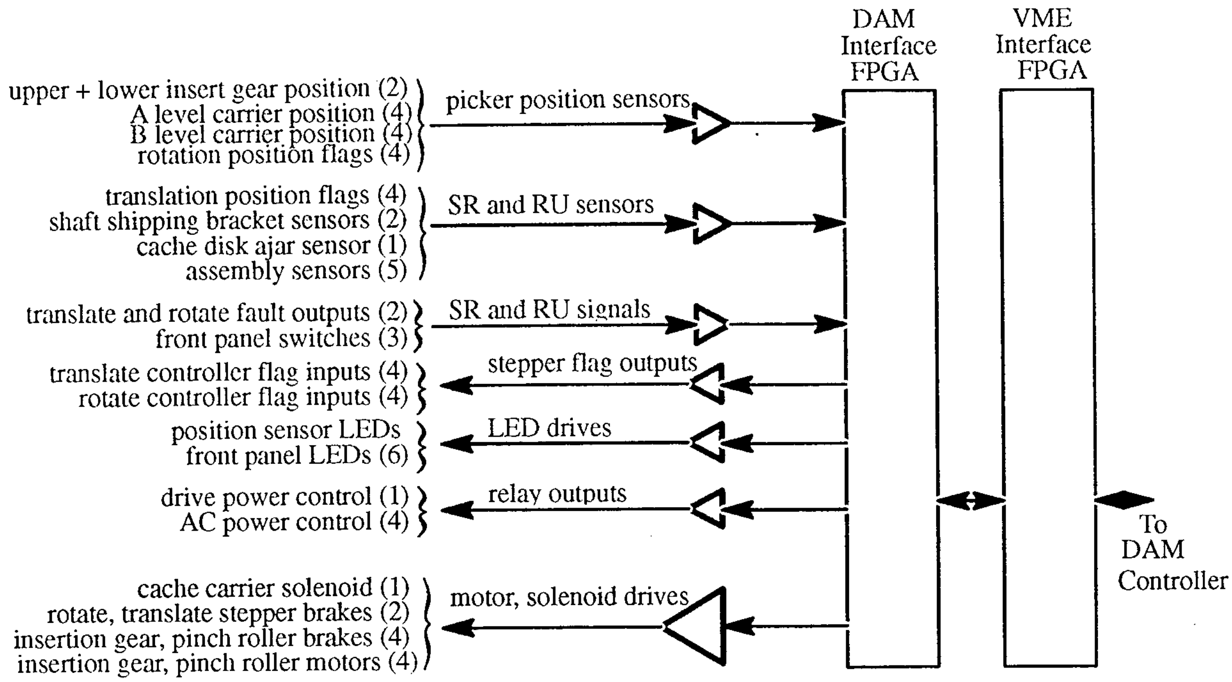

Figure 3.4.1.2–1 DAM Interface Block Diagram

break levels on each sensor signal, and reports the value when requested or generates an interrupt to the DAM Controller software via VME.

3.4.2.1 Jukebox Sensors

Jukebox sensors monitor the position of the Translation Mechanism, and verify proper and complete assembly. The Picker Assembly has a end mounted flag, which breaks the beam of four optical sensors marking four physical reference locations. Each component assembled in deployment setup of the Jukebox has a sensor verifying installation and proper alignment. The sensors are either optical or mechanical as appropriate. Figure 3.4.2.1–1 shows the location of the Jukebox Sensors.

3.4.2.2 Picker Assembly Sensors

The Picker Assembly carries optical sensors detecting disk position and rotation position. On each inner picker level (A level and B level) four sensors continually monitor disk position for speed control during insertion and extraction. Before disk translation or rotation is initiated proper disk centering within the inner picker is confirmed. Four additional optical sensors mark 4 reference positions of the inner picker rotation mechanism. Figure 3.4.2.2–1 shows the Picker Sensors.

3.4.3 Service Panel Electrical Design

The Service Panel contains the AC power input wiring and control circuitry. The toggle style input circuit breaker is normally left on when the Jukebox is deployed. System power is controlled by an illuminated pushbutton on the Front Panel. A second, pop out style circuit breaker is used to protect the drive. The Service Panel contains 4 AC solid state relays controlling power to the RU, the cooling fans, and the Drive. These relays are controlled by the DAM Controller through drive circuitry on the DAM Interface. EMI filtering is provided on the AC input lines. Figure 3.4.3–1 shows the Service Panel.

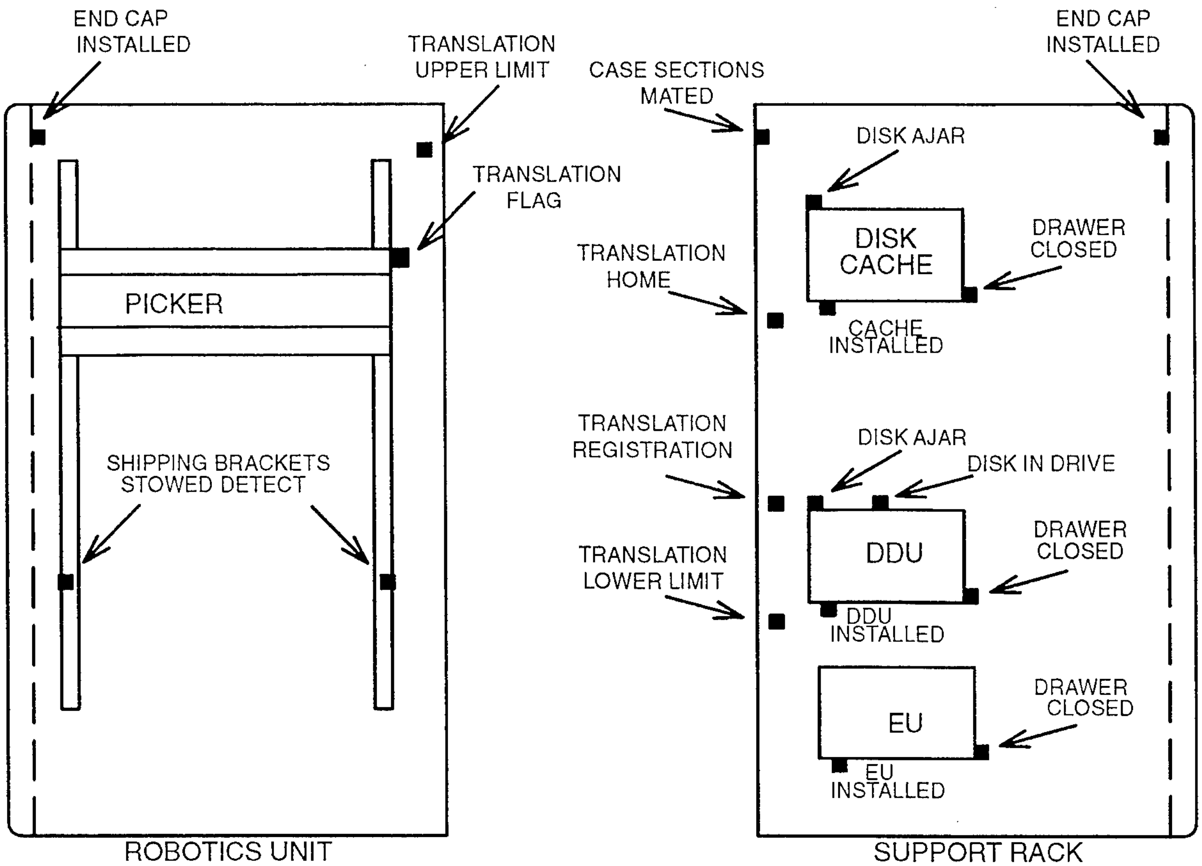

Fig. 3.4.2.1–1 Jukebox Sensors

The Service Panel also contains two SCSI–2 connectors ("mini–50" type) for daisy chaining onto a SCSI–2 bus. Input and output are interchangeable. An external active terminator is used when at the end of the bus.

3.4.4 Front Panel Electrical Design

The Front Panel contains push buttons and status indicators for Power, Self Test, and Auto/Manual, and it includes two RS–232 diagnostic ports for the DAM Controller and the Drive System Controller. The buttons and status indicators are driven by the DAM Interface module. Figure 3.4.4–1 shows the Front Panel.

At power up the power push button turns on the DAM Controller Nest only; all other power is software controlled via the solid state relays in the Service Panel. The switch is illuminated when power is on. After normal power up a second push of the power push button generates an interrupt requesting a power down. If there is no operation in progress and no mechanism faults then a software controlled power down sequence is initiated. The red and green *READY* LEDs indicators show Jukebox system status.

The Self Test push button generates a Self Test request to the DAM Controller, if no operation is in progress a Jukebox self test is initiated. The read and green *SELF TEST* indicators display the results of the go–no go test.

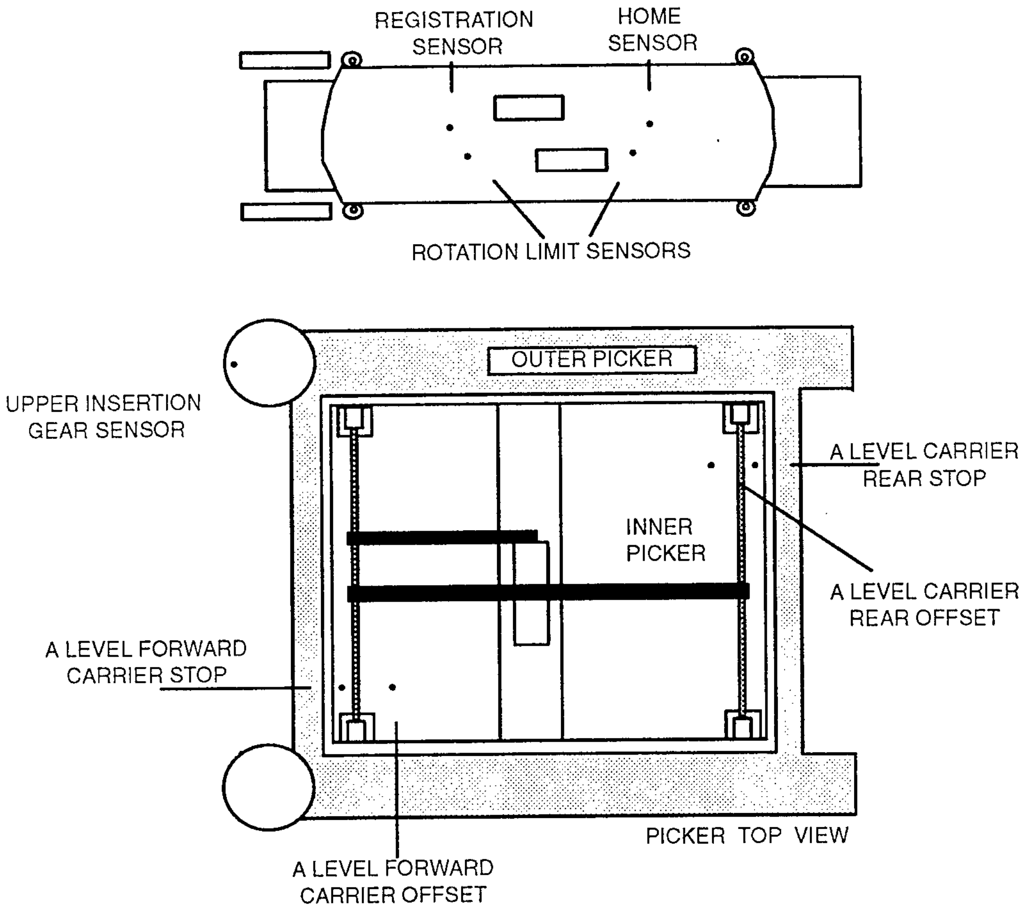

Fig. 3.4.2.2–1 Picker Sensors

The *AUTO MANUAL* pushbutton and indicators are not used. Wiring to the DAM Interface is provided for future use.

3.4.5 Cabling

The cabling harness for the RU and the SR was designed to drop in with some manual wiring connections required. An outside cable shop built the harnesses. Installation and limited final wiring was done inhouse. Two military twist lock connectors carry power and signals across the joint between the RU and SR cases. Ribbon cable is used for connection to the DAM Controller Nest, and for the Z fold cable carrying Picker Assembly signals up and down with the Picker translation.

3.5 SOFTWARE DESIGN

There are five software packages written for the Jukebox microprocessors. These Computer Software Configuration Items (CSCIs) are:

1 DAM Controller CSCI
  function: controls and coordinates Jukebox mechanisms
  target: 68020 based Radstone single board computer in the DAM Controller nest

2 Drive System Controller CSCI
  function: controls optical disk drive
  target: 68020 based Radstone single board computer in the EU

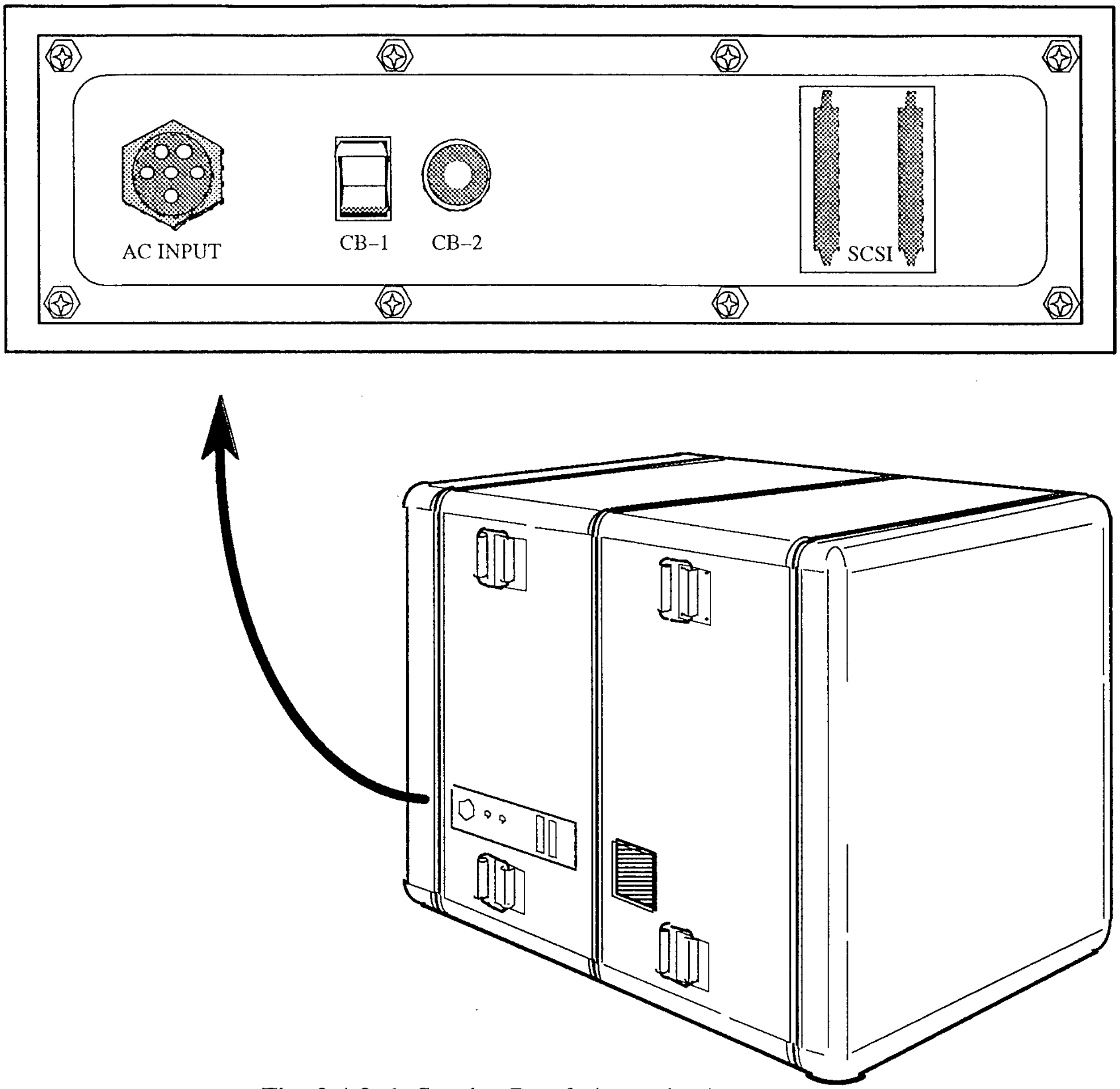

Fig. 3.4.3–1 Service Panel (rear view)

3 SCSI Adapter CSCI
function: handles SCSI 2 interface and data cache
target: 68040 based Synergy single board computer in the EU

4 Translation Indexer CSCI
function: controls translation mechanism stepper motor sequences
target: 68040 based Compumotor stepper indexer

5 Rotation Indexer CSCI
function: controls rotation mechanism stepper motor sequences
target: 68040 based Compumotor stepper indexer

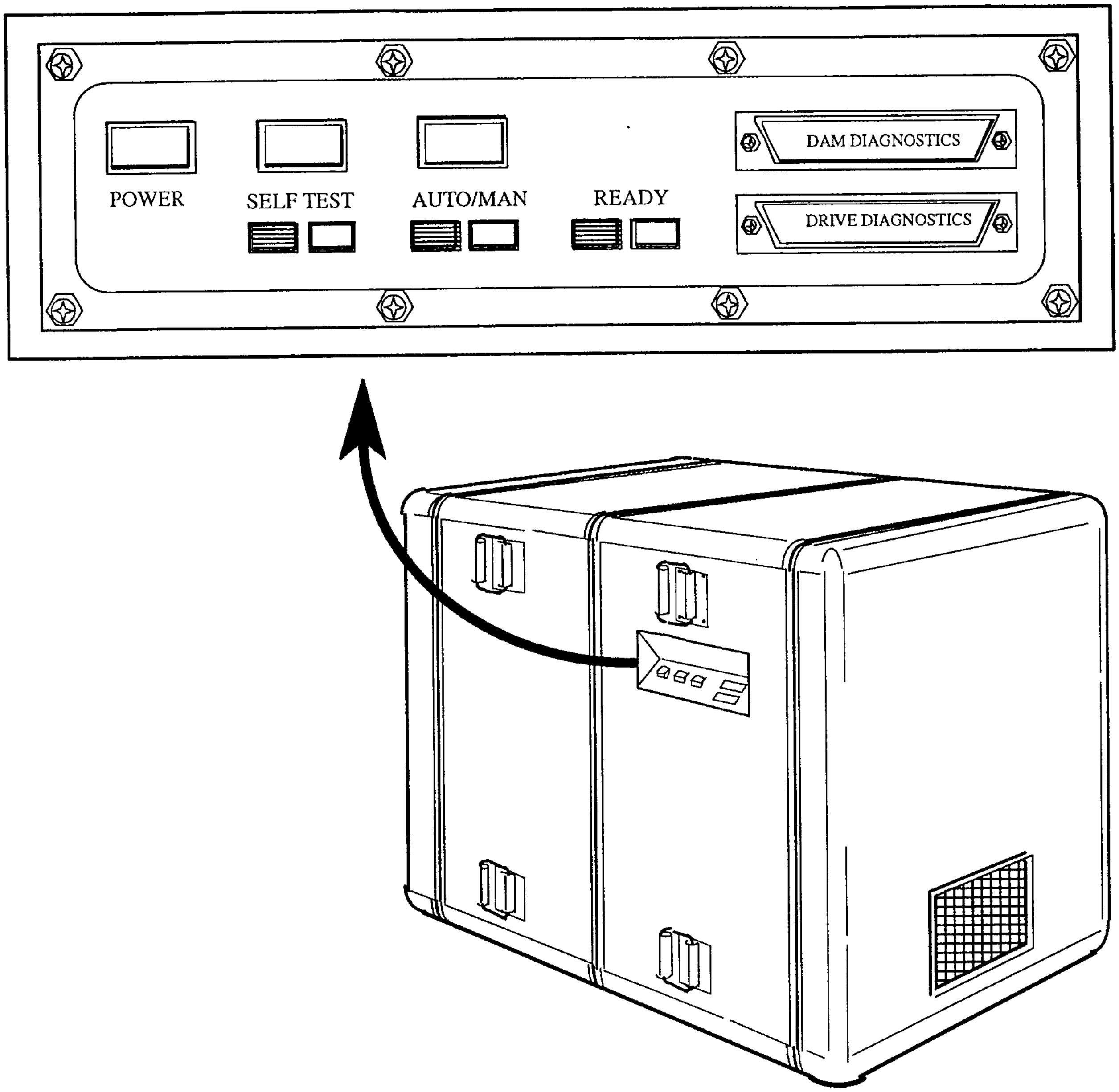

Fig. 3.4.4–1 Front Panel (front view)

3.5.1 DAM Controller Software

The DAM Controller software controls and coordinates all Jukebox disk movement operations, handles mechanism safety checks, and initialization/power down sequencing. The code runs on a 68020 CPU on the DAM Controller single board computer. The majority of the code is written in C, with some initialization and module hardware routines written in assembly language when necessary. There are approximately 7100 lines of code in this package.

3.5.1.1 Architecture

The code is state driven, with an executive passing control in turn to each of 13 Computer Software Components (CSC's). Each CSC maintains a current state, performs an incremental function when called, and returns control to the executive. Communication between CSC's is accomplished via messages, where each CSC has a message queue. Interrupts are used for critical mechanism control, timer functions, and RS232 port character I/O. The CSC's are: Executive; Initialization; Disk Drive Interface; Monitor; Terminal; Motor Control; Jukebox Operations; Front Panel; Self Test; Run Time Library; Timer; Interrupt; and HSI Tool.

3.5.1.2 Executive and Initialization

The Executive CSC performs power–up initialization of the other CSCs, the CPU module, and the DAM Interface module, and controls the execution of the other CSCs by evoking each in turn in a round robin manner. Initialization performs the safety checks and power up sequencing of the Jukebox, and coordinates the mechanism position setup sequences required prior to user operations.

3.5.1.3 Self Test

The Self Test CSC executes a sequence of Jukebox operations which fully exercise the mechanism and drive when the front panel Self Test button is depressed. Status of the test results are reported via green GO and red NO GO lamps on the Front Panel.

3.5.1.4 Robotics Control

All mechanism movement is coordinated by the DAM Controller software. The Jukebox Operations CSC performs the high level sequencing control, with Motor Operations handling low level motor and brake functions. Commands are sent to and status received from the RX and TX Indexers, the Disk Drive, and the DAM Interface module.

3.5.1.5 Communication

The CSC's request action of and report status to each other via messages. The messages are entered and retrieved on a message queue associated with each CSC. Each time a CSC is run by the Executive one message is processed and acted on.

External communication to the RX and TX Indexers, diagnostics terminal, Drive, and DAM Interface module is done by writing to and reading from memory mapped locations. The VME bus is used for the DAM Interface communication. An RS–232 DUART and RS–232 multifunction peripheral are used for the others.

3.5.2 SCSI 2 Adapter Software

The SCSI–2 Computer Software Configuration Item (CSCI) implements the SCSI interface. All mandatory SCSI commands for direct–access devices and medium changer devices are supported. A number of optional commands are provided for compatibility with standard UNIX device drivers and third party software packages. The SCSI–2 CSCI also provides up to 12 Megabytes of data cache for improved I/O throughput.

The SCSI–2 Software was developed in ANSI C with a minimal amount of assembly language. The low–level SCSI bus interface was coded in the NCR SCRIPTS language.

3.5.2.1 Software Architecture

The SCSI–2 software is organized into eight Computer Software Components (CSCs), each of which performs a separate function. A context diagram of the SCSI–2 CSCI is shown in Figure 3.5.2.1–1.

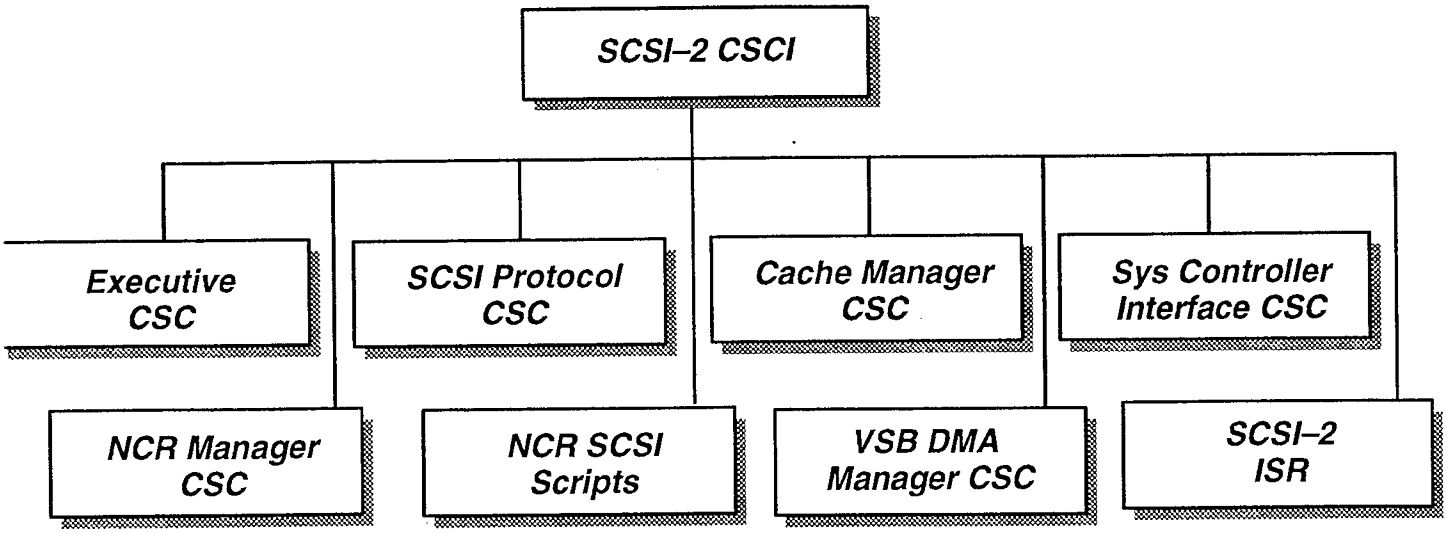

Figure 3.5.2.1–1 SCSI 2 Context Diagram

3.5.2.2 Executive CSC

The Executive CSC is activated on power up to set up the VME & VSB interfaces, the NCR 53C710 SCSI controller and initialize all global variables. The Executive CSC invokes the other CSCs in a round robin fashion.

3.5.2.3 SCSI Protocol CSC

The SCSI Protocol CSC is responsible for parsing commands and building message structures which are defined in the SCSI–2 specification. The SCSI Protocol CSC forwards all data requests (i.e. SCSI READ / SCSI WRITE) to the Cache Manager CSC. The SCSI Protocol CSC also sends certain SCSI commands to the System Controller Interface CSC so that they can be forwarded to the System Controller CSCI.

The SCSI Protocol CSC separates the S/TODS optical disk drive and the Optical Jukebox system into two different logical units. The optical disk is configured to respond to accesses to logical unit number (LUN) 0 and the medium changer will respond to LUN 1. Table 3.5.2.3–1 lists all the commands which are supported by the SCSI–2 CSCI.

SCSI Command	*S/TODS Drive (LUN 0)*	*Jukebox (LUN 1)*
FORMAT UNIT	✔	
INQUIRY	✔	✔
MODE SENSE(6)	✔	✔
MOVE MEDIUM		✔
PREVENT ALLOW MEDIUM REMOVAL	✔	✔
READ(6)	✔	
READ(10)	✔	
READ(12)	✔	

READ CAPACITY	✔	
READ ELEMENT STATUS		✔
RELEASE	✔	✔
REQUEST SENSE	✔	✔
RESERVE	✔	✔
SEND DIAGNOSTIC	✔	✔
TEST UNIT READY	✔	✔
WRITE(6)	✔	
WRITE(10)	✔	
WRITE(12)	✔	

Table 3.5.2.3–1 Supported SCSI Commands

Some of the SCSI commands (FORMAT UNIT, PREVENT ALLOW MEDIUM REMOVAL, RELEASE, RESERVE, and SEND DIAGNOSTIC) are only minimally supported so that the Jukebox meets the SCSI spec. An example is the FORMAT UNIT command. The Jukebox accepts the command and responds with a GOOD status, but does not actually perform any self–test functions. These features, however, may be enhanced or implemented at a later time if required.

3.5.2.4 Cache Manager CSC

The Cache Manager CSC handles all details associated with the SCSI RAM cache. The Cache Manager uses 15 Megabytes of the SCSI–2 CPU card's DRAM as a cache for SCSI READ/WRITE data.

The 15 Megabytes of DRAM is divided into 8 separate cache lines or cache slots Each slot is capable of holding 6 tracks worth of data in the outer most band of the S/TODS disk (band 5). In the inner bands, the tracks contain less data so some portion of the cache slot will remain unused. Dynamically adjusting the cache slot size – while more efficient – is much more difficult to manage and was not considered as a design option.

Data is allocated to a cache slot on both SCSI READ and SCSI WRITE operations. Cache replacement is based upon the least–recently–used algorithm. Modified data which is stored in the cache is only written back to the optical disk when a cache slot needs to be reused. All cache slots that have been modified are written back to the medium before the disk is ejected from the S/TODS drive.

When a SCSI READ/WRITE command is received the SCSI–2 software searches through the cache control structures to determine if the requested data is already cached in RAM. The cache search must be performed in fragments because the data request could span more then a single cache slot.

If a fragment of the requested data is found in the cache, the software notes the starting memory address and the transfer length. This information is then forwarded to the SCSI controller's DMA engine.

If a fragment is not found, the SCSI–2 software finds an appropriate slot (an empty slot or the least–recently–used slot) to cache the data and instructs the System Controller CSCI to move the desired fragment from the disk into the S/TODS Track Buffer. The SCSI–2 software moves the desired fragment into the cache and then reruns the search for the current fragment. The subsequent search will most certainly find the desired fragment within the cache.

The search for the next fragment of data continues until the entire data request has been found. This procedure is commonly referred to as "faulting" the data into the cache. It greatly simplifies the code because there are only two unique cases to handle: (1) data is in the cache (2) move data from the disk into the cache.

3.5.2.5 System Controller Interface

The System Controller Interface CSC handles the transmission of messages between the SCSI–2 CSCI and the Drive System Controller CSCI. The System Controller CSCI and the SCSI–2 CSCI communicate through a shared memory buffer which resides on the SCSI–2 CPU card. The System Controller accesses the shared memory by reading and writing over the VME bus.

3.5.2.6 NCR Manager CSC

The NCR Manager CSC handles all implementation details specific to the NCR 53C710 SCSI I/O processor. Capabilities included: read/write SCSI processor's registers, support NCR SCSI SCRIPTs Table Indirect Mode, setup NCR SCSI processor's built–in DMA bus master to READ/WRITE data directly from/to Synergy Memory, support "scatter/gather" data transfers.

3.5.2.7 VSB Manager CSC

The VSB DMA Manager CSC is responsible for VSB DMA operations between the cache RAM and the S/TODS Track Buffer. The VSB Manager sets up, starts and restarts DMA WRITEs from a cache slot to the Track Buffer. The VSB Manager sets up, starts and restarts DMA READs from the Track Buffer into a cache slot.

3.5.3 Disk Drive System Controller Software Modifications

The software in the System Controller was modified for Jukebox operation, mainly in the communication and disk load areas. The majority of the existing code written for the airborne configuration was unchanged. A number of drive performance enhancements were also made. The new and modified code was written in C, with a few low level routines in assembly. The software package consists of roughly 20,000 lines of code.

3.5.3.1 Communication

Communication software was added to send and receive messages between the System Controller and the DAM Controller. Previously the System Controller used two RS232 ports to support the Maintenance Terminal and HSI Tool diagnostic terminal interfaces; these were combined on one port. The second port was dedicated to communication with the DAM Controller. Command, status, and error messages are sent in both directions over this interface. Fault messages generated in a Drive operation abort event are sent to the DAM Controller, for display on the Jukebox Maintenance terminal. A new CSC was added to handle DAM communication functions.

SCSI communication software was extensively modified both for the SCSI 2 conversion and to handle forwarding SCSI Adapter – DAM Controller messages. A number of new SCSI commands were added and the previously used commands were modified. The error reporting to SCSI was rewritten and expanded to support the variety of more sophisticated Host interface capabilities associated with various Host software packages.

3.5.3.2 Disk Loader Control

The disk loader control was extensively changed from the airborne version, manual cartridge load and unload to handle mechanized carrier insertion and extraction from the Jukebox picker. A monitor for the new disk ajar sensor was added. This function detects a valid DDU latch on a newly inserted disk. Ajar detection allows the drive to refuse to move the disk loader when a disk is ajar due to an incomplete insertion. The goal is to prevent damage to the disk and mechanism. During disk movement operations Drive Load and Unload operations are requested by the DAM Controller over the RS232 interface.

3.5.3.3 Enhancements

A number of enhancements were made through minor redesign of the drive. They are reflected in changes in the software, improved performance and reliability, and solutions to problems identified in the airborne phase and during Jukebox integration. Some of the changes are:

1. reducing the erase/write magnet fly height, allowing increased tolerance for magnet heating caused by long term operations
2. verification and re–lock of focus if lost during stage jumps
3. automatic data cache flush on disk unload
4. Improved write laser start current algorithm when jumping to new disk radius
5. Improved track search algorithm for faster average track seek time, and allowing use of a number of disks exhibiting marginal track search performance

3.5.4 Stepper Motor Software

The Rotation (RX) and Translation (TX) stepper motors are controlled by locally stored software in the purchased Compumotor RX and TX Stepper Indexers. These two software CSCIs define and control the sequence of motor operations required for a particular mechanism movement, and define motion parameters such as acceleration and velocity. The code is written in an interpreted high level Compumotor language, and stored in non–volatile RAM in each indexer. Execution of the programmed sequences are requested by the DAM Controller via the RS232 interface during mechanism operations. Positional information, status, sequence completion, and fault messages are returned to the DAM Controller over the same interface. Each CSCI contains approximately 200 lines of code.

3.5.4.1 Rotation Indexer Software

The sequence software routines used to control the RX stepper motor are Power Up; Rotate to Park; Rotate Unpark; Find Home; Rotate to Normal Position; Rotate to Inverted Position; and Fault.

3.5.4.2 Translation Indexer Software

The sequence software modules written to control the TX stepper motor are: Power Up; Find Home; Translate to Cache Position; Index Picker 1 to Picker 2; Translate to Drive; Translate to Park; and Fault.

3.6 S/TODS DISK DRIVE MODIFICATIONS

Some design modifications were required to convert the drive from the airborne configuration to the Jukebox configuration. The modifications were made in a manner that does not preclude the conversion of the drive back to the airborne configuration.

The Drive may still be run independent of the Jukebox, when installed in the SR or when setup on a lab bench. To obtain local control of AC input power, a 2 pin molex connector on the DDU is swapped from its Jukebox remote control position to a local control panel position. This activates the original airborne power switch on the DDU Front Panel. Disks are inserted by hand into the loader, and a *LOAD* pushbutton is then depressed to load the disk. Pushing the *LOAD* button with a disk loaded initiates an unload operation, and releases the latch solenoid for 1 minute for a hand disk extraction. The airborne configuration *EJECT* button was modified for these functions. The drive *SELF TEST* button retains its original function, as do the status LEDs.

3.6.1 Disk Drive Mechanical Modifications

The S/TODS EU and DDU mounting configuration was changed from the rack mount airborne setup to tray mount for the Jukebox SR. Additional mechanical modifications for loader operation with the Picker were required.

3.6.1.1 EU Mechanical Modifications

Minimal modifications were needed to mount the EU. Four alignment guides were attached to the EU bottom for the Jukebox tray. A sealing plate was added to the EU rear fans, for mating with the cooling air exhaust duct. A unit–installed switch was added to the underside.

3.6.1.2 DDU Mechanical Modifications

DDU modifications were more extensive, due to the Jukebox requirement of handing off disks between the Picker and the DDU disk loader. The DDU airborne chassis was removed, replaced with a partially covered transport pan. The front of the pan is open, allowing the Insertion Gears of the Jukebox Picker to translate to the disk position and withdraw it from the DDU. The DDU loader sheet metal and front support shafts were modified, and new delrin guides added. Sensors were added for detection of disk ajar and disk in drive conditions.

The DDU front control panel was moved and mounted on the rear wall of the transport pan, facing the SR Endcap. This new location allows for integration/service access to the controls and status indicators. The cooling fan was also relocated to the rear of the drive.

3.6.2 Disk Drive Electrical Modifications

Minor electrical modifications were required to convert the S/TODS Drive from airborne to Jukebox operation.

3.6.2.1 EU Electrical Modifications

The minor EU electrical modifications involved new I/O connections, and conversion from 400 to 60 Hz . A new connector was added to the rear for the unit–installed sensor and the RS232 communications wiring to the Jukebox. The AC input circuit breaker was changed from a 400 Hz to a 60 Hz device. The backplane was slightly modified to accommodate the new SCSI–2 Adapter module. 60 Hz fans replaced the 400 Hz units. The single SCSI–1 I/O connector was changed to two SCSI–2 connectors in order to permit daisy chaining.

3.6.2.2 SCSI 2 Adapter

The Radstone SCSI–1 Adapter and Radstone RAM cards were removed and replaced. A new SV–400 SCSI–2 Adapter module was selected and purchased from Synergy Microsystems. It is installed in the EU VME nest. The SV400 contains a Motorola 68040 processor, an NCR 53C710 SCSI controller, 16 Megabytes DRAM, a VME bus interface and a VSB bus interface.

3.6.2.3 DDU Electrical Modifications

DDU electrical modifications involved the relocation of the control panel, new signal cabling, and 60 Hz conversion. The cooling fan was changed from 400 Hz to 60 Hz. The vacuum pump 400

Hz converter used in airborne operation was removed, and the 60 Hz pump control rewired to the AC input. Cabling for the new sensors and unit–installed switch was added to a new connector on the transport pan.

SECTION 4

PERFORMANCE AND TEST

4.1 INTRODUCTION

This section covers the results of Jukebox performance evaluations made during system integration and test. Jukebox mechanism, Disk Drive, SCSI Interface, and Media performance results are included.

4.2 JUKEBOX MECHANISM PERFORMANCE

The major performance criteria of the mechanism is cycle time, the time required to load a new disk in the Drive. Other performance criteria evaluated are deployment time, positioning accuracy, and mechanism error handling.

4.2.1 Cycle Time

Cycle time is defined as the time to unload a disk in the Drive, retrieve a new disk from the Cache, and load the new disk in the Drive. The Drive unload operation and Picker disk retrieval occur simultaneously. Loading the disk includes the time for the Drive to spin up, lock focus and tracking, read the Defect List, and indicate *READY* for a read/write operation. The maximum cycle time occurs on an exchange, where Disk 10 Side 2 is to be retrieved. Slot 10 of the Cache is furthest away, requiring the most distance motion of the Picker, and Side 2 requires a rotation operation. The Cache slot ID of the disk in the Drive to be stored does not affect cycle time, as the dual picker puts this disk away while the Drive is loading the new disk.

Specified maximum cycle time was 15 seconds. Measured performance for a worst case exchange, retrieving Disk 10 Side 2, is 15.6 seconds. This could be improved to below 15 seconds with further performance tuning. Loading a new disk with no disk in the drive varies from 10.0 seconds for Disk 1 Side 1, to 14.0 seconds for Disk 10 Side 2.

4.2.2 Deployment

The deployment requirements were specified for two man setup in 30 minutes. The time requirements were easily met; the setup was found to take 15 to 20 minutes for two experienced people. The sensor monitoring of the proper and complete assembly is very helpful in detecting and reporting operator errors in deployment.

Total Jukebox weight specification in the deployed configuration was 600 lbs maximum. This parameter was met with the system at 585 lbs assembled.

The two man lift specification was exceed on the Robotics Unit (RU). Casters were added to both the RU and Support Rack (SR), effectively allowing two people to easily move the components around and assemble the Jukebox. The remainder of the units may be lifted by two men. For transporting the RU and SR longer distances across rough terrain, where they cannot be wheeled, four side handles are provided. Four people can quite easily carry the individual units when the units are rotated over to a prone position. Table 4.2.2–1 show the transport weight and deployed weight of the Jukebox components. Transport weight includes the additional endcaps for the RU and SR mating ends, and the shipping containers for the EU, DDU, and Cache. The I/O cables are shipped in the Cache container, the cable's weight in the Transport column is included with the Cache figure.

Table 4.2.2–1 Jukebox Transport and Deployment Weight

MODULE	TRANSPORT WEIGHT	DEPLOYED WEIGHT
Disk Drive Unit	150 lbs	58 lbs
Electronics Unit	170 lbs	88 lbs
Robotics Unit	253 lbs	230 lbs
Support Rack	189 lbs	166 lbs
Disk Cache (w/ 10 disks)	91 lbs	32 lbs
Cables	included in Cache	11 lbs
TOTAL	**853 lbs**	**585 lbs**

4.2.3 Mechanism Positioning Accuracy

For smooth disk insert and extract operations highly accurate positioning is required of the Picker Assembly, as referenced to the Drive and Cache. The absolute accuracy and repeatability of both the rotation and translation mechanisms was tested.

Both rotation and translation mechanisms do a Find Home operation at power–up, where they very slowly and accurately seek a optically sensed reference position. All further position movements are based on step counts from this position. In addition, a second Registration sensor mounted on the DDU provides a reference for each Translate to Drive operation. This allows the DDU to float on it's own isolators, and still maintain robotic positioning accuracy.

Machined alignment fixtures placed in the Cache and Picker were used to get very precise alignment of the Picker, Cache, and DDU in the pitch, roll, and yaw axis. To obtain smooth operation all three axis must be well aligned. Repeated tests of translation and rotation were performed, with the positions measured to be well within the 1/32 inch desired accuracy.

After the final alignment, the Jukebox has been used in integration and testing for nearly a year without manual realignment, including many disassembly/re–assembly and shipment to Florida by standard commercial overnight service. The Jukebox has also been left powered for 4 days without a power–up automatic positional realignment. The mechanisms did not develop any detectable position errors in this test.

4.2.4 Error Handling

Appropriate mechanism control system error handling is important to avoid damage both to the mechanism components and to the limited number of valuable S/TODS disks. System integration and performance testing, along with unusual event errors during normal operation, could easily cause damage. The DAM Controller software continuously monitors positions and movement of disks and the mechanism during all operations, and will stop all motion if an abnormal event occurs. Ajar sensors in the DDU and Cache are checked before every translation and rotation sub–function to ensure disks are properly latched and not protruding into the mechanism "free space".

An Abort operation is performed by the present DAM Controller software when a problem is detected. Aborting events, such as failure of a disk to latch completely on an insert, or a mechanism reaching an overtravel position detector, cause the current mechanism move operation to stop. All motors are shutdown and all brakes applied and a message describing the event displayed on the diagnostics terminal. The Jukebox will not allow the initiation of further preprogrammed mechanism move operations until the problem is cleared by the operator.

Various error conditions were induced during different stages of power up, load, and store operations, such as manually pushing a disk slightly out of position in the Picker or Cache, or calling for an insert with a disk already loaded in the Drive. Successful Aborts and no damage occurred in all situations induced.

4.3 OPTICAL DISK DRIVE PERFORMANCE

The S/TODS Optical Disk Drive, used in both the Airborne and Jukebox program phases, has been used for a number of years without major service being required. This unit went through environmental testing and flight testing in the Airborne configuration. Read/Write performance on the good disk sides has remained good. The Drive as installed in the Jukebox has been reliable.

Minor repairs and adjustments were made to the Drive, such as replacing a failed IC and re–soldering cable connections. The IC failure was likely caused by electrostatic discharge damage to a part type that is known by the module supplier to be ESD sensitive. The write magnet position was changed to reduce the magnet to disk fly height and gain more write field margin.

A number of performance improvements were made to the Drive during the Jukebox phase. The goal was to increase the system reliability and solve some intermittent problems not eliminated during the Airborne phase. The changes were mainly in the software control algorithms and are listed in Section 3.5.3.3 Software Enhancements.

4.4 MEDIA PERFORMANCE

The custom disks developed in the Airborne phase, and used in the Jukebox, have exhibited a number of problems. Many of the 21 disks built are not fully useable by the Drive in it's present configuration. A few disk sides give excellent performance over the full radius. Therefor most read/write work has concentrated on these disk sides. Because 10 disks with both sides "good" are not available the 120 GByte capacity of the Jukebox is not realized at present.

Some design and setup changes were made to the Drive to allow it to use of disks with various problems. The results were good in some areas and limited in others. It is likely that further work in this area would provide an increase in total capacity with the available disks. As more of the problems are addressed, diminishing returns in additional capacity would be expected. It was decided not to spend additional time on this effort, as the Drive operational configuration now used provides enough capacity for the foreseeable usage of the Jukebox.

Media development is reported in Appendix B, "Optical Disk Media for Tactical Disk System" by Dr. Robert Hellen of 3M's Rewritable Optical Laboratory.

4.4.1 Disk Defects

A number of disk defect types impede or prevent operation of the Drive. Much work at reducing defects was successfully done during the development of the disks by the vendor. However, a number of problem areas were not completely solved in the development/limited production environment. The high performance design of the Drive requires good media for error free operation. Defect mapping is extensively utilized to avoid undesirable areas and as expected the price is reduced capacity.

There are several distinct types of defects. Some defects cause write errors in small areas. Some defects cannot be actively tracked through. And some defects cause write errors over large areas. Various phenomena cause these defects. All defects are handled by the Drive using a similar strategy, mapping out the affected areas.

Three levels of defect mapping are presently used. This provides the means of avoiding many types of disk defects while still allowing at least partial use of the majority of the available disks. A bad track map is maintained, where wholesale blocks of tracks are skipped over. Secondly, a map of high error sectors is maintained, where single sectors of a particular track are not written to. Both maps are stored in a system area on each disk. Thirdly, during disk writes a real–time verification detects high error sub–blocks, and they are rewritten to a spare subblock area.

4.4.2 Write Sensitivity

The low write sensitivity issue is the largest performance problem reducing capacity of the final disks. This problem shows up as an increase in read signal edge jitter, reflecting a higher than normal read noise. A second effect is a somewhat higher than normal required write power. The Drive write power servo handles the increased laser current, but excessive errors on read prevent use of the areas more severely affected. Changes were made in the laser current control software to increase the erase power, and improve the write laser current start point algorithm. These changes allowed the drive to operate over a wider sensitivity range, and enabled certification of the innermost bands of some of the low sensitivity sides where the problem is not to severe. The write power servo is working harder than planned on these areas, but appears to provide satisfactory read edge jitter.

The effect is most likely an MO layer issue, and is generally worse on the outer radius of the affected disks. Using a larger minimum feature size would be required to give more signal to noise margin, allowing error free use of these areas. This would require a significant format change in the way the Drive writes data.

4.4.3 Track Search

The ability of the Drive to locate a desired random track varies significantly from disk to disk. On the "good" disks, tracks are generally located quickly, with only a few head jumps required. On others, a higher average number of jumps are performed, with an occasional "hangup" occurring for 1 – 2 seconds before the desired track is located. In the hang–up event the head jumps back and forth between the same few tracks without acquiring the desired track. In a few disks, hang–ups occur regularly, and occasionally the tracks are never located and the Drive gives up the search. Jukebox operation for integration and test has concentrated on the good disks.

Some of the bad search sides show higher than normal eccentricity, or an area where the eccentric path of the pilot track changes rapidly. A few exhibit normal eccentricity yet still cause search problems, the mechanism in these cases is unknown. Once locked, the system is capable of tracking the higher eccentricity disks. Apparently the search algorithm had a difficult time locating tracks.

To allow use of some of the marginal disks additional intelligence was added to the track search software during certification for 10 Jukebox disks. The change reduces the number of hang–ups, and also detects hang–ups and breaks the system out of the event (limit cycle oscillation) and retries the search. This allowed reliable use of a number, but not all, disks that had been previously set aside. Additional intelligence in the track search software would improve performance further.

4.4.4 Certification and Capacity

For the Jukebox the 21 available S/TODS disks were tested, and the best 10 selected and certified. The certification process involves writing and reading the entire surface. The read/write performance is verified resulting in the creation of a bad track map and a bad sector map. Both maps are written to the disk's reserved system area. Due to their various problems the disks exhibit varying capacity and some of the sides of the 10 best disks are unusable. The approach adopted was to use the certification process as is, and do only limited investigation of any media related problems.

The total raw capacity of the 10 best disks as presently certified is 62 GBytes. The capacity per disk ranges from 1 to 12 GBytes. Four of the 10 are useable on one side only. Some of the disk areas certified exhibit what is considered marginal performance. Operation with user data over a period of time would be needed to develop confidence in the ability of the Drive to operate error free over these areas. There are a few final disks of the 21 which have yet to be tested completely, and a number of preliminary disks which could also be tested and certified.

4.5 READ/WRITE DATA RATE

The data rate between the S/TODS Drive and a SCSI Host can be measured in a number of ways. Depending on how it is measured vastly different data rate figures may result.

4.5.1 Drive Design Data Rate

The Drive is designed for 3.125 MBytes/sec (25 Mbit) continuous data rate. On a read, the drive is capable of dumping an entire 6 GByte disk side at 3.125 MBy/s continuously, buffered through the track buffer and data cache. An erase pass is required before write in the MO recording process; if the disk is pre–erased the Drive is also capable of writing 6 GBytes at 3.125 MBy/s continuously. This is done in the Certification process, where pseudorandom data is written to an entire 6 GByte side in 32 minutes. When moving data over the SCSI bus, the track buffer is designed to handle data flow from the disk to the SCSI data cache without restricting the flow on or off disk.

4.5.2 SCSI–2 Data Cache Implementation

The S/TODS SCSI Adapter module handles Host system logical block addressing using a data cache. The drive does all disk read/erase/write operations on a per track basis. Individual sectors may not be erased and written. The SCSI Adapter reads disk data on a multiple track basis, holds the data in a cache, and updates sectors requiring change. Six track "cache slots" are presently used, as 6 tracks is the capacity of Track Buffer.

Data is transferred over the VSB bus in units of one cache slot between the Track Buffer and the data cache. Each slot contains 6 tracks of data, of approximately 1 MByte (varies with disk Band). Disk operations are always done in 6 track units. On a write, 6 tracks are transferred over VSB to the Track Buffer, then to the disk sequentially. Simultaneous write mode handshaking transfers from cache to Track Buffer to disk are not implemented by the present SCSI software. Disk reads are done with simultaneous handshaking; as soon as one full track is read from disk to the track buffer the VSB transfer to the data cache begins.

Due to unique properties of a given host system, data is typically transferred over SCSI in much smaller blocks between the Host and the data cache. For example, the block size is only 16KBytes for the Sun file system. Multiple blocks may or may not be sent in one SCSI transfer. The idle time and handshaking overhead in SCSI is very high when the host system specifies single block transfers. Net overhead decreases when larger contiguous block transfers are specified.

A write to S/TODS requires reading a cache slot (6 tracks) from the disk to the track buffer, a VSB transfer to the cache, then a SCSI transfer from the Host to the cache updating a logical block. Further writes to logical blocks in the same cache slot go directly to the cache without disk reads. The slot is left in the cache until an empty slot is required for further operations, or the disk is unloaded. To return the updated cache slot to disk the 6 tracks are erased, then the data is written to the Track Buffer, then dumped to disk.

4.5.3 Throughput Testing

Bandwidth and throughput are very different figures. The bandwidth of the "Fast Narrow" SCSI bus in this context refers to the 10 MByte/sec transfer rate during the data phase. It is a statement of the data clocking speed. The bandwidth of the VSB bus–Track Buffer–disk operations is 3.125 MBytes/sec (reading, or writing to an erased area). This gives the S/TODS drive a potential bandwidth of 10 MByte/sec, 3.125 MByte/sec sustained.

Throughput in this context refers to the speed with which the user's data is transferred, the speed he sees when working with the system in a particular application. The separate erase pass, logical block addressing, and sequential transfer nature of the Host – SCSI – Cache – Track Buffer – Disk operations of the present implementation inherently lower the data throughput rate. The Host application and architecture also significantly lower the throughput. The user may observe a throughput figure for large data transfers considerably less than the observed data bandwidth figure.

Observation of continuous SCSI data write operations showed the read, erase, and write disk access operations occupy only 25% of the time used. Track searches use another 12%, with the rest used by software setup, Sun disk drive and operating system, SCSI and VSB transfers, and disk rotational latency.

Throughput testing with various Host applications was done. Three important applications are tape archive "tar" transfers, file system copy "cp" transfers, and Metior HSM file system "cp" transfers. The integration of these applications with S/TODS is discussed in Section 5.

Below are some throughput benchmarks measured with a directory of ten 3 MByte map data files (30 Mbyte total), with the exception of the Metior figures which were measured with one 30 MByte file. For reference, measured throughput between two internal Sun hard drives is included (both rated at "10 MByte/sec").

Table 4.5.3–1 Throughput Measurements, Ten 3 MByte Files

Data Transfer Application	Write Throughput	Read Throughput
Sun File System cp Sun hard drive – S/TODS	220 KBytes/sec	540 KBytes/sec
Metior File System cp Sun hard drive – S/TODS	420 KBytes/sec	175 KBytes/sec
UNIX tar utility Sun hard drive – S/TODS	360 KBytes/sec	490 KBytes/sec
Sun file system cp Sun hard drive – hard drive	1800 KBytes/sec	1800 KBytes/sec

The measured throughput to and from S/TODS varies considerably with modification of the file system tuning parameters, both for the Sun File System and the Metior File System. Effort to maximize throughput by tuning was done and is discussed in Section 5. The "tar" performance is viewed as the maximum possible for the present SCSI–2 implementation. The SCSI bus bandwidth is 10 MBytes/sec, S/TODS disk operations bandwidth is 3.125 MBytes/sec in all cases. It is interesting to note the tar read throughput is 490/3125 = 16% of the disk bandwidth; about the same as the Sun disk drive measured throughput/bandwidth of 1.8/10 = 18%. Write throughput is inherently slower due to the additional operations required, though it is closer to the read performance than was expected. Metior HSM read performance is slower than was expected; perhaps additional tuning efforts would improve this figure.

4.6 SCSI INTERFACE PERFORMANCE

Problems with the SCSI bus communication between the Sun host and the S/TODS Drive when running at the SCSI Fast rate of 10 MByte/sec occurred during system test, and throughout the Host integration efforts discussed in Section 5. The observed failures range from a number of missed clocks causing the Sun to reduce the bus bandwidth to 1/2 or 1/4 of the SCSI Fast rate, to total inability to communicate. The bus problems were addressed by modify the termination strategy, careful selection of cables, and the use of differential signaling and a bus repeater in some connection configurations.

4.6.1 SCSI Bus Termination

One mechanism of SCSI bus failure is reflections of signals from the bus ends obliterating signals at the detection point. At Fast SCSI speeds, the round trip time of a signal and one reflection can be 50% of the bit window, easily causing problems. Many SCSI products, including the SCSI module purchased for S/TODS, use a passive resistor network for termination. The passive network does not match the impedance of the cabling well, causing reflections, and allows crosstalk between bits.

To reduce these effects the termination on the Synergy SCSI–2 module was removed and an external active termination was installed. The active termination uses a voltage regulator and single resistor termination to obtain low crosstalk and better impedance match. Using external termination also allows S/TODS to be placed in the center of a daisy chained bus rather than at one end only.

4.6.2 SCSI Cabling

It was found that the majority of SCSI cables on the market are not suitable for use at SCSI Fast rates. These cables are sometimes successfully employed (but not recommended) with very short length busses of a few feet or less. A number of different cables were purchased and tested, it was found that top quality cables were required to get to the 15 foot bus length desired. The good cables have the correct impedance and pairing, heavy shielding, and additional internal shielding on the critical clock signals.

With single ended communication, using top quality cables, cable length between the Jukebox and the Sun was limited to 10 feet before bus problems occurred. This length requires the Sun to be either on top of the Jukebox, or on a cart directly next to the unit. Total bus length including Sun, Jukebox, and Drive internal cables is about 17 feet, close to the specified 20 foot maximum for SCSI Fast Synchronous transfers.

4.6.3 Single–Ended vs. Differential Communication

SCSI busses may use either single ended or differential communication. Some high performance systems use differential for it's higher noise immunity and longer allowed lengths. The vast majority of SCSI products are single ended. This includes the systems S/TODS is likely to interface with. For this reason the Synergy SCSI–2 module was purchased in the single ended version.

The Sun used in Jukebox integration has both single ended and differential SCSI capability. A differential to single ended converter was purchased to allow use of S/TODS with the differential bus. The differential SCSI bus permits the Sun to be located up to 75 feet from the Jukebox. It also makes integration and test easier because it puts S/TODS on a separate bus from the internal Sun components. Much of the early integration work was done in this configuration, and few bus problems were experienced.

4.6.4 SCSI Repeater

To connect to single ended SCSI equipment with cables longer than 10 feet a SCSI repeater was purchased. This device bidirectionally repeats SCSI signals, allowing doubling of the cable length. In the lab, the Sun was located 20 feet from the Jukebox using the repeater without causing bus errors.

SECTION 5

HOST INTERFACE AND PERFORMANCE TESTING

5.1 INTRODUCTION

This section covers the integration between the Jukebox and various Host systems and software packages. Host integration was done over a SCSI–2 interface with a Sun Workstation and the Special Operations Forces Planning and Rehearsal (SOFPARS) system. Software packages integrated with were the SunOS and Solaris operating systems; Sun File Manager; Air Force Mission Support System (AFMSS); and Metior Hierarchical Storage Management (HSM) software.

5.2 CONNECTION TO SUN WORKSTATION

The Jukebox was connected to a Sun SPARC 10 workstation via the SCSI 2 bus, under both the SunOS and the Solaris operating systems. Disk Drive read and write operations with the Sun file system were performed. Jukebox disk movement operations were demonstrated under control of the Sun, via a custom software disk load tool.

5.2.1 SCSI 2 Connection

The Jukebox was connected to the Sun as a standard disk drive peripheral, over the SCSI 2 bus, Fast Narrow options (8 bits, 10 MBytes/sec). Both single ended and differential connections were used at various times, though most final integration effort used single ended. All mandatory commands for a direct access device and for a medium changer device are supported, along with some additional commands found necessary for integration with the Sun file system and Metior HSM. Initial SCSI 2 integration and performance testing are covered in Section 4 of this volume.

5.2.2 Sun File System Operation

The Jukebox was operated as a normal Sun file system standard disk drive. A Sun "Label" and "Format" operation is done on each disk, where directory information and file system tuning parameters are written to disk. With the disk loaded in the drive a Unix "mount" operation is done. S/TODS then appears as a standard directory to the operating system, all Unix file manipulation commands work normally. The user may copy files back and forth to an S/TODS disk, and run application programs using data on S/TODS, by simply changing to the mounted directory.

5.2.2.1 Tuning Parameters

The values of various tuning parameters set up in the Label and Format operation are critical to read and write performance. These parameters were modified and tests run, yielding excellent performance results when optimized for S/TODS.

Initial file system integration, using the Sun default tuning parameters, gave poor results due to the differences in the physical organization of data on the optical disk as compared to a magnetic hard drive. Magnetic hard drives are inherently sector addressable, and use very small physical block sizes as compared to a large format S/TODS disk. Standard file system parameters are optimized for multihead, small block, sector addressed systems. This configuration is ideal for many small files; S/TODS disk architecture and cache structure is optimized for transfer of large amounts of sequentially located data. The demonstrations conducted at the end of the Airborne Phase used mainly default parameters, resulting in very low throughput figures. Subsequent file system investigation and tuning efforts resulted in an order of magnitude improvement in read and write throughput, by forcing the Sun File System to allocate logical blocks in a manner which maximizes the S/TODS Cache and physical data block location utilization.

Tuning parameters which gave major performance improvements related mostly to the logical block allocation and disk information inodes. Using a large fragmentation figure, a large number of cylinders per group, and a 0 rotational delay selection caused the file system to allocate contiguous logical blocks when writing the large files of the typical S/TODS application. This allows the system to utilize the cache in an efficient manner, by generally updating a large number of file system blocks before writing a cache slot to disk. In this manner disk accesses are reduced, and each access tends to write or read a larger volume of data.

A second major improvement resulted from using a high number of bytes per inode. The inodes contain information about each file, stored on disk in predetermined locations spread around the disk. Inodes must be updated each time a file is accessed, typically requiring a stage move as the inodes are on separate tracks from the data. With a high bytes/inode selection the number of updates to disk is reduced, preventing the Drive from wasting too much time jumping around updating inodes.

5.2.2.2 Performance

The file system tuning parameters described above, along a number of others, resulted in good performance. Read and write throughput using the copy "cp" command approached the tape archive "tar" speed, which is seen as close to the physical maximum throughput the SCSI 2 – S/TODS interface will support. Further performance increases would require modification of the Drive's SCSI–2 interface implementation, increasing both the "tar" and "cp" measured throughput.

5.2.3 Load Tool

A software tool was written for the Sun to allow the operator to move disks between the Drive and Cache from the workstation. Both graphical (GUI) and command line versions were written and demonstrated. The GUI version presents a window with buttons to select disk number, side number, and fetch or store operations. The operator simply points and clicks on the desired disk to request a Jukebox disk movement operation. The command line version is used where the GUI tool cannot run, such as when logged in remotely under rlogin or telnet, or when running AFMSS.

5.3 AFMSS MISSION PLANNER INTEGRATION

The Jukebox was integrated with the Air Force Mission Planning System (AFMSS). This system normally utilizes multiple hard drives for storage of map data used in flight mission planning. A Sun hard drive was sent to Lockheed Sanders and loaded with the AFMSS software. A Sun Sparc 10 at the Camden facility was then booted from this drive, and interfaced via SCSI to the S/TODS Jukebox.

With S/TODS mounted as a standard UNIX file system the planning system was integrated. Maps were loaded onto a number of Jukebox disks with tuned Sun file systems installed. An AFMSS Table of Contents file was generated for each disk by the AFMSS software, and stored on each disk with the maps. This standalone mission planning system, consisting of a Sun workstation, external hard-drive with applications data, and S/TODS Jukebox with map data was then demonstrated in the lab.

The Sun host with the Jukebox was connected to the Lockheed Martin network. This allowed operation of the system from anywhere in the company. Much of the integration work was done from the office area on a different floor, moving disks around the Jukebox remotely. Lockheed Sanders engineers were directly involved in the integration effort from New Hampshire, remote logged in to the Sun–S/TODS system over the common corporate network.

To operate AFMSS with S/TODS, the Load Tool is used to request a Jukebox disk load and Sun file system mount of the disk with the desired map data. The Load Tool is run from a command line window within AFMSS. S/TODS is mounted to appear as a standard hard drive to AFMSS, and map data is accessed from the Jukebox transparently to the AFMSS software. Maps of different areas on different disks may be loaded and viewed at will.

The read performance of the Jukebox under AFMSS operation was found to be somewhat slower than hard drive map storage operation, as was expected. The speed was found to be reasonably fast, fast enough to be of no concern to the operator. The ability to have 6 GBytes of map data under the head, and 120 GBytes available within 15 seconds from one command line operation is a significant advantage.

5.4 METIOR HSM INTEGRATION

The Metior Hierarchical Storage Manager (HSM) software was installed on the Sun host and integrated with the Jukebox. Some modification to the Jukebox SCSI 2 interface software was required, to conform with Metior's expected message formats. The installation became a significant task due to problems setting up the Sun and the Solaris operating system to work with Metior.

Metior sits between the Sun file system and the Jukebox, managing the disks and the robotics mechanism transparently to the user. The user accesses data on Jukebox disks by simply changing directories or running applications with data residing on the Jukebox. Metior automatically requests the Jukebox to load and store disks and access data. The HSM provides the full Jukebox capacity of 120 GBytes transparently, in a single directory if desired, and potentially can read and write data faster than a standard Sun file system is capable of.

A demonstration of Sun/Jukebox operation with the Metior file system was conducted. Files were written and read from S/TODS to the Sun, using the standard unix copy "cp" command. Metior was shown to automatically request a load of the required disk, and return the disk to the cache after completion of the operation, making the Jukebox disk operations transparent to the user.

Measured write throughput with the Metior file system was 130 KByte/sec, and read was 200 KByte/sec. Testing was done on a directory of sixty 230 KByte files (14 MBytes). This speed represents an improvement of about 7X over the speed of the system during the Air Force demonstrations at the end of the Airborne Phase, where slow write performance under the Sun File System was an impetus to investigation of Hierarchical Storage Managers. For reference, unix "tar" writes and reads were measured at 400 KBytes/sec for the same directory. With further performance tuning, operation under Metior should approach the tar transfer speed figure.

5.4.1 AFMSS Operation under Metior HSM

Map data was loaded onto S/TODS disks through the Metior file system, and AFMSS operation demonstrated. A link to the normal hard drive map directory was replaced with one to a directory managed by Metior, containing the map data on the Jukebox. Running the AFMSS package and displaying map data caused automatic load and read of Jukebox disks, transparently to AFMSS. Read performance, moving around on an AFMSS map under Metior, was found to be significantly slower than from the tuned standard Sun file system. Further tuning would be needed to use Metior with satisfactory performance.

5.5 SOFPARS INTEGRATION

The Jukebox was integrated with the Air Force SOFPARS Desktop mission planning system at Hurlburt Field, Florida, running the AFMSS mission planner. Disks were loaded and unloaded using a Load Tool installed on the Sun workstation, map data was written and read from disk, and the planning system operation with S/TODS was demonstrated. Overall performance was found to be satisfactory. Rapid setup and disassembly of the deployable Jukebox system was also demonstrated.

Connection to the SOFPARS system required simply installing the Load Tool on their Sun, adding UNIX link files pointing to the Jukebox, and attaching the Jukebox to their SCSI bus. The integration was done with the Jukebox mounted as a normal Sun file system, and required no modifications to the AFMSS application software. The Metior hierarchical file manager was not installed on the SOFPARS system, due to the installation/removal complexity and performance issues.

SCSI bus errors were found to occur with the intended cable setup, requiring use of very short cables to gain reliable operation. This required placement of the Jukebox very close to the planning system, acceptable for the demonstration but inconvenient or impossible in other interface scenarios. The working (single ended) setup used a six foot cable from the S/TODS EU to the SCSI repeater, and a two foot cable from the repeater to the planner.

On return to the Camden facility the cabling used with SOFPARS was setup with the standalone Sun AFMSS system. The observed problem was not repeated. Cable lengths were increased to the point where the SOFPARS system would not even boot, and still no bus errors occurred. It is unknown if the bus problems at Hurlburt were related to the SOFPARS desktop system SCSI bus itself or to the additional equipment present on the bus. Shorter cables made an obvious improvement, pointing to impedance/reflection, load, and crosstalk problems.

In future demonstrations or permanent installation of the Jukebox conversion to differential SCSI signaling would eliminate cabling concerns. A standalone converter would then be used for connection to single–ended Hosts, located very close to the Host equipment.

APPENDIX A

LIST OF ACRONYMS

1	C	The C Programming Language
2	CPU	Central Processor Unit
3	CSC	Computer Software Component
4	CSCI	Computer Software Configuration Item
5	DAM	Disk Accessing Mechanism
6	DDU	Disk Drive Unit
7	EU	(Disk Drive) Electronics Unit
8	HSI	Hardware Software Integration
9	RU	Robotics Unit
10	RS–232	EIA Standard for Computer Data Interface, circa 1965
11	SCSI–2	Small Computer Systems Interface
12	STODS	Strategic Tactical Optical Disk System

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