DOC. TYPE 2
DATA CAT. SE

JSC-10084
2 JULY 1976

NASA CR-
147877

Online Mass Storage System Detailed Requirements Document

(NASA-CR-147877) ONLINE MASS STORAGE SYSTEM DETAILED REQUIREMENTS DOCUMENT (Aeronutronic Ford Corp.) 76 p HC $5.00 CSCL 09B

N76-31919

Unclas
G3/60 03432

Contract NAS 9-15014

DRL LI No. 2.2

prepared for

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center

Houston, Texas

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Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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FOREWORD

This document is prepared by Aeronutronic Ford Corporation, Space Information Systems Operation, in response to the requirements of Engineering Order (EO)-001P, Schedule V, Contract NAS 9-1261, and as specified in DRL Line Item 2.2 of the Statement of Work.

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1. Scope

This document sets forth the requirements for an on-line high density magnetic tape data storage system that can be implemented in a multipurpose, multihost environment, and satisfy the guidelines specified by Engineering Order (EO) 001P in support of RTOP #656-11-05-51.

Also included in an appendix of this document is the results of a market survey and analysis of candidate vendor who presently market high density tape data storage systems.

2. Applicable Documents

2.1 Research and Technology Objectives and Plans. Number 656-11-05-51, On-Line Mass Storage System. Johnson Space Center, Houston, Texas.

2.2 On-Line Mass Data Storage Requirements Document, SISO - TN790, Aeronutronic-Ford, SISO, Houston, Texas.

2.3 On-Line Mass Storage System Functional Design Document, JSC 10029, December 1975.

2.4 On-Line Mass Data Storage Engineering Order (EO) Number 001P, Amendment Number 2, EI Number 4, Dated 3 March 1976.

3. Requirements

This section shall describe the requirements for the mass storage system (MSS) to be coupled to a small computer and ultimately to multiple large scale computers.

3.1 Objectives

The objective of the MSS is to provide a facility for the compact storage of large quantities of data and to make this data accessible to computer systems with minimum operator handling.

3.2 General Requirements

The following requirements pertain to the initial system and the fully expanded system, except where range is indicated.

3.2.1 Capacity

The MSS shall have the capability of being modularly expanded to 16 to 400 billion bits of data. Included in the capacity count is only that data which is generated by the host computer. Any additional data generated for the purpose of file heading, code recovery, or due to recording technology are not included in this count. Storage capacity of each removable storage module should exceed that of a 3330 type disk module.

3.2.2 Error Rates

The unrecoverable error rates should not exceed 1 in 10^{11}.

3.2.3 Technology

The technology used in the MSS shall consist entirely of off the shelf devices with field confirmed sets of reliability values.

3.2.4 Recording Media

The recording media shall be reusable and shall be available off the shelf.

3.2.5 Latency

The above mentioned storage capacity should be available without manual intervention. The storage modules shall be easily mountable and removeable from the storage devices.

3.2.6 Availability

The fully expanded system should be capable of running on a 24 hour-a-day schedule with maintenance capable of being performed with the system operating in degraded mode.

3.2.7 MSS Interface

The MSS shall be capable of interfacing to a small dedicated computer initially and be ultimately expanded to servicing multiple large scale host computers.

3.2.8 Persistence

The recording medium shall be capable of being stored at least as long as a CCT without significant compromise of the recorded data.

3.2.9 Self Test

The system shall be capable of performing diagnostics upon itself and reporting malfunctions to the MSS operator.

3.2.10 Transfer Rate

The expanded system shall be capable of handling a sustained data rate of 10^7 bits per second with a single host.

3.2.11 Transfer-ability

The storage modules written on one drive shall be readable among like drives.

3.3 System Organization

3.3.1 Hardware

The hardware components are partitioned into three sections:

1. The host computer which issues requests for and produces data to be recorded in the MSS.
2. The storage media which shall retain the information and the controllers necessary to activate the recorders of the information.
3. The interface which will provide for the mapping of files from the MSS media format into pseudo-CCT format for forwarding to the host processor.

3.3.2 Host Services

The Mass Storage System (MSS) shall be required to provide to the host computer those services the host will need to create, maintain, and retrieve a host's files on the MSS. These services shall be broken down into the following MSS functions:

- File Initialization
- File Termination
- File Read/write
- File Positioning
- File Statusing
- Operator Message Service

3.3.2.1 File Initialization

The MSS will be required to process a function to initialize the MSS for processing of other file functions. For this discussion, the initializing function shall be called "the file open function", or simply, "open". The open command shall be the first command the host will issue for any series file service it wishes to perform.

The MSS shall be required to respond to the open in accordance with the mode supplied by the requesting host. The required mode, action and responses for the MSS are as follows:

- Read Mode - The MSS shall search its tables to locate the file to be opened. If it can find the needed information about the file, the MSS will position its recording media to a position ready to read the file and then set the appropriate status for the host. If the information cannot be found, the MSS will set the appropriate error status and terminate the file action.
- Write mode - The MSS shall search its tables to check for a file with the same identification. If a duplicate file is found, the MSS shall set the appropriate error status for the host and terminate the file service. If no duplicate file is found, the MSS shall allocate space for appropriate data on its recording media and position to portion of media in preparation for writing. The MSS shall set status to inform the host that the MSS is positioned and ready for a write function.
- Write-append Mode - The MSS will search its tables to locate the file the host wishes to add data to. If the file cannot be located, the MSS will set the appropriate error status and

terminate the file service. If the file is located, the MSS will allocate space for the segment to be added on any storage module that can accommodate the additional data. The MSS will then position media and set status to indicate that it is ready to perform a write append.

3.3.2.2 File Termination

The MSS shall be required to provide for the proper termination of a service requested by the host computer. For this discussion, the function to terminate a file service shall be called a "normal close" or simply, "close". The close procedure shall operate in the same mode as the open function. Since the mode of a file has been established when the file was opened, the MSS close procedure will determine the mode of the service performed and not require the host to supply it.

The procedures required for closing of a file determined by the mode of the open are described below:

- Read Mode - The MSS shall release the device and terminate the file service for that host.
- Write Mode - The MSS will record the end-of-information marker for the file, then enter the parameters for the new file in its directory. The MSS will then terminate the service for that host releasing the storage device for other use.
- Write-append mode - The MSS shall change the end-of-information pointer for the file, link the old segment of the file to the additional file data, make any changes to its directory and table needed, flag the file so that it may be rewritten into one continuous file at the MSS convenience, and terminate the file service for that host.

The MSS shall be required to provide to the host a means of releasing the host file space when it is no longer needed by that host. This function, for this discussion, will be called a "close-release".

When the MSS receives a close-release from the host, the MSS will remove all reference to the file from its directories and tables and return the space on its storage media held by the file for use by other files. The host will then terminate the service it is performing for the file.

3.3.2.3 File Read/Write

The MSS shall be responsible to the host for retrieving and storing data in an efficient manner regardless of the host's transfer rate. Since the size of the physical data blocks differ greatly between the MSS and host computers, it will be required that the MSS transfer data to and from the host in data blocks which are compatible with the host system. The MSS shall be required to respond to two data transfer functions from the host. The MSS will respond to one function for inputting data from the host for storage on the MSS media, called a "write" for this discussion, and one for outputting data from storage media to the host, called a "read".

The MSS will be required to respond to a host's read function request only after the host has provided for the opening of the file for the read mode. On receipt of the first read function after the file has been opened, the MSS will be required to establish the buffers necessary to hold the physical data blocks from the MSS media. The MSS will then read physical blocks into the buffers. The MSS will then be required to determine from the host's read function, the amount of data the host wants to receive and then transfer that amount of data to the requesting host. The MSS will continue to transfer the amount of data the host requests for each function from its buffers unitl the buffers are nearly empty. At that time, the MSS will again fill the buffers from its storage media. This operation will continue until the host sends a close or file rewind function or the MSS detects the end-of-information.

The MSS will be required to respond to the host's write function only after the host has opened the file to one of the two write modes (write or write-append). On receiving the first write function, the MSS will establish all needed buffers it needs to hold the contents of one or more physical media block of data. The MSS will fill buffers with data supplied by the host and write it to the media when the host has supplied the proper amount of data to write one or more physical data blocks on the MSS media. The write function will continue until the MSS receives a close function. When the write function is terminated in the above manner, the MSS will be required to flush the buffers by writing any data in the buffers to the MSS media and recording end of information.

3.3.2.4 File Positioning

The MSS shall be required to perform one basic positioning function. The function will be called "file rewind" for this discussion. When the MSS receives a file rewind function, it will be required to locate the starting point of the MSS file for which it is performing the service and position its media to that point. The "file rewind" will have the effect of closing a file and reopening it for a read at its initial point. This operation is precluded on files opened by a WRITE APPEND.

3.3.2.5 File Statusing

The MSS shall be required to respond to a host request for the status of a file operation. If the host does not specify which file, the MSS shall return the MSS status. For files which have been opened and are not busy, the MSS shall be required to return the status that the file was left in after the last operation was performed. For files which have been opened and are busy, the MSS shall be required to return MSS status indicating that the file is presently busy. If the MSS receives a status request and the file has not been opened, the MSS shall return an indication of that file's availability, e.g., mounted on an active reel.

3.3.2.6 Operator Message Service

The MSS shall be capable of receiving a message from a host processor for display to the MSS operator.

3.3.3 UTILITIES

The Mass Storage System (MSS) shall be required to supply the MSS operator and/or host computer system with certain utilities. These utilities shall be required to be self contained in the MSS so that they perform their tasks without the control of the host. The utilities shall be defined in one of the following categories:

- Hardware Control Utilities
- File Control Utilities
- Media Control Utilities,
- System Control Utilities

3.3.3.1 Hardware Control Utilities

The MSS shall be required to provide to the MSS operator those utilities needed to ascertain the present condition of the MSS hardware and to modify the MSS system hardware configuration. The following is a basic list of those utilities required to perform the above function:

- Test - The MSS will be required to provide the MSS operator with hardware diagnostics needed to determine the operational status of any and all hardware components of the MSS.
- Reconfiguration - The MSS is required to respond to the MSS operator command to disable by software interactions any MSS drive or MSS access path to reconfigure the MSS system to bypass failing hardware components.
- Initialize/Restart - The MSS shall be required to respond to the MSS operator command to initialize the MSS for operation, either at MSS system start up or following a MSS or host system interruption, e.g., transient power failure.

3.3.3.2 File Control Utilities

The MSS shall be required to provide to the host and/or MSS operator file utilities needed to maintain file security and ensure the validity of data. The following is a list of basic utilities needed:

- File copy - the MSS will provide a copy of a file from one MSS media to another MSS media.
- File purge - the MSS will respond to host and operator commands to purge a file from its directories and media.
- File compare - the MSS will provide a utility which will compare two like files on two separate medias for equality.
- File read check - the MSS will provide a utility which will ascertain if any recording errors have developed within a given file.

3.3.3.3 Media Control Utilities

The MSS will be required to supply the MSS operator with the utilities needed to control and maintain the MSS storage media modules. The MSS will be required to supply a demarking utility which will be used to certify the recording characteristic of the media and to provide a format mechanism for blocking the media for data storage if appropriate. In addition to the above requirements, the MSS will be required to provide utilities to the MSS operator and host for the dismounting of a module, for the removing of an on-line storage module to an off-line state, and for the mounting of a module, placing an off-line module on-line.

3.3.3.4 System Control Utilities

The MSS will be required to provide those utilities needed to determine the present state of the MSS system. The basic utilities are as follows:

- Status Utility - The MSS shall be required to provide a utility which will inform the operator of the current configuration of the MSS. Including in the information should be the current status of all mounted storage modules, MSS buffers, opened MSS files, and specification of active hosts.
- List Log Utility - The MSS shall produce as required a tabulation for the operator of all MSS activities performed by the MSS.

3.3.4 File Management

Since the Mass Storage System (MSS) shall be designed to service more than one host system, the MSS will be required to maintain the Master File Directory (MFD) of all files.

The MFD will be used by the MSS to locate a host file and determine certain file characteristics. For the above reasons, the MFD shall be required to contain at least the following information about the file:

- File identification
- File maturity date
- File size
- Date of last reference
- Creation date
- Indication of file activity
- File location
- Indication of Error history of file

In addition to MFD, the MSS shall be required to keep and maintain additional data. The information shall include:

- Location and size of available space on storage modules known to the MSS.
- List for holding MSS transaction history.
- MSS error history.

The MSS shall use the above MFD and tables to provide the following file management functions:

- Provide for automatic distribution or redistribution of MSS file for the purpose of reducing access time to more active files within the system.
- Provide for the concatenation of appended file segments and rewriting of files to one continuous file.
- Provide for the ability to restart interrupted utilities.

All of the above information and services shall be available on-line to the MSS regardless of whether a relevant storage module is on-line or not.

3.4 System Concept and Discussion

As stated in 3.1, the MSS is to compress and automate the handling of a large amount of data. Ultimately this system is to provide simultaneous support to several large computers, e.g., UNIVAC 1108's. The test bed host will be a DEC - PDP 11/45 and the system is to be developed and checked out as far as possible in this environment.

The concept of the system partitions it into three parts, 1) the hosts being serviced, 2) the storage media its driver and controllers which are to be procured and, 3) the interfacing equipment which may be procured separately. To the user within the host the MSS will appear to be essentially equivalent to a tape drive, consistent with this the ensuing discussion will describe the system in terms associated with normal CCT (½" magnetic tape) though the actual system may use something considerably different.

The initial system to be procured under this project is described schematically in figure 3.4-1. The channel interface provides the link between the host and the MSS. The data passing across this interface will be identical to that which would go across a CCT interface and the commands shall be very nearly so. The minicomputer will contain the MSS controlling software and will provide for the blocking and deblocking of data within its buffers. Data will then pass thru the media interface to the media controller where error detecting and correcting codes would be appended and processed. The data would then be forwarded to the specified drive for recording onto the mounted media (A or B).

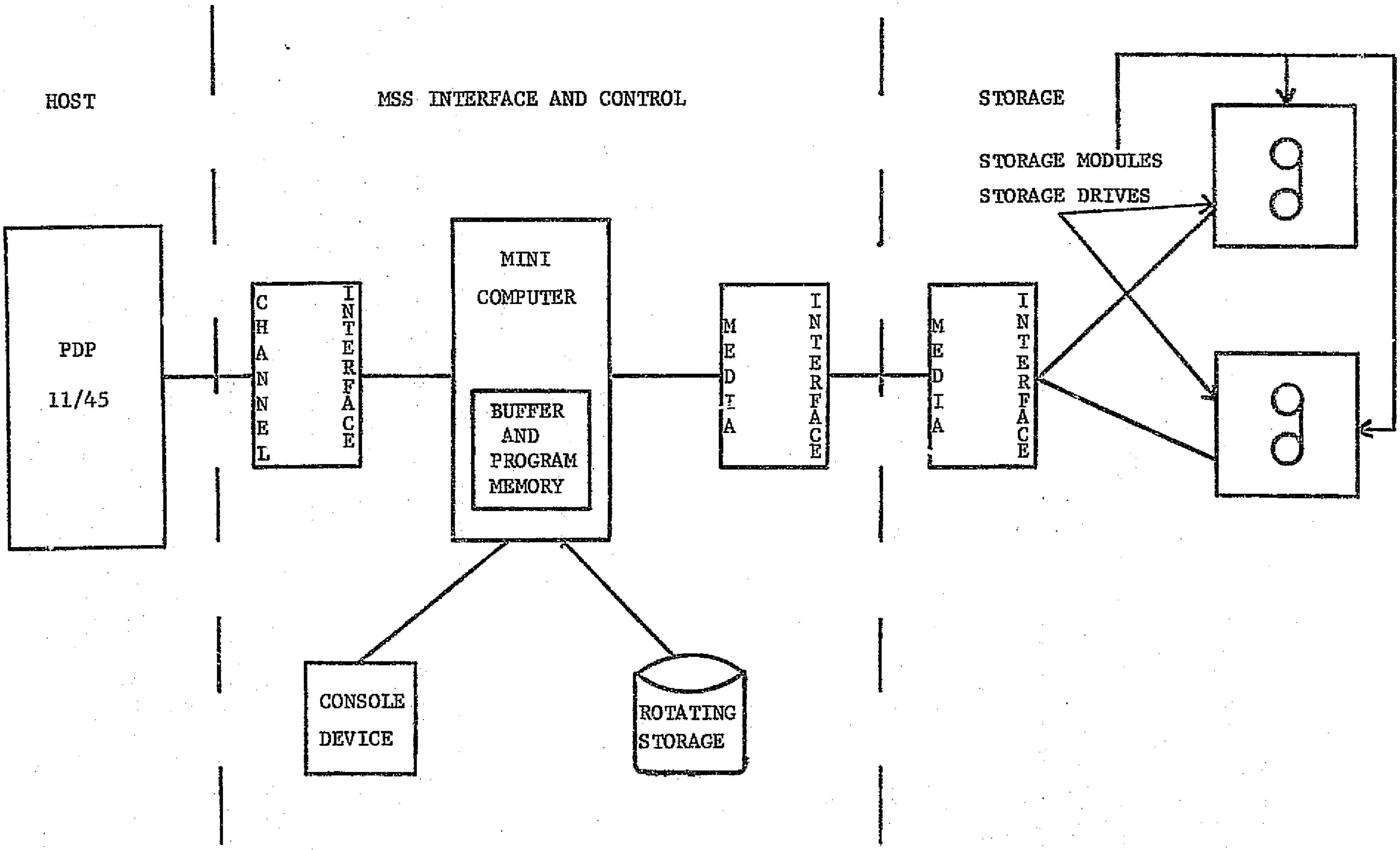

FIGURE 3.4-1. INITIAL SYSTEM

Tables would be maintained on rotating storage indicating the location of the information written as well as the location of information on all other storage modules A through E. The console device is available to the operator to interrogate these tables as well as to indicate to the system the replacement of storage modules.

The ultimate system schematic is shown in figure 3.4-2. This system is fully developed so that there are no single failing components which can take the entire system down and maintenance can be performed while the MSS continues in a degraded mode. In this version, all tables are maintained on duplicate disks. Only a single printer is required since its function is to produce reports not critical to the realtime operation of the system.

It is the responsibility of the system to block records to the convenience of the storage devices and to block files on a single storage module.for stringing across multiplical modules. The MSS shall not be expected to simultaneously process two files on a single storage module but action should be available to the operator to relocate these files if he is aware of their simultaneous need in advance.

Though the system will maintain a maturity date on each file, it will not purge a file. The expiration date shall be used only for reporting purposes.

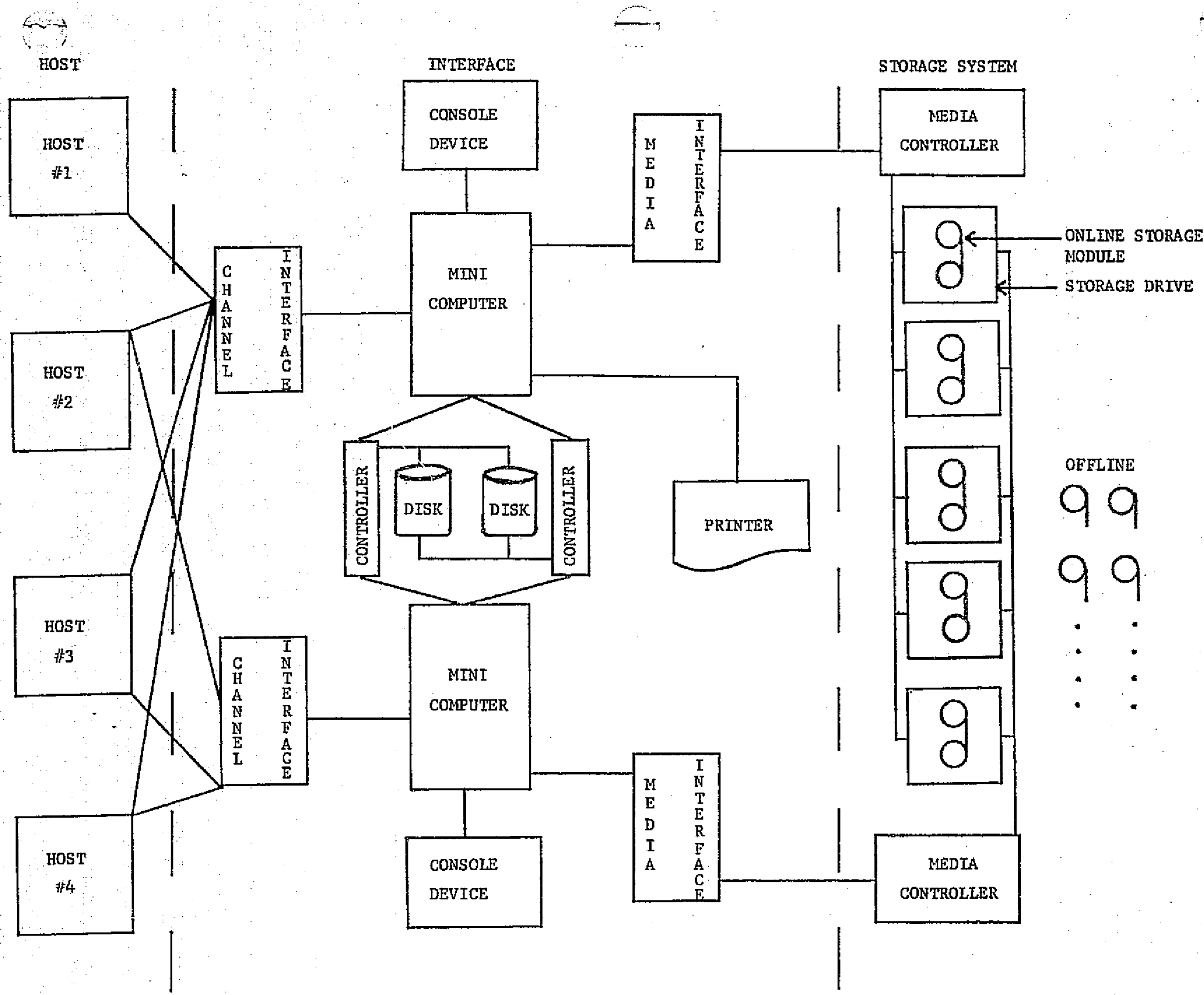

Figure 3.4-2 Target MSS Configuration

APPENDIX A

SYSTEMS ANALYSIS

APPENDIX A

In this section, the characteristics of the viable systems produced by our study of available systems are discussed. The order of the topics parallels that in Section 3.2

A.1 Capacity

As stated in Section 3., storage media and system capacity requirements for a MSS are:

1. Minimum media capacity of 12.5×10^6 bits
2. System capacity range of $16 - 400 \times 10^9$ bits

Table A-1 summarizes the storage media and system capacities of potential on-line mass storage candidates as they relate to the MSS capacity requirements. It should be noted that while all candidate system capacities meet or exceed MSS storage capacity requirements, the Data Cell does not meet minimum media storage requirements.

TABLE A-1

CANDIDATE MSS STORAGE CAPACITIES

	AMPEX TERABIT	CDC 38500	CALCOMP 7110 (@ 6250 bpi)	IBM 3850	IBM DATA CELL
Media unit data capacity (bits)	46.8×10^9	64×10^6	1.44×10^9	400×10^6	(1.6×10^6)
Max. System on-line capacity (bits) w/one controller	3.0×10^{12}	2.08×10^{12}	9×10^{12}	1.88×10^{12}	2.56×10^{10}
% max MSS capacity (400×10^9 bits)	750.	650.	2250.	470.	6.4

(   ) denotes capacity requirement not satisfied

A.2 Error Rates

A.2.1 Ampex Terabit

Utilizes polynomial encoding, dual redundant recording, and retry on read to achieve on error rate of 5×10^{-10}.

A.2.2 CDC 38500 and IBM 3850

Both systems achieve approximately 10^{-11} error rate by means of polynomial encoding. The IBM system uses an extended group code to correct 32 of up to 208 bytes. Single error bursts of up to 11 bits may be corrected. The CDC system uses a format similar to the standard 6250 bpi 9 track tape.

A.2.3 Error Rate Improvement

An examination of error rate improvement using concatenated codes indicates that it is theoretically possible but very impractical. One may use the existing error correcting code as the inner code and encoding with an outer code in cascade to improve overall error rate. However, the error correcting codes used by the recording systems are generally of long block length (approximately 900 bits in the case of Ampex) and the resulting concatenated code would be of excessive block length.

A.3 Technology

The technology used within the mass storage system shall consist entirely of "off the shelf" components. The devices utilized in each subsystem shall have two sets of confirmed reliability values.

The recording and reproducing devices should be mechanically reliable and proven by field usage. Time and budget constraints of the project do not allow a normal research and development period for devices to be developed and tested for implementation within this system.

Comparisons of the technologies and field usage of the candidate mass storage systems, are noted as follows:

AMPEX TBM - Developed basically from TV video techniques of 1967 technologies. First system built in 1972 for NSA. Subsequent systems built in 1974 and 1975 for ARPA-NET and NCAR.

CALCOMP ATL - The ATL mechanically selects CCT reels and mounts the reel on host self-loading tape transport automatically. Originally developed by Xytec Corporation of Boulder, Colorado during 1973. Xytec merged with CALCOMP in 1974. Two systems were installed in Denver area during 1974, Colorado National Bank and Mountain Bell Telephone Company. IBM 3420 Tape Transports at 6250 cpi were announced in March, 1973.

CONTROL DATA 38500 - CDC 38500 was announced, as a prototype unit only, at the National Computer Conference, May 1975. Since that time, two production units have been built and are presently being installed for in-house usage. No reliability data has been confirmed since the units are being utilized for software development only so far. The recording techniques are the same as for 6250 cpi therefore only the mechanical cartridge and tape handling (heads, guides, start/stop) positions of the system need to be verified.

IBM 3850 - IBM announced the 3850 System in November, 1974. The first production units were sold to NASA Goddard for the TELOPS system with a delivery scheduled for August 1975, system has been operational since December 1975. IBM presently has eleven systems in the field in various stages of installation, field testing and operational usage. Although it is not IBM policy to disclose MTBF and MTTR figures, several users were identified which might provide this type information for their installation.

Longitudinal Recording (See figure A-1)

Longitudinal recording is the most common format used with digital tapes. Longitudinal recorders position the data lengthwise on the tape, usually with a multiple track head. Head design is simplified since no head motion is required. However, increased bit density necessarily implies a smaller polarized area on the tape for each bit. In order to produce the same flux change for reliable reading, the tape must be moved past the head of a greater speed. Thus high density requires greater tape and reel speed with their attendant mechanical problems.

Transverse Recording (See figure A-1)

Transverse recording uses a wide tape (typically 2 in.) with a rotating head assembly, the axis of which is parallel to the longitudinal axis of the tape. The head assembly will typically have six to eight heads. The rotating head assembly allows rapid motion of the head relative to the tape, hence the high bandwidth and high density. Then the speed of the tape and reels may be much less than that for longitudinal recording for the same bandwidth. However, a more complicated head design is necessary with a servo system to synchronize head motion with tape motion.

Helical Scan Recording (See figure A-1)

In the helical scan technique, the tape is wrapped completely around the rotating head assembly and the motion of the head across the tape is diagonal to the longitudinal axis of the tape. A narrower tape may be used (as low as 0.25 in.) for a given length scan. Bandwidth is typically not as great as for transverse scan although it is greater than that achievable with longitudinal recording for the same tape speed. Also, the 360° wrap of the tape around the rotating head requires a more complicated tape handling mechanism than transverse scan.

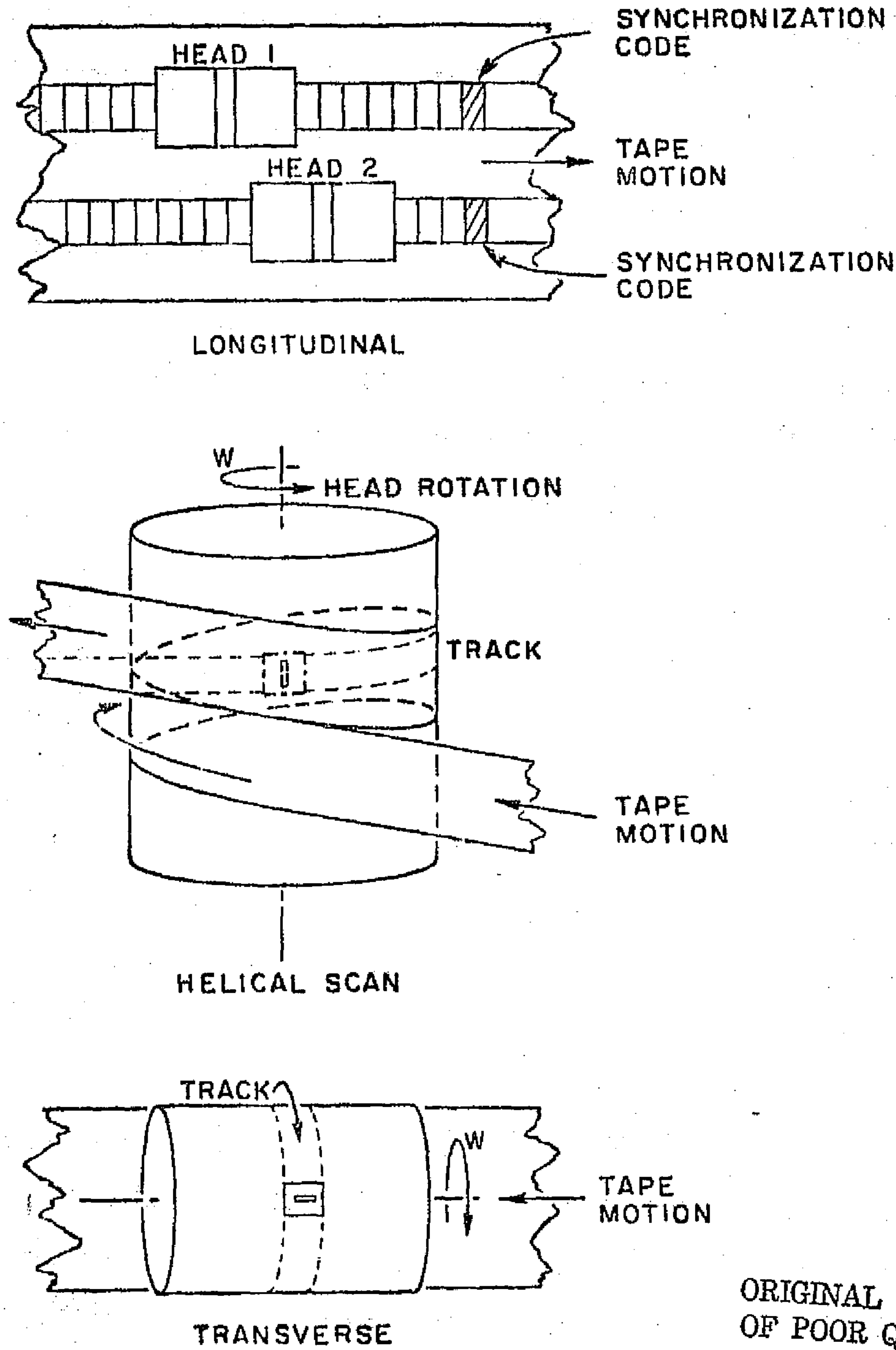

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Figure A-1 Magnetic Tape Recording Techniques

A.4 Recording Media

The storage media should provide for data erasure and modification. The file activity in an on-line data storage system exhibits properties similar to direct access storage devices (DASD's) such as; read, modify, create, save and purge activites. These functions demand a storage media capable of supporting continuous record, read and erase activities.

As specified in paragraph .2.3, the recording media also shall be of proven technology and readily available from off-the-shelf sources.

To satisfy these conditions, the recording media will consist of a magnetic type recording. Magnetic bubbles, electron beams, holograms, etc., technologies have not developed to "field proven" point to be sufficient in the time frame allowed to develop this system.

Of the four major candidates for mass storage devices, all use magnetic film as the recording media.

AMPEX TBM - 2 inch wide Video Tape, 3600 ft. reels (Multiplical sources)

CALCOMP ATL - ½ inch CCT, 2400 ft. reels, longitudinal 6250 bpi (multiplical sources)

CONTROL DATA 38500 - 2.7 inches wide, 100 inch per cartridge, longitudinal 6250 bpi (singular source)

IBM 3850 - 3 inches wide, 770 inch per cartridge, Transverse Tracks (singular source)

A.5 Latency

It is a requirement that the stated storage capacity should be available on-line and therefore the modules should be easily mountable and removeable from the storage devices.

Each system however has different characteristics and techniques for data storage, therefore the amount of time a host system must wait before the requested data file is made available will differ for each candidate system. The following paragraphs provide an indication of the access time for these systems and the time to transfer a typical file (1 cylinder 3330 disk) to the host system.

A.5.1 AMPEX TBM - The AMPEX TBM system utilizes a reel-to-reel type tape drive in which all files are stored sequentially on tape. Search is done on an address track at 1000 inches per second.

Access time:

Average search time	15.0 sec
Data transfer time (1 cylinder 2 Mbits)	0.4 sec
Total	15.4 sec

A.5.2 CALCOMP ATL - CALCOMP utilizes ½ inch CCT's at 6250 cpi with IBM 3420 compatible tape drives. Search and read are both done at 200 ips.

Access time:

Retrieve next reel	11.0 sec
Tape load time	4.0 sec
Average Search time	48.0 sec
Data transfer time	0.2 sec
Total	63.2 sec

A.5.3 CONTROL DATA 38500 - CDC utilizes 2000 small cartridges in a large honeycomb. Minimum record size is 1 Megabyte, read ½ MB in forward direction and ½ MB in reverse direction. Data is formatted similar to 6250 CCT's. No search time is necessary since read operation always starts at BOT mark and returns at completion. Tape is 100 inches long and is always read down and back at 129 ips.

Access time:

Retrieve next reel (select and deliver)	5.0 sec
Tape load time	2.0 sec
Data Transfer time	1.55 sec
Total	8.55 sec

A.5.4 IBM 3850 - IBM utilizes 700 small cartridges containing approximately 65 feet of 3 inch magnetic tape. Data is placed on tape in stripes (diagonal) across the tape. The tape is physically positioned at the beginning of cylinder mark, then the read/write head is rotated the length of the data stripe while the tape is held in the fixed position. Minimum data transfer is one disc cylinder (approximately 2 Mbits).

Access time:

Retrieve next cardridge	8.0 sec max.
Tape load and verify VTOC	5.0 sec
Search to requested cylinder	3.8 sec
Data transfer time	1.0 sec
Total	17.8 sec

A.6 Availability

A.6.1 IBM 3850 and CDC 38500

Reliability information is incondusive on the IBM 3850 and CDC 38500 systems since these units have been in the field only a short time. The most frequent failure mode to be expected would probably be in the automatic picker mechanisms. Operations on a 24 hour a day basis could probably be expected after an initial break-in period. It would not be unreasonable to expect this period to last from 6 months to one year.

A.6.2 Ampex Terabit System

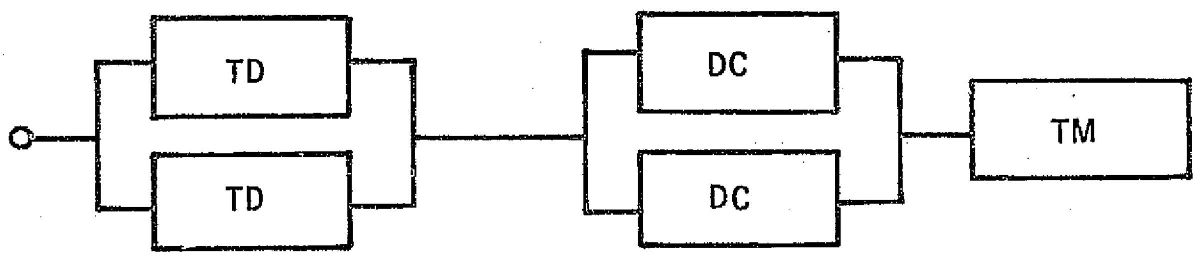
Ampex has provided the following information on the three basic modules of the Terabit system:

	MTTR	Availability
Transport Driver	0.87	94%
Transport Module	0.55	96%
Data Channel	1.05	98%

Yielding calculated MTBF figures

	Failure rate	MTBF figures
Transport Driver	$0.069\ hr^{-1}$	14.5 hrs
Transport Module	$0.073\ hr^{-1}$	13.75 hrs
Data Channel	$0.019\ hr^{-1}$	52.5 hrs

Using these figures for MTBF on a minimal system consisting of one transport module, two transport drives and two data channels, the resulting reliability diagram would be



resulting in a system MTBF of 7.61 hours.

A.6.3 Calcomp ATL

Specific hardware MTBF and MTTR figures are not available for the ATL. The "fail soft" mechanism utilized, however, should allow the system to meet the 24 hour a day usage requirement. Should the mount hardware fail, a message is issued to the operator identifying tape reels and their locations so that these tapes may be manually mounted, the ATL software continues management functions, checks errors, and maintains the Data Base in an off-line mode.

A.7 MSS Interface

A.7.1 Ampex Terabit System

Ampex has produced one Terabit system which has been interfaced to a PDP-11/45 single host. Multiple 1108 and/or 1110 host systems have not as yet been produced.

A.7.2 IBM 3850

IBM has so far provided an interface only to their 360/370 systems in either single or multihost configurations. They have not shown any willingness to provide interfaces to alter machines.

A.7.3 CDC 38500

CDC has provided a 360/370 interface and may be operated in a multihost environment. They plan to produce an interface for their own mainframe series in the near future. However, they have no plans for interfaces for other mainframe series at this time.

A.7.4 Calcomp ATL

The Calcomp ATL is currently capable of interfacing with the IBM 360/370 series using either the OS/MVT, OS/MFT, OS/VS1, or OS/VS2 operating systems. Univac 1108 and/or 1110 interfaces or PDE-11/45 interfaces are not currently available.

A.8 Persistence

A.8.1 Ampex Terabit

Utilizes frequency modulation, bit serial recording on magnetic tape as used in color vidoe recording F.M. recording reduces print-through effect suffered by conventional computer compatible tapes. Redundant, transverse recording and polynomial error detection/correction techniques employed should produce tapes with a shelf life exceeding that of CCT.

A.8.2 CDC 38500

Utilizes 6250 bpi tape housed in individual cartridges. Longitudinal recording technique is employed. Error protection technique is group encoding. Tape has shelf life comparable to the CCT.

A.8.3 CALCOMP 7110

Utilizes standard CCT transport.

A.8.4 IBM 3850

Utilizes a helical scan storage technique on magnetic tape cartridges ($2x \cdot 10^5$ bits/in^2) and employs an extended group coded recording error correction technique. Shelf-life should equal or exceed that of CCT.

A.8.5 IBM Data Cell

Utilizes magnetic tape strips and standard character/block parity techniques. Shelf life unknown but strips are subject to wear.

A.9 Vendor Self Test Facilities

All major vendor supply a self test facility depending on the hardware/software capabilities of their system. The following is the basic list of self text facilities supplied by the different vendors.

CALCOMP 7110 - CALCOMP uses its Field Engineering subsystem to perform self test function without using any resources assigned to the host system. The functions performed are:

- Perform diagnostic function while normal system is active without interfering with normal operation.
- Loads diagnostic control programs into the system control unit.
- Performs functions as specified via console commands.
- Records all hardware exceptions in a system file.
- List contents of system hardware exception file.

CDC 38500 - CDC 38500 under the VDAM operating system provides both on-line and off-line self-test function. The functions performed by VDAM are:

- Automatic error recording to an engineer file.
- On-line diagnostic which exercise selected components while the remaining component continue to operate on-line.
- Trace facility which logs all system events for performing problem determination and diagnosis.
- Stand-alone diagnostic which provides diagnosis without host processor.

IBM 3850 - IBM provides the following:

- Microdiagnostic which are entered from a diskette.
- On-line test which can be executed in degraded mode to measure accessor motion, isolate failures, report cartridge store addresses and conditions of access errors, report

addresses and control checks, analyze path, test interface, and update microcode.

- System data analyzer to store and analyze sense data, buffered-usage-log data and data logged.

AMPEX TBM - The AMPEX TBM provides mainly those self test services needed for alignment and maintenance of tape drives. These services are:

- A maintenance and diagnostic monitor for running diagnostic routines.
- An alignment of routines for software alignment of tape drives.
- A pretest to determine the accuracy for drives and tapes.
- An initialized routine to permit the adding of new tapes to the system.

A.10 Transfer rate

As stated in Section 3., the MSS shall be required to support sustained data rates up to 10 megabits/sec (10^7 b/s). This mode of operation would be primarily for the recording of downlink telemetry data from a single host in a continuous write mode. Achievement of this throughput rate is dependent on many factors, some of which are:

1. Host/MSS interface characteristics
   a. Transfer rate across interface
   b. Interface data blocking (buffer size)
   c. Interface processing overhead

2. MSS characteristics
   a. Storage media capacity
   b. Transfer rate to/from storage media
   c. Start/stop, search/position & media switch timing factors
   d. Data blocking factors
   e. MSS processing overhead

   g. MSS file structure and organization
   h. Bit error rate
   i. Error recovery timing factor

These factors present numerous design considerations for each of the candidate MSS's, greatly complicate MSS interface and hardware configuration selection and ultimately determine effective MSS throughput capability. The following is a summary of the major limiting factors for each of the candidate MSS's.

A.10.1 Ampex TBM Memory System

The Ampex TBM can be configured to provide a storage range of 10^{11} to 3×10^{12} on-line data bits utilizing transport units having a bit capacity of 4.6×10^{10} bits. The stated data channel transfer rate for a TBM read or write channel is 5.6×10^6 bits/sec.

Assuming a 10^7 b/s data rate can be accommodated by the TBM, a storage unit would need to be refreshed approximately every 76 minutes. This should provide ample time for premounting and initializing a new storage unit for continuation.

A.10.2 CDC 38500 Mass Storage Facility

The CDC MSF has a stated transfer rate of 6.4×10^6 bits/sec; however, the relatively low cartridge capacity of 64×10^6 bits makes continuous recording at 10 megabit rate impractical since a new cartridge would have to be selected approximately every 6.4 sec., with an average cartridge access time of 2.5 seconds and additional 5 seconds to initialize the tape.

A.10.3 CALCOMP 7110

The Calcomp 7110 uses standard vendor CCT's. For this discussion, a 6250 bpi transport with a tape speed of 200 ips was used to calculate transfer rate. Using this tape drive, the transfer rate of the Calcomp 7110 will be 1×10^7 bits/sec.

A.10.4 IBM 3850

The IBM 3850 has a max transfer rate of approximately $.86 \times 10^6$ bits/sec, an order of magnitude below the MSS throughput requirement. Media capacity dictates a 40 second fill time at a 10 megabit rate. Since the time to load a new cartridge is about 8 seconds, this would preclude using a single 3850 in this fashion.

A.10.5 IBM 2321 Data Cell

The peak transfer rate of 4.4×10^5 bits/sec and low media bit capacity (1.6×10^6 bits) of the 2321 Data Cell would definitely preclude using this storage device in a continuous 10 megabit recording mode.

A.11 Transferability

Transferability of modules between like drives is a design characteristic of each of the systems under consideration. The extent to which this characteristic is available in practice is a function of the adjustment tolerance which may be maintained in each system, hence is a system reliability consideration.

APPENDIX B

SYSTEM DATA SHEETS

B.1 System Data Sheets

The following data sheets present the relevant parameters for the candidate storage systems. The data sheet on the UNIVAC system being currently used in IDSD is included for comparison.

TABLE B-1

STORAGE SYSTEM CHARACTERISTICS

SYSTEM: AMPEX TBM

			Comments:
Module Characteristics			
Reel length	(ft.)	3800	2 in. wide, 10½ in. reel
Bits/reel	(Mb)	45,320	2 reels per Transport
Persistance	(yr.)	15 yr.	FM recorded, not saturated
Volume	(ft^3)	70 cu. inches	
Price	($)	150.00	
Drive Characteristics			
Bpi	(bpi)	10^6	x 10^6 bits of user data
Data tracks	(#)	TRANSVERSE 184/inch	
Min. record size	(bits)	10^6	
Start/stop time	(ms)	300	
Record gap	(in.)	None	
Ips	(ips)	5	83, 248, 1000 search
Reels/drive	(#)	2	
Ft^2	(ft^2)	6.3/7.5	TD/TM
Power	(watts)	7.5/0.6 KW	TD/TM
Btu	(btu/hr)	25000,2000	TD/TM
Maint. cost	($/month)	2400	
MTBF	(hr.)		
MTTR	(hr.)	87 hrs.	
Price	($)	160,000	1 Xport Module & 1 Xport Driver
Controller Characteristics			
Max. data rate	(kbps)	5600 per channel	22.4×10^6 bps w/4 channels
Drives/controller	(#)	32	
Corrected error rate	(#)	5×10^{11}	
Power	(watts)	0.6 kw	
Btu	(btu/hr.)	4000	
Ft^2	(ft^2)	6.3	
Maint. cost	($/month)	710	
MTBF	(hr.)		
MTTR	(hr.)	1.05 hours	
Price	($)	~~71,000~~	1 Data channel

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TABLE B-2

STORAGE SYSTEM CHARACTERISTICS

SYSTEM: IBM 3850

			Comments:
Module Characteristics			
Reel length	(ft.)	64 ft.	770 inches
Bits/reel	(Mb)	403.2	50.4 Mbytes
Persistance	(yr.)	Saturated Normal CCT	706 cartridges/system
Volume	(ft^3)	2 in. dia x 4 in. lng	
Price	($)	20.00	
Drive Characteristics			
Bpi	(bpi)	$.591 \times 10^6$	
Data tracks	(#)	Transverse 3838 track	202 cyl @ 19 Tks/cyl
Min. record size	(bits)	1.98×10^6	1 cyl min. = 19 Tks x 13030 bytes/trk
Start/stop time	(ms)		
Record gap	(in.)	none	
Ips	(ips)	3.8 average	Xter rate of 1 cyl/sec
Reels/drive	(#)	706	
Ft^2	(ft^2)	TBS	
Power	(watts)	TBS	
Btu	(btu/hr)	TBS	to be supplied
Maint. cost	($/month)	1400	
MTBF	(hr.)	NA	not available at present
MTTR	(hr.)	NA	
Price	($)	$491,120	
Controller Characteristics			
Max. data rate	(kbps)	860 max/248 avg.	Channel rate/Avg. R/W rate
Drives/controller	(#)	2 accessors & 8 DRD's	Extended group coded - corrects 32 of up to 208 bytes detected. DASD corrects single bursts of up to 11 bits.
Corrected error rate	(#)	1×10^{11}	
Power	(watts)	TBS	
Btu	(btu/hr.)	TBS	
Ft^2	(ft^2)	TBS	
Maint. cost	($/month)	256.00/mo.	
MTBF	(hr.)	NA	
MTTR	(hr.)	NA	
Price	($)	187,240.00	

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TABLE B-3

STORAGE SYSTEM CHARACTERISTICS

SYSTEM: CALCOMP ATL

			Comments:
Module Characteristics			
Reel length	(ft.)	2400 ft.	Standard ½ in. CCT
Bits/reel	(Mb)	1800 m bits	2400 ft x 6250
Persistance	(yr.)	Saturaged CCT	
Volume	(ft^3)	dia = 10½ x ½ inch width	
Price	($)	30.00	
Drive Characteristics			
Bpi	(bpi)	6250	
Data tracks	(#)	9	
Min. record size	(bits)	18 characters	
Start/stop time	(ms)	1.5/2.6 ms	
Record gap	(in.)	.3 inch	
Ips	(ips)	up to 200 ips	
Reels/drive	(#)	746 - 6122	reels in cabinet
Ft^2	(ft^2)	29.5	
Power	(watts)	12480	Combined total - Control & Storage Units
Btu	(btu/hr)	10,800	Combined Total - Tape Drive not included
Maint. cost	($/month)	$3954/month	Combined Total - Tape Drives not included
MTBF	(hr.)		
MTTR	(hr.)		
Price	($)	224,100	Combined Total - Tape drives not included
Controller Characteristics			4 LSU's & tape drive hook ups
Max. data rate	(kbps)	10 Meg bps	CONTROL UNIT 6250 x 200 ips
Drives/controller	(#)	to 16 LSU's & 32 tapes drives	Tape drive dependent*
Corrected error rate	(#)	1×10^{11}	
Power	(watts)	See LSU	
Btu	(btu/hr.)	See LSU	
Ft^2	(ft^2)	30.2	
Maint. cost	($/month)	See LSU	
MTBF	(hr.)		
MTTR	(hr.)	See LSU	
Price	($)		

TABLE B-4

STORAGE SYSTEM CHARACTERISTICS

SYSTEM: CDC 38500

			Comments:
Module Characteristics			
Reel length	(ft.)	100 inches	
Bits/reel	(Mb)	64×10^6 bits	2000 cartridges
Persistance	(yr.)	Saturated normal CCT	
Volume	(ft^3)	4.5 cu inches	1½ dia x 3½ in long
Price	($)	15.00	8 per pkg = $120, $30, 720 per System
Drive Characteristics			
Bpi	(bpi)	6250	Selector & R/W Sta.
Data tracks	(#)	144 Longitudinal	1 megabit (½ FWD - ½ REV)
Min. record size	(bits)	8×10^6 bits	2 m sec start/2 m sec stop
Start/stop time	(ms)	4 m sec	
Record gap	(in.)	.6 inch	normal 9 track CCT
Ips	(ips)	129 ips	
Reels/drive	(#)	2052	76.7 x 128 x 27 storage module
Ft^2	(ft^2)	29.75	71 x 53.6 x 31 library adapters
Power	(watts)	5700	71 x 26.6 x 31 xpt
Btu	(btu/hr)		
Maint. cost	($/month)	450	
MTBF	(hr.)	NA	
MTTR	(hr.)	NA	
Price	($)	154,000 - 258,000	
Controller Characteristics			Controller Adapter Unit
Max. data rate	(kbps)	6448 max.	806 K bytes/sec
Drives/controller	(#)	4 R/W Sta. max	(each with 2 sets R/W Heads)
Corrected error rate	(#)	approx. 1×10^{11}	comparable to 6250 cpi tapes
Power	(watts)	7200	
Btu	(btu/hr.)	11,000	
Ft^2	(ft^2)	11	60 x 28 x 44.5 controller
Maint. cost	($/month)	$660	
MTBF	(hr.)	NA	no reliability figures available
MTTR	(hr.)	NA	" " "
Price	($)	100,000 - 138,000	

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TABLE B-5

STORAGE SYSTEM CHARACTERISTICS

SYSTEM: IBM 2321 (DATA CELL)

Module Characteristics			Comments:
Reel length	(ft.)	2.25" x 13"	3021 data cell width x length of magnetic strip, 200 strip/cell 1 strip = 1.6 MB non-volatile, non-permanent;
Bits/reel	(Mb)	320 MB/cell	
Persistance	(yr.)		
Volume	(ft^3)		
Price	($)		

Drive Characteristics			
Bpi	(bpi)	1230	2321 Data cell drive
Data tracks	(#)	100 TRKS/strip	
Min. record size	(bits)	1 byte	
Start/stop time	(ms)	25-550	
Record gap	(in.)		
Ips	(ips)	250	
Reels/drive	(#)	10 cells,drive	10 strips/subcell;
Ft^2	(ft^2)	4' x 6'	20 subcells/cell;
Power	(watts)		
Btu	(btu/hr)		
Maint. cost	($/month)	523	
MTBF	(hr.)		
MTTR	(hr.)		
Price	($)	117,650	+ 6055/attachment unit

Controller Characteristics			
Max. data rate	(kbps)	440	2841 storage control
Drives/controller	(#)	8	206 KBS effective MAx #
Corrected error rate	(#)		
Power	(watts)		
Btu	(btu/hr.)		
Ft^2	(ft^2)		
Maint. cost	($/month)	62	
MTBF	(hr.)		
MTTR	(hr.)		
Price	($)	23,530	

TABLE B-6

STORAGE SYSTEM CHARACTERISTICS

SYSTEM: Univac/Uniservo VIII C

Characteristic	Unit	Value	Comments:
Module Characteristics			
Reel length	(ft.)	2400	
Bits/reel	(Mb)	5.76, 16, 23 max	(for 200, 556 & 800 bpi)
Persistance	(yr.)	CCT	
Volume	(ft^3)	70.5 in^3	(for 10½ inch reel)
Price	($)	20.00	(certified 800 bpi)
Drive Characteristics			
Bpi	(bpi)	200, 556, 800	
Data tracks	(#)	7 tracks	9 track - special order
Min. record size	(bits)		
Start/stop time	(ms)	1.3 to 2.5 max	
Record gap	(in.)	.75 inch max	
Ips	(ips)	120 ips	
Reels/drive	(#)	1	
Ft^2	(ft^2)	5.34 ft^2	27 x 28 5/8 inches
Power	(watts)	1.9 Kw	
Btu	(btu/hr)	5460	320 cfm underfloor
Maint. cost	($/month)	124.00	
MTBF	(hr.)	1565	
MTTR	(hr.)	1.3 hours	
Price	($)	21,275.00	
Controller Characteristics			TYPE 5008 CONTROLLER
Max. data rate	(kbps)	24, 66.7, 96	(for 200, 556 & 800 bpi)
Drives/controller	(#)	16	
Corrected error rate	(#)	1×10^{-9}	
Power	(watts)	.075 Kw.	
Btu	(btu/hr.)	2354	
Ft^2	(ft^2)	4.33 ft^2	500 cfm underfloor
Maint. cost	($/month)	136	24 x 26 inches
MTBF	(hr.)	7076	
MTTR	(hr.)	2.6	
Price	($)	40,580.00	

APPENDIX C

SYSTEM PRICE/PERFORMANCE ANALYSIS

C.1 Objectives

An analytical model of the storage portion of the system was felt to be necessary in order to provide a means of measuring the relative price/performance characteristics of the systems. The systems considered in the study involve sufficiently disparate technologies that a straight feature for feature comparison is meaningless. Hence a model has been developed which will give an overall dollar per bit value for a range of system capacities.

C.2 Parameters

The parameters fed into the model were taken from the data sheets of Section 5, when available, and were estimated when not available. The model accepts the following parameters:

Symbol	Units	Description
Operations		
OBUR	%	Operator burden rate
OSAL	$/hr	Operator salary
ONUM	people	Number of operators
SHIFT	#	Number of shifts per working day
Device Cost		
RNTDR	$/mo	Rent per drive per month
RNTCNT	$/mo	Rent per controller per month
DIC	$/drive	Drive installation cost
CIC	$/ctlr	Controller installation cost
SMAIN	$/mo	Monthly maintenance contract cost
MC	$	Shipping Cost of equipment

Device Characteristics

DWATT	WATTS/DR	Drive power consumption
CWATT	WATTS/ctlr	Controller power consumption
CNTSQF	ft^2/ctlr	Floor area for controller
DRSQF	ft^2/drive	Floor area for drive
MTBF	hr	Mean time between failures
MTTR	hr	Mean Time to repair
AVGAC	sec	Average access time
MODBIT	bits	Bits per storage module
DPC	#	Drives per controller

Facilities

CUFTMD	ft^3/mod	Storage space for off-line modules
SQFTRT	$\$/ft^2$	Cost for rental space
FC	$	Facilities modification cost

System

E	yrs	System life

Miscellaneous

MTC	$	Machine time costs for mini
PTC	$	Programming costs for mini
MODMON	sec	Off-line module mount time
WATT	$	Cost of watt-hour of power

C.3 Method

The following expression is evaluated for the various systems and online capacities of ¼, ½, 3/4 and total storage volume being online:

$$\$ = \frac{L \cdot R \cdot (C + I + E \cdot (O + D + P + M + F))}{E \cdot V}$$

where

$ - cost per bit of storage

L - latency of average bit in the system

R - system reliability

C - system conversion cost

I - installation cost

E - life of the system

O - operating staff cost

D - equipment cost

P - power cost

M - maintenance cost

F - facilities cost

V - total storage volume

The resulting units are dollars per bit. The latency coefficient is directly multiplicative since it was felt that a positioning time of twice the amount was worth half as much. When the reasoning is applied to offline modules, the results are drastic and will need to be adjusted.

C.4 Format

Each model run produces a graph giving the dollar per bit cost for systems of varying capacities. The integers plotted with indicate the quarters of the capacity which are on line, e.g., 2 - with 50% online.

C.5 Program Listing

The following is a listing of the procedures executed to produce the price versus capacity plots at the end of the section. The language used is APL which is available on a timesharing terminal at SISO where additional graphs with different parameters can be made as required.

```
        ∇INIT[⎕]∇
      ∇ INIT
[1]     OPERATIONS
[2]     DEVICECOST
[3]     DEVICECHAR
[4]     FACILITIES
[5]     MISCELLANEOUS
      ∇
        ∇OPERATIONS[⎕]∇
      ∇ OPERATIONS
[1]     OBUR←1
[2]     OSAL←4.81
[3]     ONUM←1
[4]     SHIFT←3
      ∇
        ∇DEVICECOST[⎕]∇
      ∇ DEVICECOST
[1]     MODCST←150
[2]     RNTDR←708.33
[3]     RNTCNT←1216.5
[4]     DIC←0
[5]     CIC←3300
[6]     SMAIN←3000
[7]     MC←0
      ∇
        ∇DEVICECHAR[⎕]∇
      ∇ DEVICECHAR
[1]     DWATT←8100
[2]     CWATT←600
[3]     CNTSQF←6.3
[4]     DRSQF←13.8
[5]     MTBF←1000
[6]     MTTR←1.05
[7]     AVGAC←15.4
[8]     MODBIT←45320000000
[9]     MPD←2
[10]    DPC←32
[11]    E←10
      ∇
        ∇FACILITIES[⎕]∇
      ∇ FACILITIES
[1]     CUFTMD←70÷(12×12×12)
[2]     SQFTRT←0.0009582
[3]     FC←0
      ∇
        ∇MISCELLANEOUS[⎕]∇
      ∇ MISCELLANEOUS
[1]     MOHR←521.7857
[2]     MTC←0
[3]     PTC←10000
[4]     RNTINT←2317
[5]     MODMON←300
[6]     WATT←6E¯5
      ∇
```

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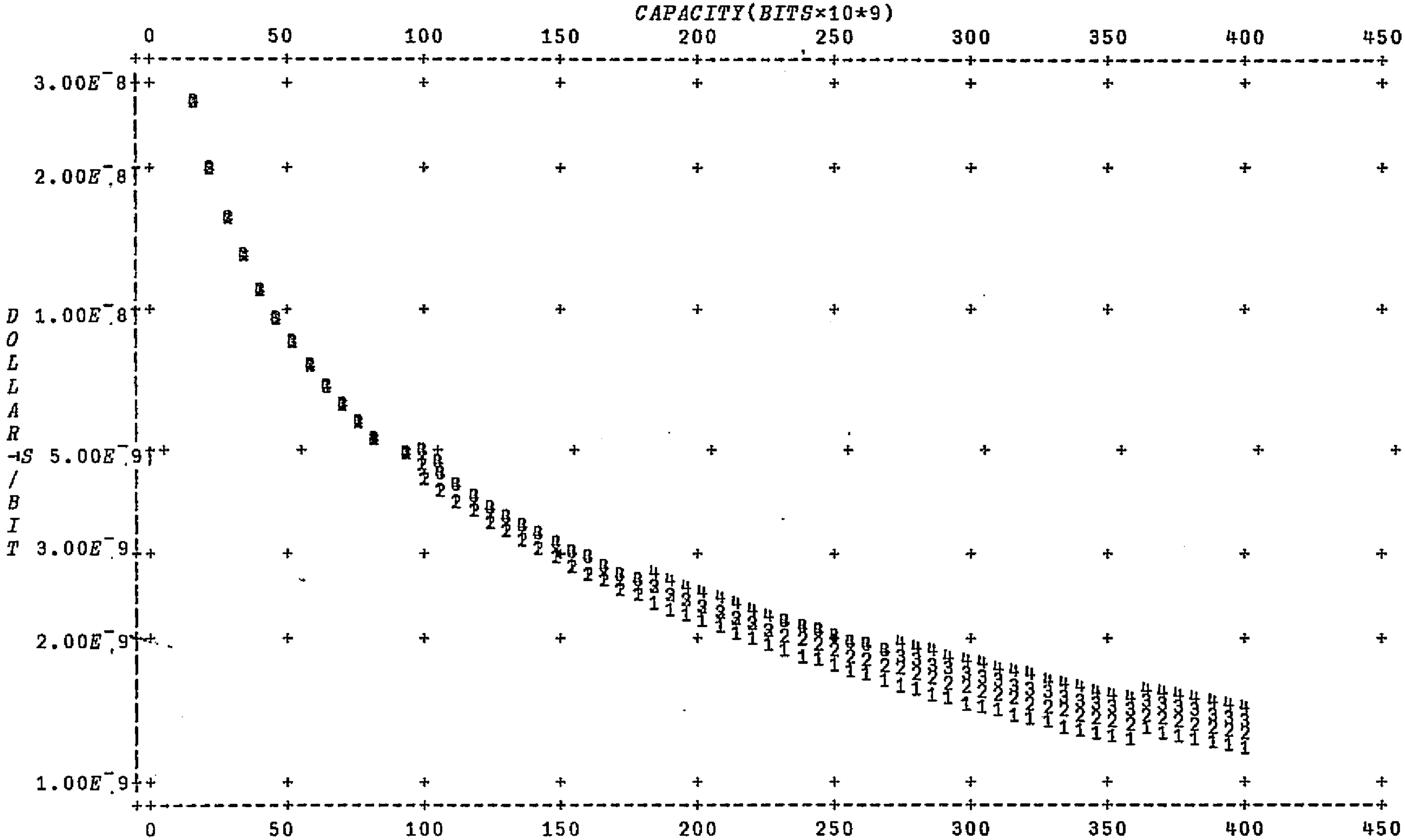
```
      ∇MASS[⎕]∇
    ∇ MASS
[1]   INIT
[2]   STEP←6
[3]   COSTPERBIT←0
[4]   GRAPH← 0 4 ρι0
[5]   IV←16
[6]  LOOP:BV←IV×10*9
[7]   COSTPERBIT EVAL BV
[8]   GRAPH←GRAPH,[1] COSTPERBIT
[9]   IV←IV+STEP
[10]  →(IV≤400)/LOOP
[11]  XX←16+STEP×¯1+ι(ρGRAPH)[1]
[12]  PRINT PLOT GRAPH VS XX
[13]  PARAMETERS
    ∇
      ∇EVAL[⎕]∇
    ∇ CPB EVAL V
[1]   MODS←⌈(V÷MODBIT)
[2]   NODR←⌈((ι4)×MODS÷4)÷MPD
[3]   CALCMD←MODS×MODCST
[4]   NOCNT←⌈(NODR÷DPC)
[5]   OFFMD←MODS-NODR×MPD
[6]   CALCO←ONUM×OSAL×1+OBUR
[7]   CALCD←((RNTDR×NODR)+(RNTCNT×NOCNT)+RNTINT)÷MOHR
[8]   CALCP←WATT×(NODR×DWATT)+NOCNT×CWATT
[9]   CALCI←(NODR×DIC)+(NOCNT×CIC)+MC+FC
[10]  CALCF←SQFTRT×(CNTSQF×NOCNT)+(DRSQF×NODR)+(CUFTMD÷7)×OFFMD
[11]  CALCM←SMAIN÷MOHR
[12]  CALCE←12×MOHR×E
[13]  CALCC←MTC+PTC
[14]  CALCR←÷0.85
[15]  CALCL←AVGAC
[16]  COSTPERBIT←CALCL×CALCR×(CALCMD+CALCC+CALCI+CALCE×CALCO+CALCD+CALCP+CALCM+CALCF)÷V×CALCE
    ∇
```

COST PER BIT PLOT FOR AMPEX TERABIT SYSTEM

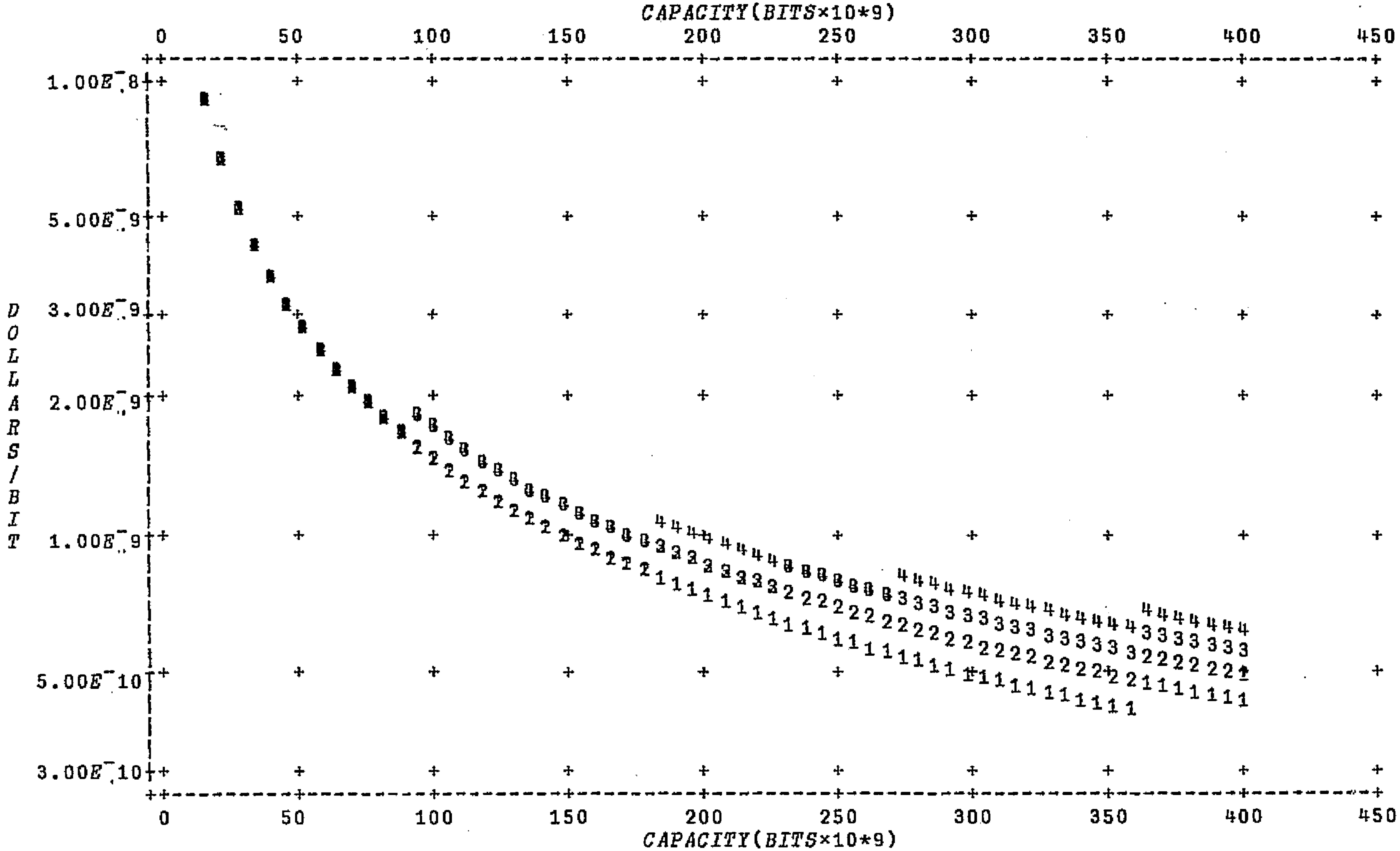


PREPARED BY AERO. FORD-HOUSTON

PARAMETERS

OBUR=1 *OSAL*=4.81 *ONUM*=1 *SHIFT*=3 *RNTDR*=708.33
DIC=0 *CIC*=3300 *SMAIN*=3000 *MC*=0 *DWATT*=8100
CWATT=600 *CNTSQF*=6.3 *DRSQF*=13.8 *MTBF*=1000 *MTTR*=1.05
AVGAC=15.4 *MODBIT*=4.532E10 *DPC*=32 *CUFTMD*=0.040509259
SQFTRT=0.0009582 *FC*=0 *E*=10 *RNTCNT*=1216.5 *MTC*=0
PTC=10000 *MODMON*=300 *WATT*=6E¯5 *MPD*=2 *MODCST*=150
RNTINT=2317

COST PER BIT PLOT FOR AMPEX TERABIT SYSTEM

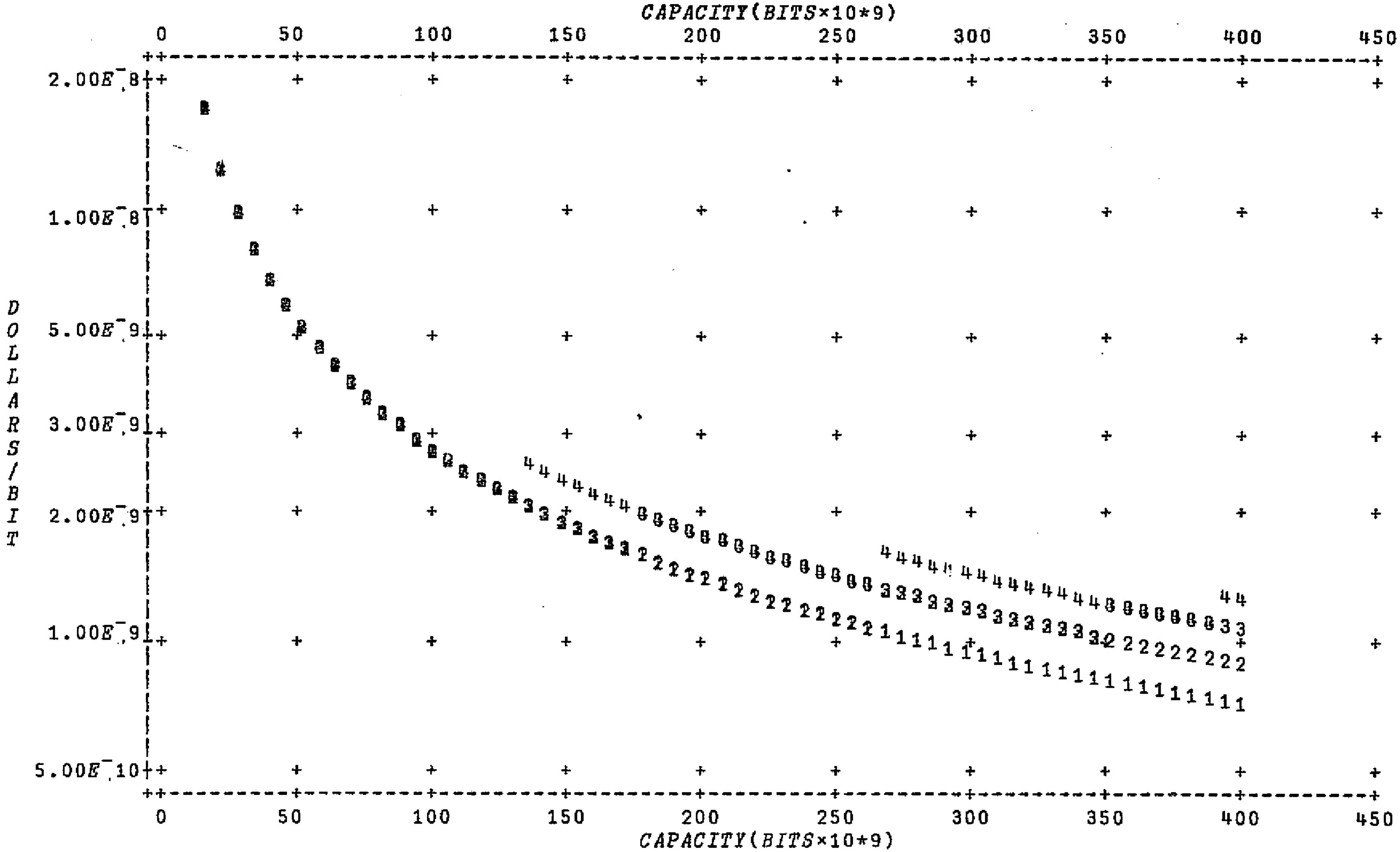


PREPARED BY AERO. FORD-HOUSTON

PARAMETERS

OBUR=1 *OSAL=4.81 ONUM=0 SHIFT=3 RNTDR=708.33
DTC=0 CIC=0 SMAIN=0 MC=0 DWATT=0
CWATT=0 CNTSQF=0 DRSQF=0 MTBF=1000 MTTR=1.05
AVGAC=15.4 MODBIT=4.532E10 DPC=32 CUFTMD=0
SQFTRT=0.0009582 FC=0 E=10 RNTCNT=1216.5 MTC=0
PTC=0 MODMON=300 WATT=6E¯5 MPD=2 MODCST=150
RNTINT=2317

COST PER BIT PLOT FOR CDC 38500 MASS STORAGE SYSTEM



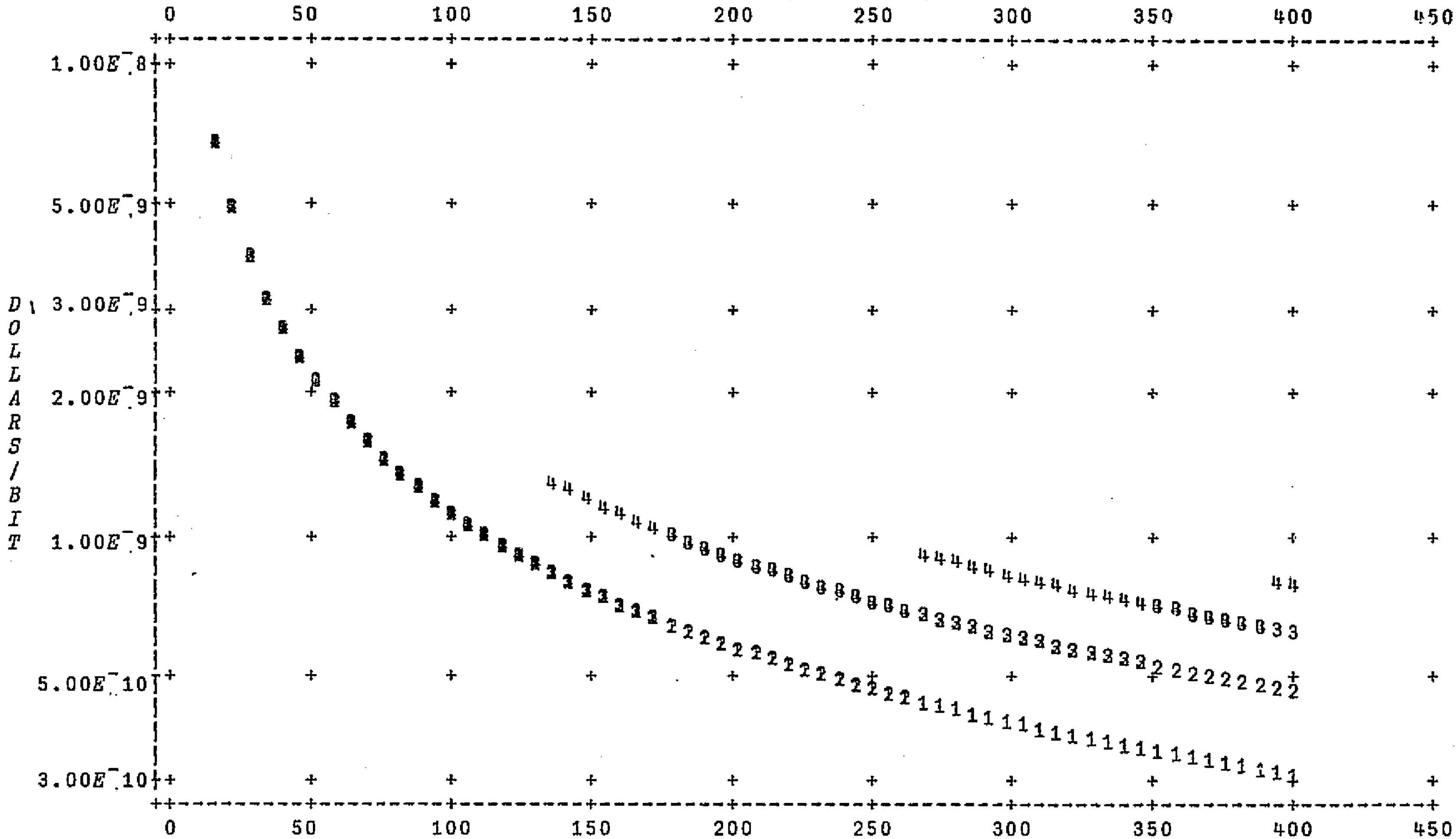
PREPARED BY AERO. FORD-HOUSTON

PARAMETERS

OBUR=1 OSAL=4.81 ONUM=1 SHIFT=3 RNTDR=2150
DIC=0 CIC=3300 SMAIN=3000 MC=0 DWATT=5700
CWATT=7200 CNTSQF=11 DRSQF=29.75 MTBF=1000 MTTR=1.05
AVGAC=8.55 MODBIT=64000000 DPC=1 CUFTMD=0.0026041667
SQFTRT=0.0009582 FC=0 E=10 RNTCNT=1150 MTC=0
PTC=10000 MODMON=300 WATT=6E¯5 MPD=2052 MODCST=15
RNTINT=2317

COST PER BIT PLOT FOR CDC 38500 MASS STORAGE SYSTEM

CAPACITY(BITS×10*9)



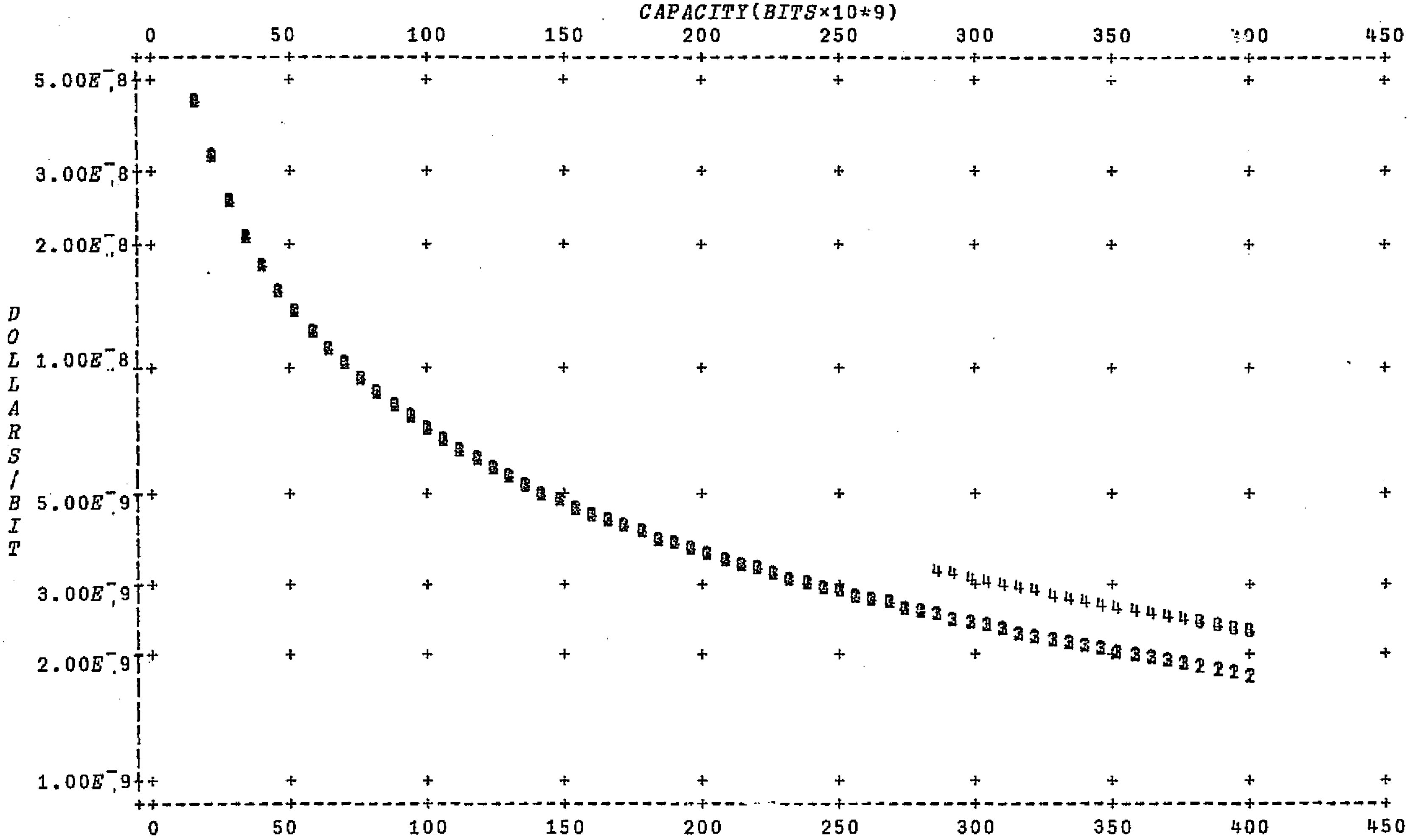
CAPACITY(BITS×10*9)

PREPARED BY AERO. FORD-HOUSTON

PARAMETERS

OBUR=1 OSAL=4.81 ONUM=0 SHIFT=3 RNTDR=2150
DIC=0 CIC=0 SMAIN=0 MC=0 DWATT=0
CWATT=0 CNTSQF=0 DRSQF=0 MTBF=1000 MTTR=1.05
AVGAC=8.55 MODBIT=64000000 DPC=1 CUFTMD=0
SQFTRT=0.0009582 FC=0 E=10 RNTCNT=1150 MTC=0
PTC=0 MODMON=300 WATT=6E¯5 MPD=2052 MODCST=15
RNTINT=2317

COST PER BIT PLOT FOR IBM 3850 MASS STORAGE SYSTEM

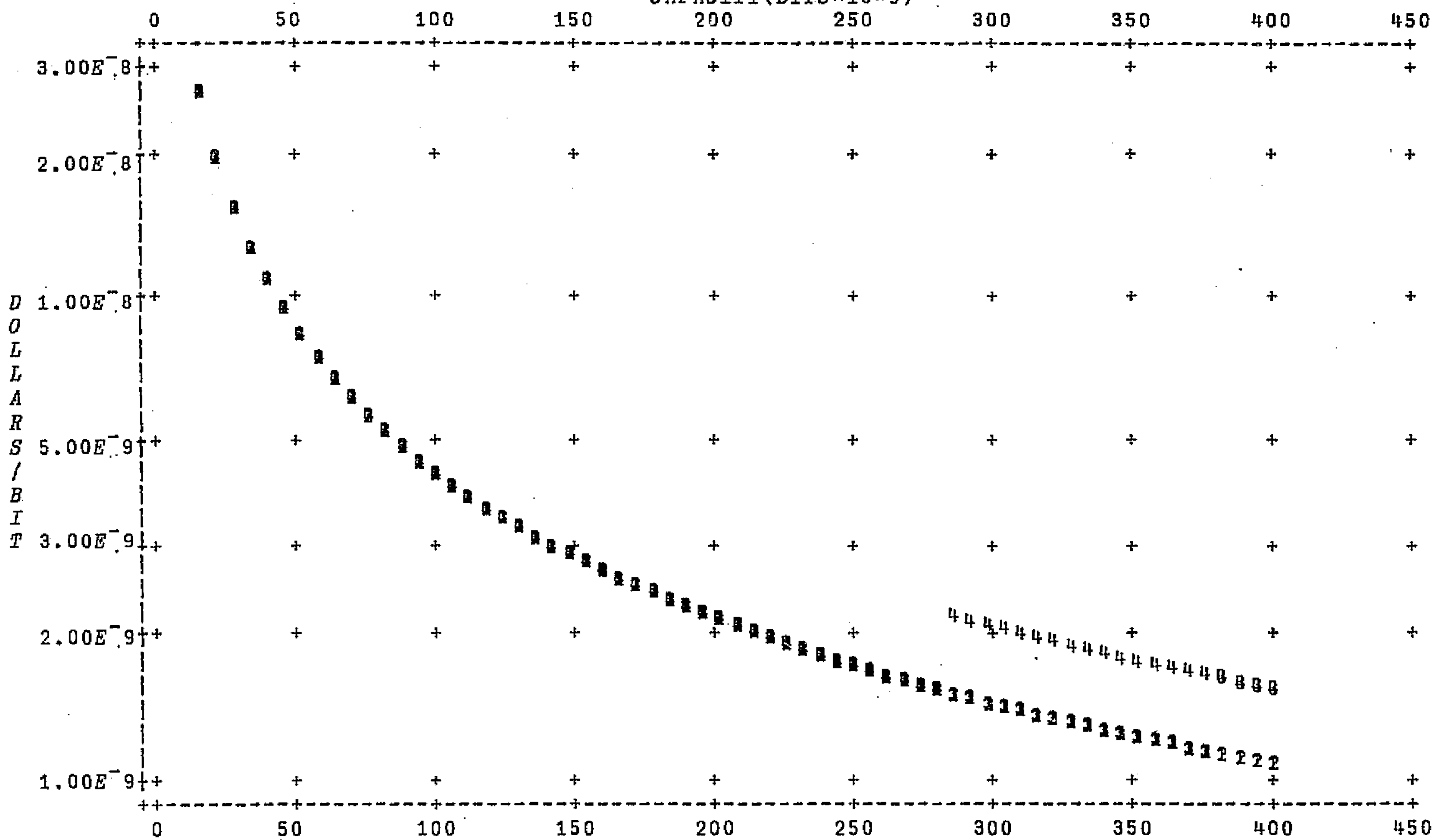


PREPARED BY AERO. FORD-HOUSTON

PARAMETERS

OBUR=1 *OSAL*=4.81 *ONUM*=1 *SHIFT*=3 *RNTDR*=4092.6
DIC=0 *CIC*=3300 *SMAIN*=3000 *MC*=0 *DWATT*=5700
CWATT=7200 *CNTSQF*=11 *DRSQF*=29.75 *MTBF*=1000 *MTTR*=1.05
AVGAC=14.8 *MODBIT*=4.032E8 *DPC*=1 *CUFTMD*=0.0072685185
SQFTRT=0.0009582 *FC*=0 *E*=10 *RNTCNT*=1560.3 *MTC*=0
PTC=10000 *MODMON*=300 *WATT*=6E¯5 *MPD*=706 *MODCST*=20
RNTINT=7220

COST PER BIT PLOT FOR IBM 3850 MASS STORAGE SYSTEM

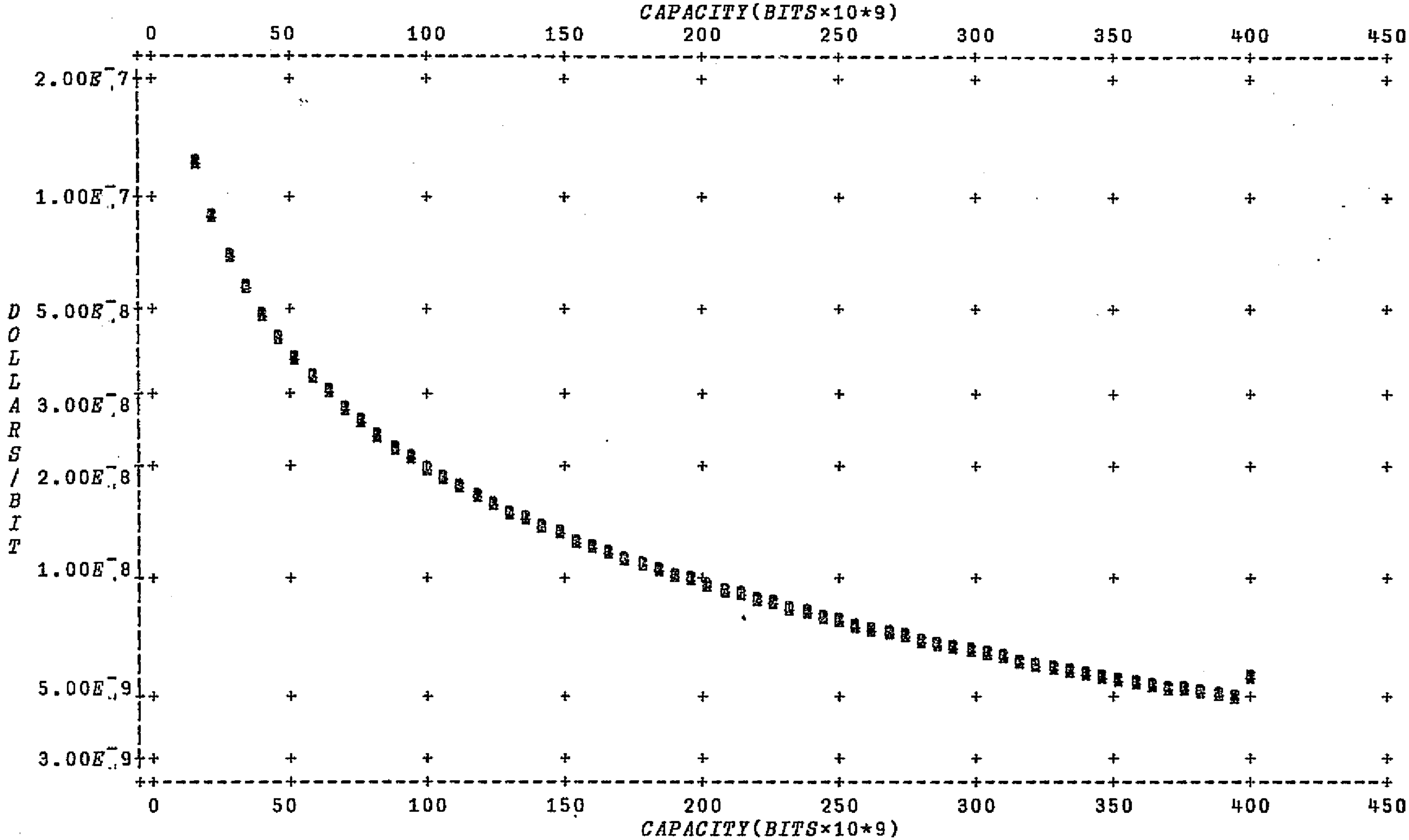


PREPARED BY AERO. FORD-HOUSTON

PARAMETERS

OBUR=1 OSAL=4.81 ONUM=0 SHIFT=3 RNTDR=4092.6
DIC=0 CIC=0 SMAIN=0 MC=0 DWATT=0
CWATT=0 CNTSQF=0 DRSQF=0 MTBF=1000 MTTR=1.05
AVGAC=14.8 MODBIT=4.032E8 DPC=1 CUFTMD=0.0072685185
SQFTRT=0.0009582 FC=0 E=10 RNTCNT=1560.3 MTC=0
RNTINT=7220

COST PER BIT PLOT FOR CALCOMP ATL WITH 6250 B.P.I. TAPE DRIVES

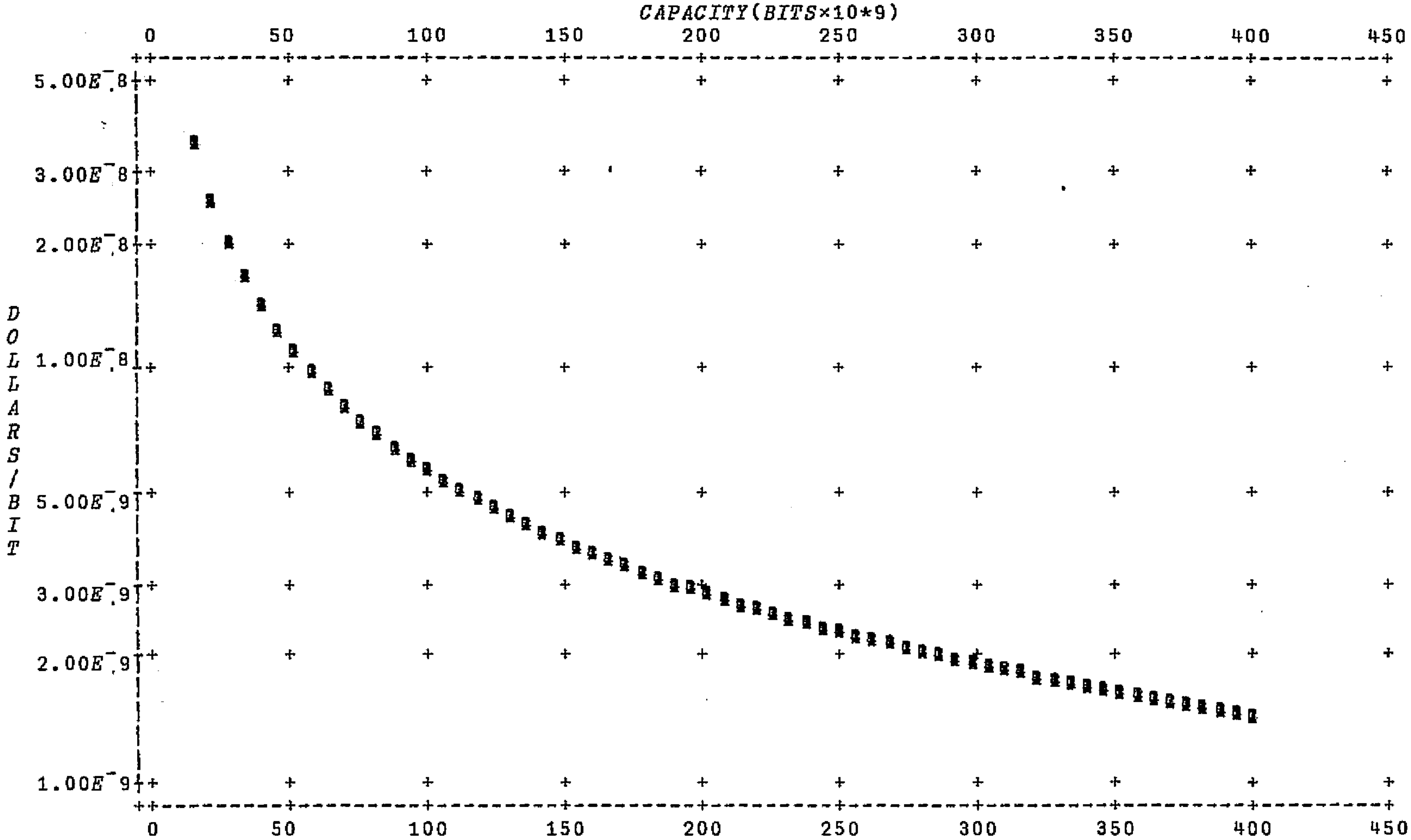


PREPARED BY AERO. FORD-HOUSTON

PARAMETERS

OBUR=1 *OSAL*=4.81 *JNUM*=1 *SHIFT*=3 *RNTDR*=328.65
DIC=0 *CIC*=3300 *SMAIN*=3000 *MC*=0 *DWATT*=2750
CWATT=12480 *CNTSQF*=29.5 *DRSQF*=6.25 *MTBF*=1000 *MTTR*=1.05
AVGAC=63.2 *MODBIT*=1.8E9 *DPC*=32 *CUFTMD*=0.024884259
SQFTRT=0.0009582 *FC*=0 *E*=10 *RNTCNT*=646.4 *MTC*=0
PTC=10000 *MODMON*=300 *WATT*=6E¯5 *MPD*=1 *MODCST*=30
RNTINT=2317 *NODR*=2

COST PER BIT PLOT FOR CALCOMP ATL WITH 6250 B.P.I. TAPE DRIVES

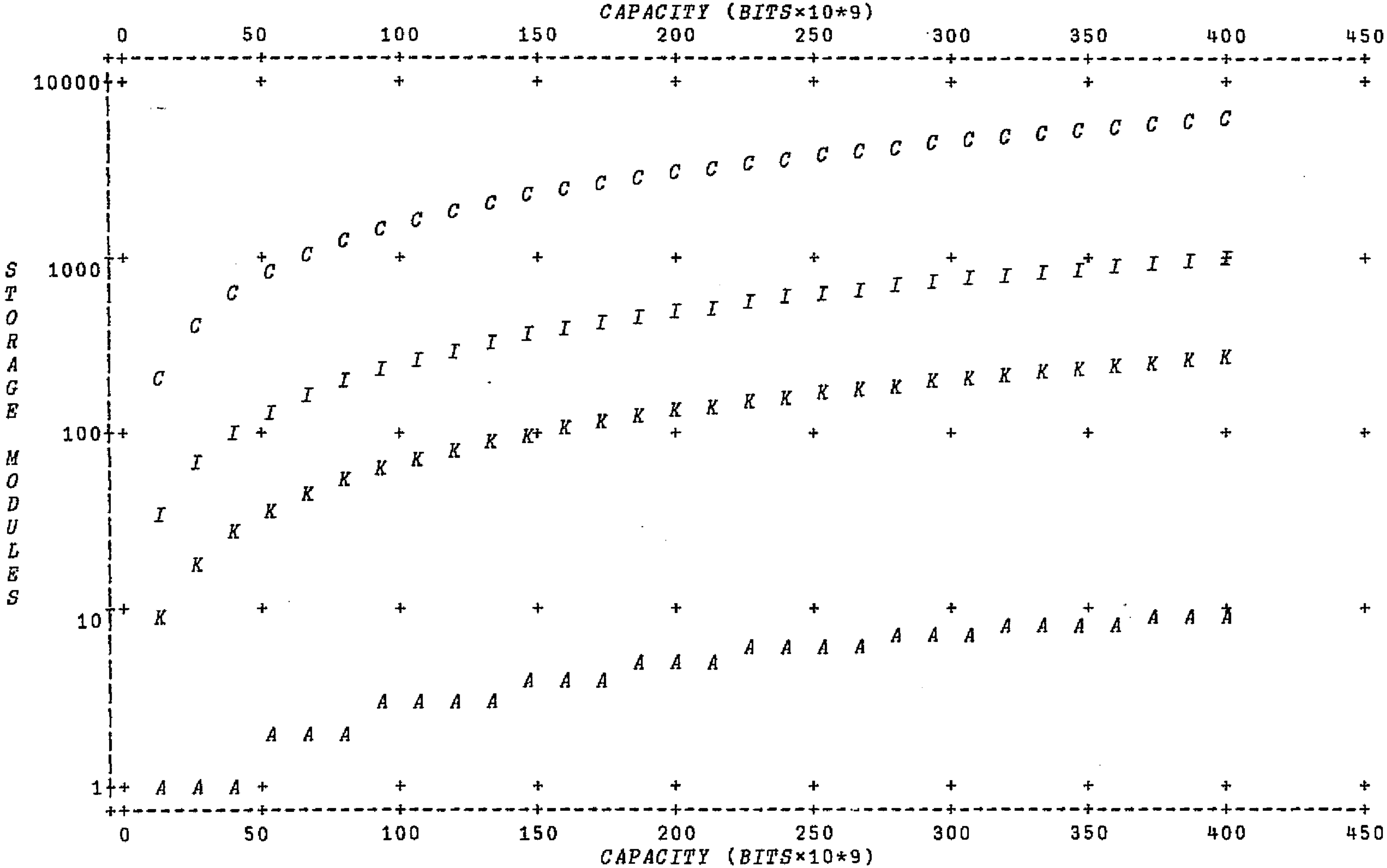


PREPARED BY AERO. FORD-HOUSTON

PARAMETERS

OBUR=1 OSAL=4.81 ONUM=0 SHIFT=3 RNTDR=328.65
DIC=0 CIC=0 SMAIN=0 MC=0 DWATT=0
CWATT=0 CNTSQF=0 DRSQF=0 MTBF=1000 MTTR=1.05
AVGAC=63.2 MODBIT=1.8E9 DPC=32 CUFTMD=0
SQFTRT=0.0009582 FC=0 E=10 RNTCNT=646.4 MTC=0
PTC=0 MODMON=300 WATT=6E¯5 MPD=1 MODCST=30
RNTINT=2317 NODR=2

NUMBER OF STORAGE MODULES REQUIRED

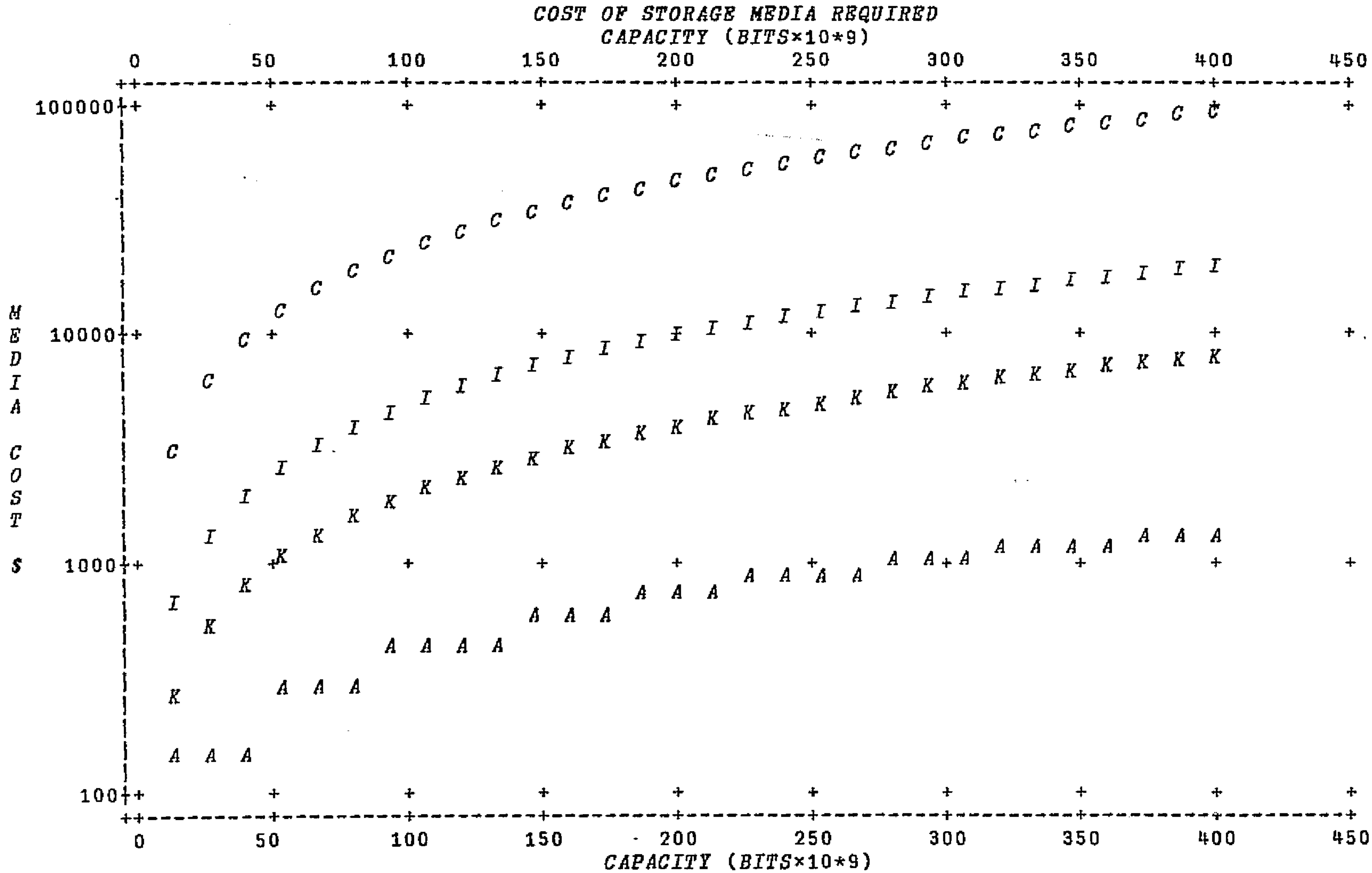


LEGEND: A-AMPEX C-CDC I-IBM K-CALCOMP

PARAMETERS

MCAL=30 VCAL=1500000000 MIBM=20 VIBM=403200000 MCDC=15 VCDC=64000000

MAMP=150 VAMP=4.532E10



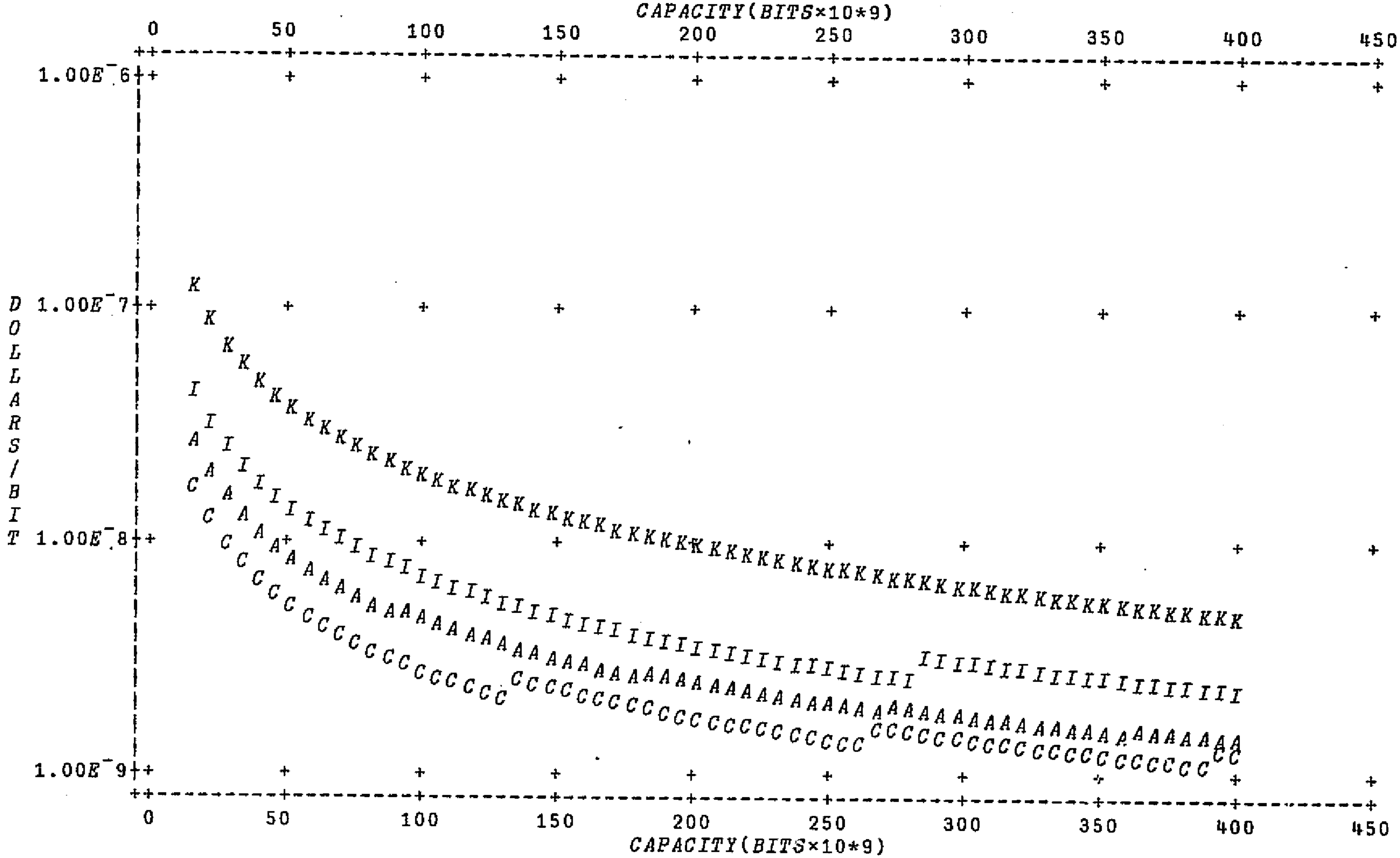
<u>LEGEND</u>: A-AMPEX C-CDC I-IBM K-CALCOMP

<u>PARAMETERS</u>

MCAL=30 VCAL=1500000000 MIBM=20 VIBM=403200000 MCDC=15 VCDC=64000000

MAMP=150 VAMP=4.532E10

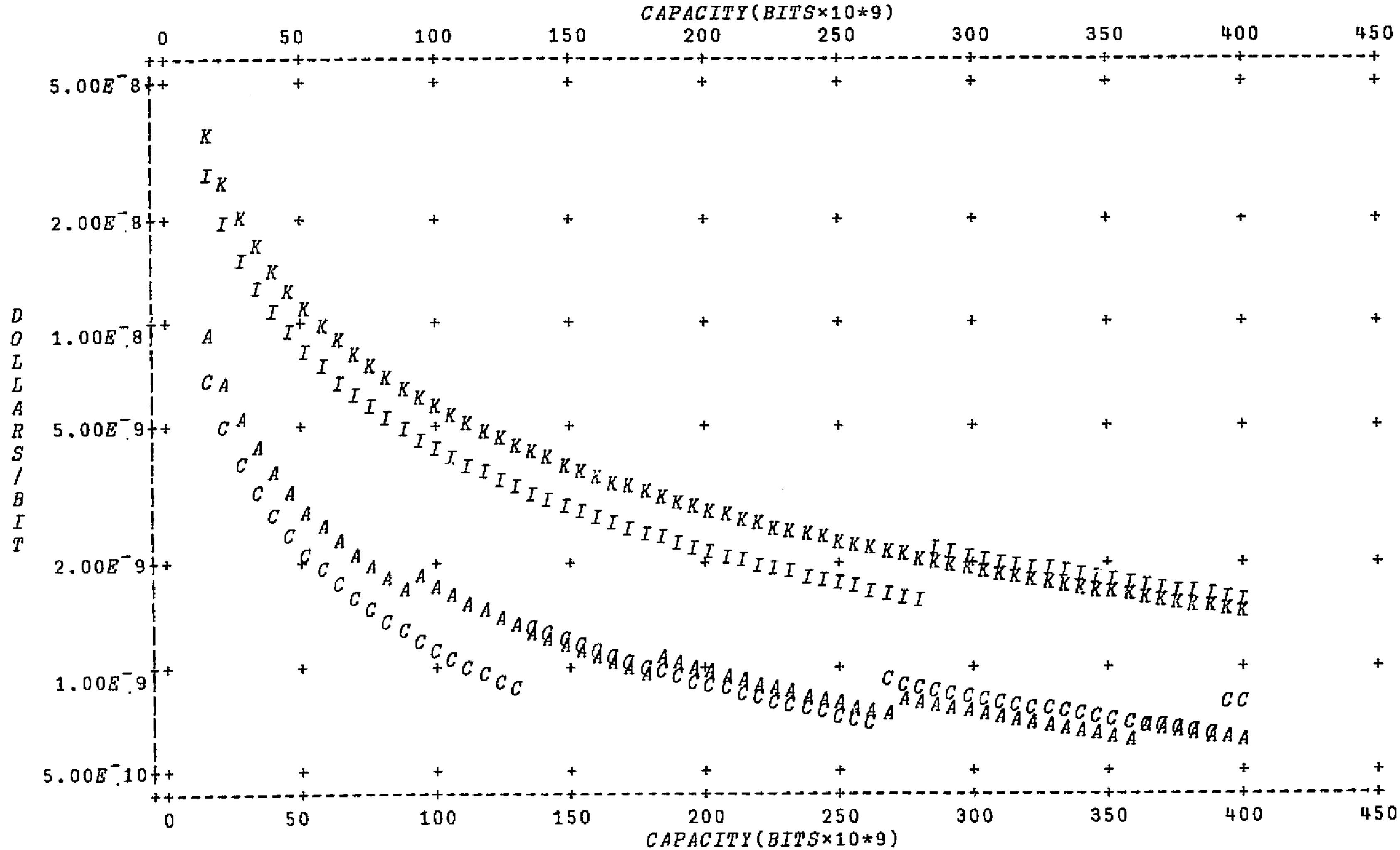
COST PER BIT COMPOSITE PLOT FOR CANDIDATE MSS SYSTEMS



PREPARED BY AERO. FORD-HOUSTON

<u>LEGEND</u>:A-AMPEX C-CDC38500 I-IBM3850 K-CALCOMP
****NOTE:OVERHEAD COSTS INCLUDED*

COST PER BIT COMPOSITE PLOT FOR CANDIDATE MSS SYSTEMS



PREPARED BY AERO. FORD-HOUSTON

<u>LEGEND</u>:A-AMPEX C-CDC38500 I-IBM3850 K-CALCOMP

***NOTE:OVERHEAD COSTS NOT INCLUDED