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Terminal Information Processing System (TIPS) Consolidated CAB Display (CCD) Comparative Analysis

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Loni Czekalski

April 1982

Final Report

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16. Abstract

The Terminal Information Processing System (TIPS) and the Consolidated Cab Display (CCD) were analyzed in terms of air traffic control (ATC) requirements, system engineering, conceptual differences and similarities, central processors, software, and central processing system cost. In broad terms, this report outlines the ATC users requirements, what the Federal Aviation Administration (FAA) requested in specification form, vendor responses to the specifications and the recommendation to include flight data management in the CCD System.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

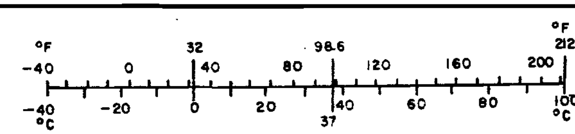


TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose	1
Background	1
AIR TRAFFIC CONTROL (ATC) SYSTEM REQUIREMENTS	2
General	2
TIPS	3
Consolidated Cab Display (CCD)	4
Summary	4
SYSTEM CONCEPTS	5
Information Management Language	5
Reliability	5
Expandability	8
Data Display	9
Real-Time Operational Program	9
PROCESSORS	10
Bus Architecture	10
Parity	13
Memory Addressing Capability	13
Main Memory	13
Logical Memory Organization	13
Input/Output	14
SYSTEM SOFTWARE	15
General	15
TIPS Software	17
CCD Software	17
SYSTEM COST	22
TIPS	22
CCD	23
ANALYSIS	26
System Philosophy	26
Reliability	28
Systems Software	29
Expandability	29
Commercially Available/Off-The-Shelf Systems	32

TABLE OF CONTENTS (Continued)

	Page
CONCLUSIONS	37
RECOMMENDATION	37
REFERENCES	38
BIBLIOGRAPHY	38
GLOSSARY	41
APPENDICES	
A — Engineering Requirement Conceptual Similarities	
B — Engineering Requirement Conceptual Differences	
C — System Processor Summary	
D — Tandem System Software	
E — Detailed Tandem System Cost	

LIST OF ILLUSTRATIONS

Figure		Page
1	TIPS Design	6
2	CCD Design	7
3	Typical Fault Tolerant System	8
4	Advanced Bipolar Processor Architecture	11
5	Tandem 16 System Architecture	12
6	Tandem 16 I/O Processor Interface	14
7	CCD Recommended System Configuration	24
8	CCD Central Processing System Configuration	25
9	TIPS/CCD Configuration	40
10	CCD/TIPS Configuration	41

LIST OF TABLES

Table		Page
1	Instruction Execution Times in Microseconds	10
2	PACE Disc Operating System (DOS)	18
3	TIPS Software	19
4	Tandem Real-Time Software	20
5	CCD Applications Software	21
6	TIPS Cost	22
7	System Cost Summary	23
8	Proposed System Configuration	26
9	IBM Models 4953 and 4955 Characteristics	30

INTRODUCTION

PURPOSE.

This report compares, at the request of the System Research and Development Service (SRDS), the Terminal Information Processing System (TIPS) with the Consolidated Cab Display (CCD) System, and examines the feasibility of combining both into a single terminal data management system. It briefly outlines a history of both and then presents the basic working guidelines used in developing the specifications for TIPS and CCD. It then examines each specification, pointing out conceptual similarities and disparities between the systems. After considering what each specification required of prospective bidders, this report analyzes what the successful bidder (TIPS) intends to furnish. The report discusses proposed processor architectures, system software, the cost for hardware and system software and analyzes the interrelationship of these factors. Finally, it presents conclusions and recommendations.

In preparing this report, all of the references were carefully scrutinized. Far more documentation was available on the actual CCD hardware and system software than on the TIPS hardware and system software. Consequently, this report presents more information on CCD. Very little documentation was available on the TIPS processor. However, it is the intent of this report to highlight the areas of design and cost impact rather than attempting to devote equal time to detailing each system.

BACKGROUND.

Originally, the Acting Director of Air Traffic Service (ATS) requested that the Director of SRDS establish a program to replace flight data entry and printout (FDEP) equipment at the terminal facilities with an improved method of distributing and updating flight data. Subsequently, SRDS experimented with a variety of ways to distribute and update flight data. Then in 1979, SRDS contracted with Lockheed for two prototype terminal information processing systems, one to be installed and evaluated at a field site (probably Boston) and one to be installed and evaluated at the Federal Aviation Administration (FAA) Technical Center.

During 1976, ATS, Airway Facilities Service (AFS), and SRDS jointly embarked on a program to consolidate terminal air traffic control (ATC) and maintenance monitoring information. Subsequently, the Technical Center developed a laboratory for terminal remote maintenance monitoring and consolidating status and weather information. In 1978, the Technical Center wrote the engineering requirement for the CCD system. In mid-1979, AFS released a request for proposals (RFP) for two prototype systems. The RFP called for one system to be installed and evaluated at Boston and one at Atlanta.

In the future, flight data distribution/update and status/weather display consolidation will be provided in the terminal environment. That is to say, both the TIPS functions and the CCD functions will exist at terminal facilities. However, the proliferation of systems, each with its attendant hardware/software maintenance needs and each requiring space in the terminal facility, present compelling reasons to combine these separate systems.

AIR TRAFFIC CONTROL (ATC) SYSTEM REQUIREMENTS

GENERAL.

The FAA, as it provides increased service to en route and terminal aircraft, finds it necessary to collect and to distribute information in great quantity with even greater alacrity in the National Airspace System (NAS). Furthermore, as the FAA enters a decade of increased automation, information passed through NAS will be not only that data directly used in ATC but also that data used in monitoring the hardware/software system performance. As one facet in a unified NAS, ATS, AFS, and SRDS undertook development of two systems; one which improves flight data distribution in the terminal facilities, and one which consolidates terminal ATC and maintenance monitoring information.

Certain administrative decisions molded the form of emerging systems. The first administrative decisions constrained systems procured from 1976 onward with a zero maintenance growth policy. An AFS letter (AAF-3) dated June 9, 1976, specifically applies this policy to the remote monitoring program stating, "As you know, the director has on numerous occasions spoken of the need to implement,.... his zero maintenance growth policy. (Typically, the initial action taken in response to his concern has been the planned conversion of facilities utilizing tube-type equipment to those that will be implemented with completely solid-state equipment, thereby enhancing the reliability of the systems and correspondingly reducing the maintenance demands on our work force.)

"Another aspect of the zero maintenance growth program is the inclusion of remote monitoring in our maintenance concepts which establish how maintenance intensive each of our facilities will be — and correspondingly the cost of maintenance to the FAA.

"The inclusion of remote monitoring technique in our NAS system is long overdue and consideration should be given promptly to a total program that will carry this technique as far as feasible in the immediate future with a continuing attention to implementing it eventually through the system."

One constraint on all systems in this era of balanced budgets, Congress imposed directly by limiting funds available to all government agencies. This action required all agencies to reduce system life cycle costs.

Shortly thereafter, the Acting Administrator for Engineering and Development (E&D) strongly urged the regional directors to coordinate through the appropriate headquarters office any equipment purchase used in the ATC operational environment. Thus, eliminating one-of-a-kind equipment with attendant maintenance staffing and budget impacts. In his request, the Administrator quoted AO 1100.5, para. 222f(2): "...maintenance staffing is determined and budgeted on the basis of the national facilities and equipment program. If allowed to go unchecked, regional procurement of equipments can very soon impose significant unbudgeted maintenance load. With today's severe restrictions on Airway Facilities Service staffing, this unprogramed burden is most difficult to justify. "One-of-a-kind" equipments also result in obvious training and supply support problems.

"Order 1100.5 FAA Organization - Field, para. 222j(2), expressly prohibits regional procurement of equipment or devices to be used for air traffic control or navigation for which the specifications have not received prior headquarter's approval.

"In view of the above, regional equipment procurements are to be undertaken only in response to pressing and immediate requirements, and only after full coordination with the appropriate headquarters office or service (reference 1)."

Each of these broad constraints contributed significantly in molding the form of both terminal control systems.

TIPS.

On August 29, 1973, the Acting Director of ATS, requested the Director of SRDS, to initiate a program to replace the FDEP equipment at terminal facilities with an improved flight data distribution method. At that time, ATS imposed some system requirements. The improved system was required to:

1. Minimize controller input/output (I/O), transfer actions. Individually, these actions may not exceed the actions required in the present manual system for the same function.

2. Present data consistent with terminal procedures. Make no unusual demands on controllers.

3. Present legible data at normal viewing distances.

4. Selectively pass only required data to the particular position, although a position may also call up a full flight plan.

5. Rearrange, add, delete, and modify presented data.

6. Display data in most usable format on either radar display, digital display, or on both.

7. Accommodate displays and keyboard in available space.

8. Have display and keyboard equipment designed for easy accessibility.

9. Permit flexibility in combining and decombining operational positions.

10. Expand modularly to accommodate future growth.

11. Provide fail-safe/fail-soft operation at proposed enhanced Automated Radar Terminal System (ARTS) III sites. For other locations, the system must, in the event of system failure, retain the last screen image presented to the controller.

12. Record and store data for future reference.

13. Collect and compile statistical information on system performance.

14. Communicate with adjacent ARTS III.

15. Communicate with NAS and Central Computer Complex (CCC).

CONSOLIDATED CAB DISPLAY (CCD).

The original CCD requirements came from a regional meeting of the Air Traffic Plans and Program Branches, AFS, SRDS, and the Technical Center in September 1976. Additional requirements were imposed on the system design in June 1977, and again later in April 1978. These systems requirements were:

1. Use of off-the-shelf components.

2. Turn-key installation.

3. The ability to display static weather sequence data and status board information at the respective controller positions.

4. Remote input from satellite terminals.

5. Flashing/blinking lines/words, to signal alerts.

6. The ability to record data.

7. Master consoles.

8. Slave consoles.

9. Formatting and informational flexibility.

10. Consolidated display which shows critical information at all times.

11. Time-shared display for information used infrequently.

12. Modular central processing with interfaces for adding central processors for processing more information.

13. Remote or local maintenance and control displays which allow input/query, control and certification.

14. Equipment to be monitored of primary concern and discretionary concern.

15. Fail-safe functional availability for single component failures.

16. Informational requirements for each control position.

Together, all these requirements defined a framework within which the Technical Center created a consolidated display system design.

SUMMARY.

In a broad sense, ATS requested a fail-safe data base management system for both the TIPS and for the CCD system. Specifically, the data displays for both TIPS and CCD were to be legible, easily accessible for operational use and for maintenance, and must fit into the available space. Furthermore, both systems had to either reduce the controller workload or at least keep it constant. In no case would either system impose additional workload on the controller. The TIPS and CCD should present operational information so that the presentation is readily changeable. Air Traffic Service required recording historical and statistical performance data for both systems. Finally, both systems had to be modular and flexible to accommodate future growth.

SYSTEM CONCEPTS

Conceptually, TIPS and CCD are data management systems. Both systems address different functions but both remain management systems. Each specification requires the hardware and software to be modular, flexible, expandable, and reliable. Each specification requires off-the-shelf equipment and a similar maintenance policy. These systems differ in methods of achieving those goals, that is to say, they differ in where and how those qualities of modularity, flexibility, expandability, and reliability are placed in the system. This section addresses five concepts having major design impact. They are:

1. Information Management Language
2. Reliability
3. Expandability
4. Data Display
5. Real-Time Operational Program

The remaining divergent concepts (summarized in appendix A) do not impact the design nearly as much as these five. Appendix B summarizes the conceptual similarities.

INFORMATION MANAGEMENT LANGUAGE.

Placement of software flexibility is one area where these systems diverge. Each specification calls for modular, expandable, efficient, and flexible software. However, CCD takes these requirements one step further, placing them not only on the software design but also on the user, man-machine interface. In essence, it requires the data definition language to be a translator rather than a compiler level language with final translator output being single linked tables to the data base. It also requires that I/O formatting capability be coupled with that translator. The combination of I/O formatting and data definition provides a software system in which only algorithms need programming.

RELIABILITY.

Another facet in which TIPS and CCD diverge is reliability. The TIPS has a mean time between failure (MTBF) requirement of 500 hours. The CCD system on the other hand, must be fail-safe with no data loss for single component failures.

This disparity in requirements allowed two distinct system architectures to evolve. Figure 1 shows the TIPS design. Figure 2 shows the CCD design.

Each service, SRDS and AFS, had a good rationale for choosing their particular reliability goal.

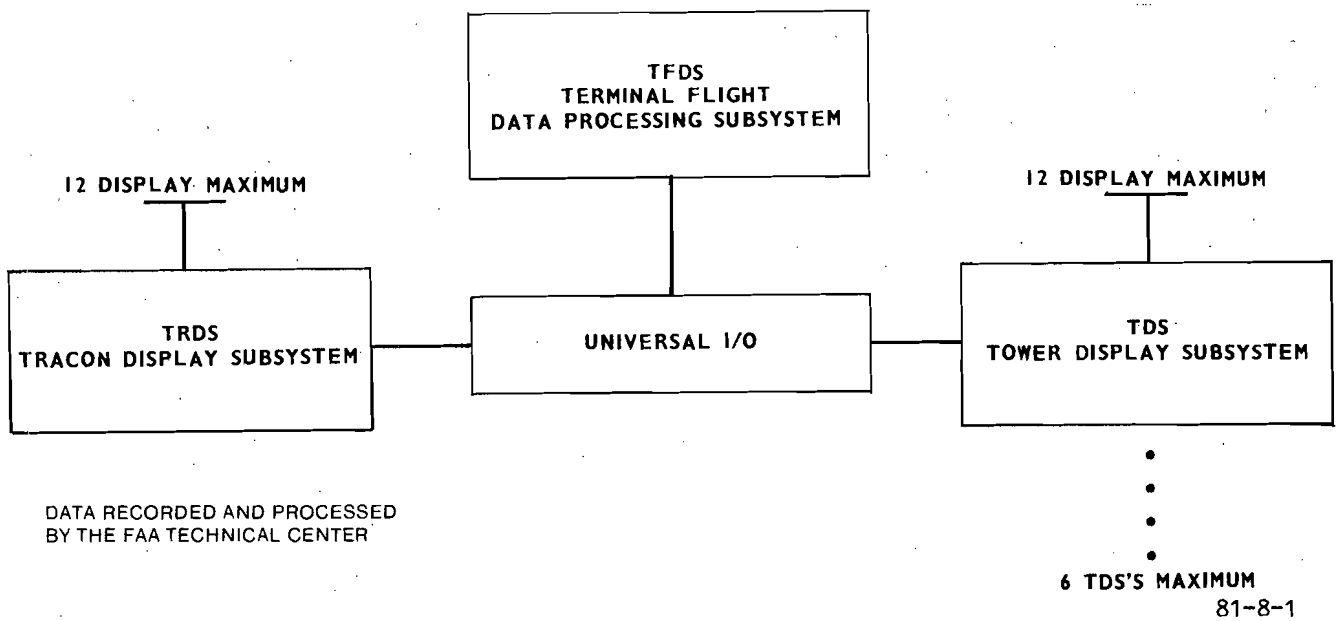


FIGURE 1. TIPS DESIGN

In TIPS, SRDS wanted to develop a prototype to prove the system concept first. Later, after the concept proved acceptable, SRDS would add a fail-safe requirement. The specification carefully reminded any prospective contractor to keep a future fail-safe requirement in mind while designing the initial system.

Most systems, developed in this manner, add a bus switch and a standby redundant computer to make the system fail-safe. However, many single point failures still can degrade system operation. Figure 3 shows this general fault-tolerant system architecture.

In CCD, the AFS/SRDS specifications stated that any system design must be fail-safe with no data loss for single component failures. Originally, AFS/ATS required fail-safeness, because both prototype systems are to continue operation at the field sites after evaluation. This allowed CCD bidders the opportunity to choose an off-the-shelf, fault-tolerant architecture at the start of system design rather than attempting to add it later as an afterthought.

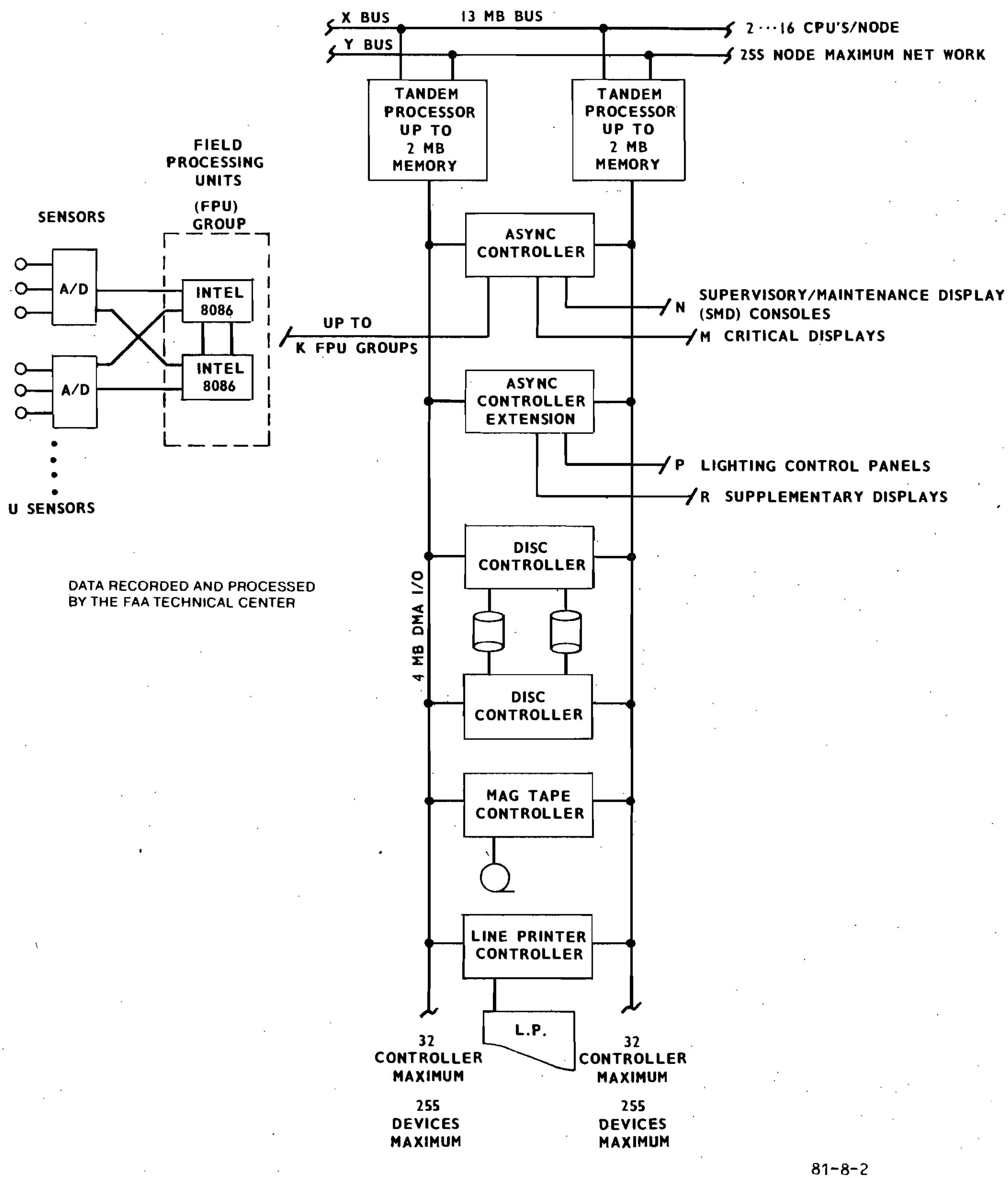


FIGURE 2. CCD DESIGN

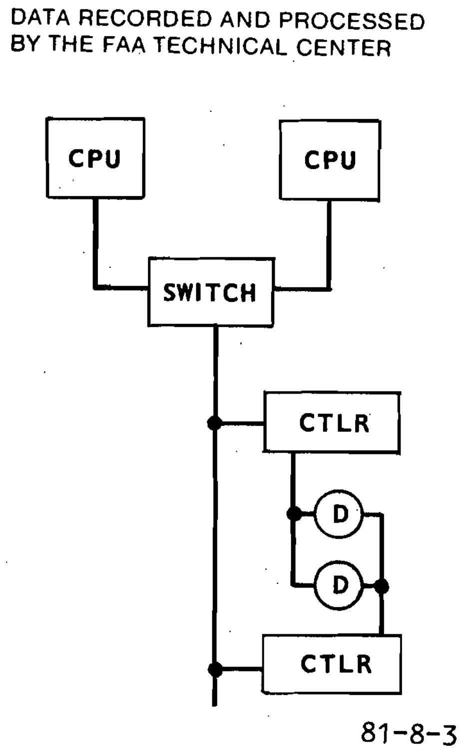


FIGURE 3. TYPICAL FAULT TOLERANT SYSTEM

EXPANDABILITY.

The system expandability requirements for TIPS and CCD differ greatly. The TIPS specification approaches expandability in a very traditional manner, defining maximum numbers for: tower display systems (TDS), terminal flight data processor (TFDP) interfaces, TDS I/O channels, and TDS displays. It further defined a maximum memory capability percent increase and maximum disc storage capacity percent increase. The CCD specification used a somewhat less conventional approach to system expansion. It specified a percent limit for central processing in the phase I design while it deliberately omitted maximum numbers for displays or field processing units. The foreword cautioned that the engineering requirement was prepared in parts, allowing the FAA to procure and implement CCD in stages. The parts to be provided for each phase were to be specified in the contract. The specification went on to identify processors, peripherals, displays, and one field processing unit for tower subsystem interface as phase I contract deliverables. It required the phase I design to include provisions for monitoring remote transmitter/receiver, instrument landing system and lighting/runway visual range subsystems. The specification further required the initial CCD design to include the capability to expand the system data acquisition functions and processing capability beyond what was originally described in the various parts of the specification.

DATA DISPLAY.

This section addresses the methods of information display used in TIPS and CCD While these systems approach data display from distinctly different philosophies, it helps to remember that both systems were developed in response to differing information needs. So, in some measure, one expects variety in information displayed and the method used.

TIPS. TIPS supplied one fixed format paged cathode-ray tube (CRT) at each control position. On these displays, the screen is divided in regions for lists, quick action, preview, readout response, and status-weather. Data entry is accomplished basically with menu select touch entry. Paging allows presentation of data when the number of table entries exceeds the capacity of the display matrix. It should be noted that page formats are all fixed, so that format changes require programmer assistance.

CCD. The CCD supplies two displays at a control position: (1) a fixed format, continuous incandescent display, and (2) a 12-page flexible format CRT.

The Transportation System Center (TSC) and the Technical Center analyzed CCD requirements for individual control positions. Both groups concluded that controllers need certain information present at all times. Other information may be available to controllers on a time-shared basis. Therefore, CCD provides the fixed format display and the flexible format display. This flexible format display resolves some human factor problems because it permits controllers to display required information in a manner most amenable to themselves. Then, at any time, if they discover they absolutely cannot work with information presented in a certain format, they can change the data presentation to a more useful format without programmer assistance. Also, if they discover they require more information than originally anticipated, then as long as those data are available to them from some source and needs no algorithmic transformation, they may expand the data base to include that new information. Information may be deleted from the system just as easily. The intent was to enable the user to easily change, add, and/or delete data without programmer intervention. The mechanism to control information rests more with the user in the CCD system.

REAL-TIME OPERATIONAL PROGRAM.

The last area of divergence is real-time operation program content. The TIPS operational program consists of an executive, a message switch, flight data application programs, and I/O drivers. The CCD operational program consists of a fail-safe executive operating system, data base manager, communications manager, CCD applications programs, system performance monitor, diagnostics, program development and data reduction and analysis software.

The question is, Should all those functions occur concurrently in real-time? Might it not be better to limit on-line, real-time functions to only those found in the TIPS operational program and perform the remaining functions off-line?

There is an advantage in allowing all the CCD operational functions to occur concurrently. Concurrent executions of all those functions exercise most logic continually in each machine. That is the best diagnostic to run on any machine.

Therefore, the supervisor always knows the status of each component in the system. This technique removes the anxiety involved with switching processors in the event of a failure.

Executing all those functions concurrently has a human benefit, too. No one waits to be serviced since data base query, trend analysis, alarm processing, system performance monitoring, etc., all execute concurrently. From a human view, it is much better to have an answer to a question when you want it and not need to schedule system time to obtain that answer.

PROCESSORS

Appendix 3 summarizes significant features of both the Lockheed Advanced Bipolar Processor (ABP) and the Tandem T16 Processor. Table 1 furnishes the raw computing speeds of both processors.

TABLE 1. INSTRUCTION EXECUTION TIMES IN MICROSECONDS

	Lockheed ABP	Tandem T16
Load	1.8	1.4
Store	1.8	1.1
Add	1.1	0.5
Subtract	1.8	0.5
Multiply	17.8	3.4
Divide	21.6	3.1
Compare	1.4 to 2.8	0.5
Branch	1.4	0.0 to 1.7

There are many areas in which the processors differ. Of these areas, six represent major design departures; the remainder are design implementation differences. Each major design departure will be considered individually in this section.

BUS ARCHITECTURE.

Of the six areas in which the processors differ, bus architecture represents probably the most noteworthy difference. Figure 4 shows the ABP's single bus structure. Figure 5 shows the T16's multiple bus structure.

The ABP's structure permits bus contention to develop quite quickly even with a bus transfer rate of 2MB. In designing the instruction set, Lockheed recognized the likelihood of bus contention or a time-consuming instruction tying up the bus. Therefore, the move, search, block input, and block output instructions were redesigned to be interruptable after each word. At that time, the ABP services interrupts, then returns to the instruction, continuing where it left off.

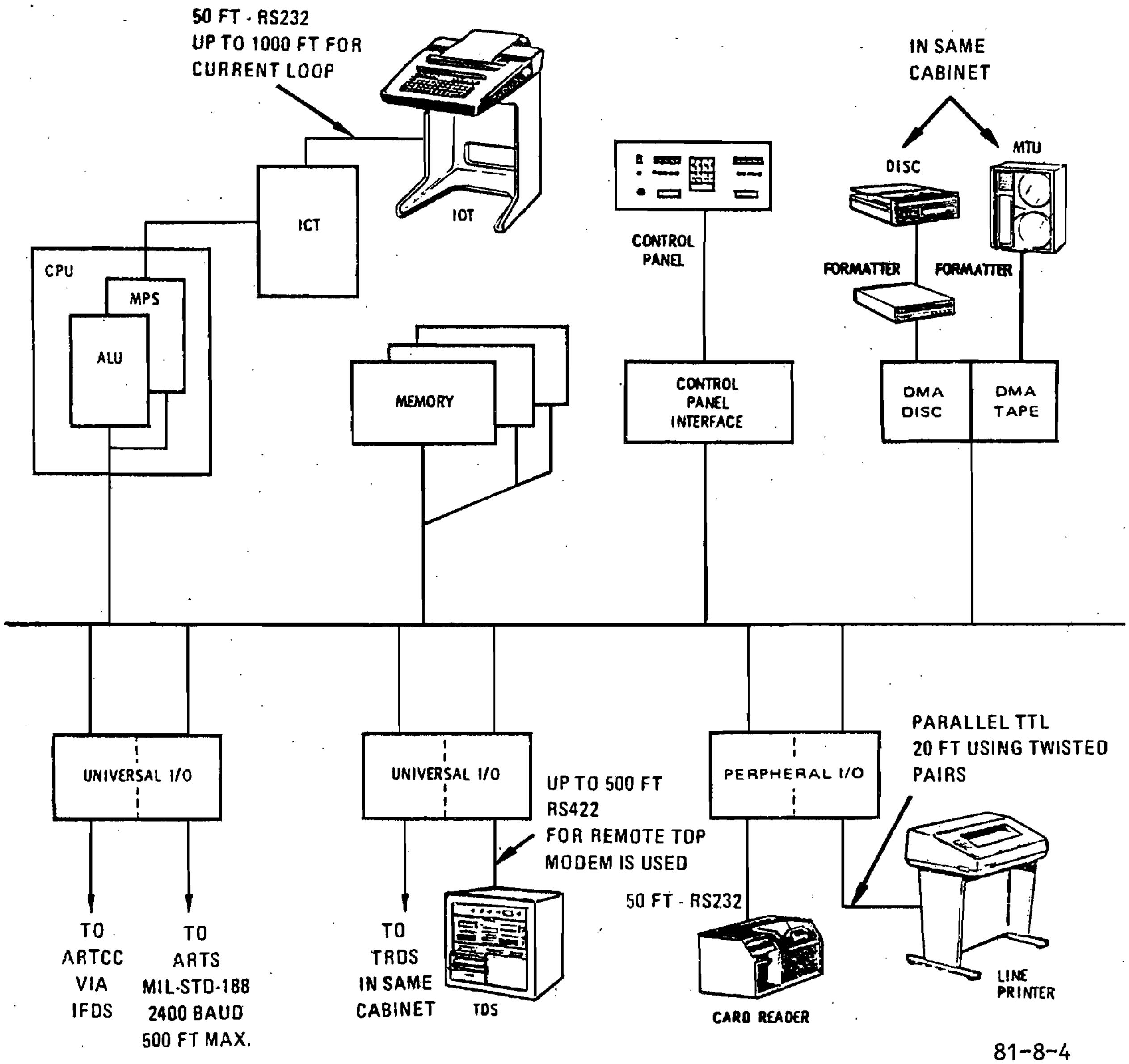


FIGURE 4. ADVANCED BIPOLAR PROCESSOR ARCHITECTURE

DATA RECORDED AND PROCESSED
BY THE FAA TECHNICAL CENTER

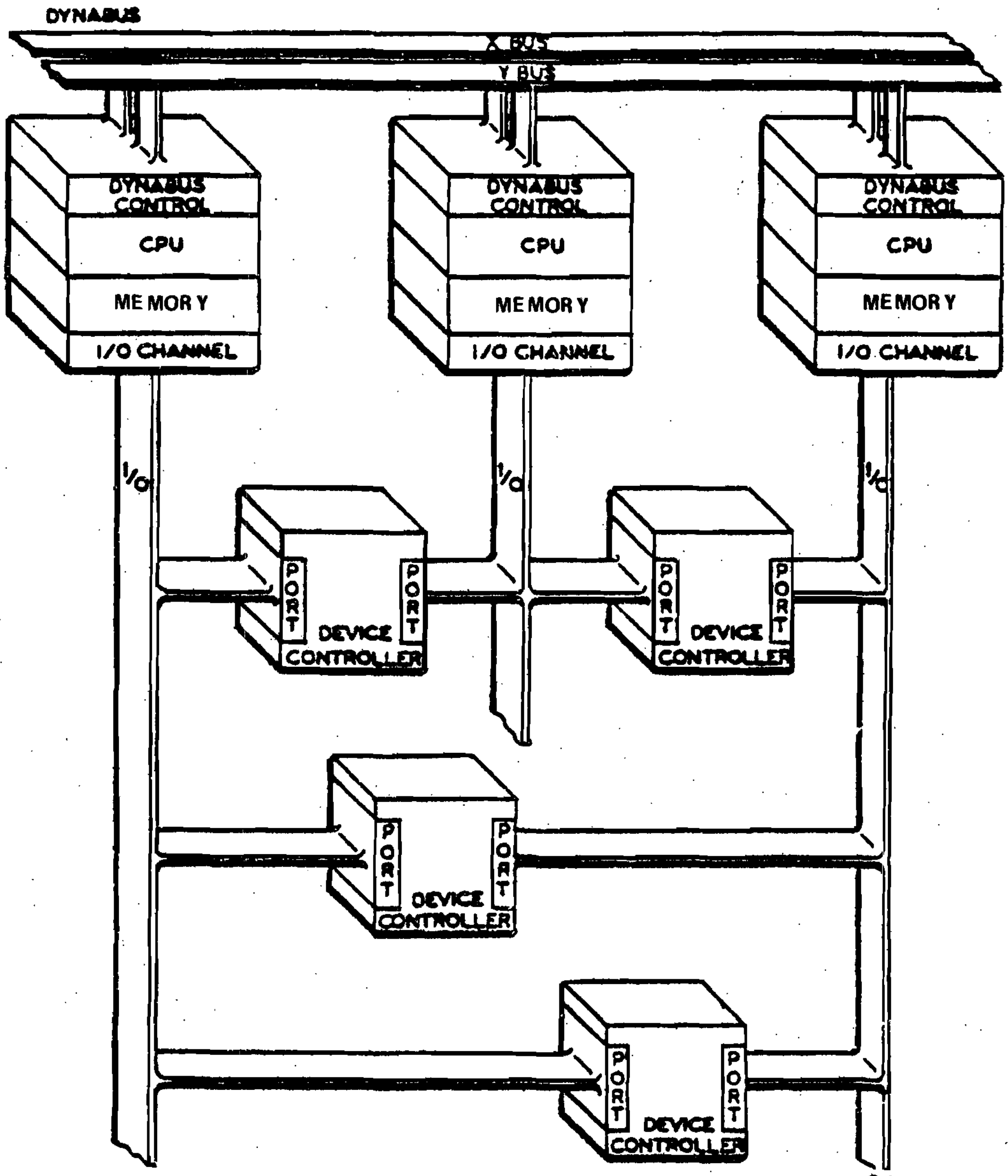


FIGURE 5. TANDEM 16 SYSTEM ARCHITECTURE

One more note on bus contention. If, in the future, FAA adds more processors to provide fail-safeness, these processors will be added to the main address/data bus. Two control signals then handle system bus sharing. Therefore, while adding processing capability to the system, the single bus architecture diminishes the effective processing time by creating bus contention.

As can be seen in figure 5, the T16 uses a multiple bus structure. There are two interprocessor buses which operate at 13MB/second (sec) each and a peripheral bus which operates at 4MB/sec. Interprocessor buses interface to three high-speed cache memories: an incoming queue for each interprocessor bus and a single outgoing queue switchable to either interprocessor bus. All caches are 16 words long, and all interprocessor messages occur in 16-word packets; therefore, all interprocessor transfers are cache-to-cache. Each processor may also send and receive simultaneously.

This multiple bus structure permits the processor to communicate as a member in a distributed processing node while simultaneously communicating with its own peripheral devices and users.

PARITY.

The second area in which the processors differ is memory error detection. The ABP detects single-bit error. The T16's 6-bit error correcting code corrects all single-bit error, detects all double-bit errors and most multiple-bit errors.

MEMORY ADDRESSING CAPABILITY.

The third area in which the processors differ is memory addressing capability. Lockheed's ABP directly accesses 65,536 memory locations. Four software controlled external flags allow bank-switched access to 262,144 memory locations; i.e., 512KB. Tandem's T16 processor uses a virtual addressing technique. Memory is logically divided into four virtual address spaces. Each space is addressed by a 16-bit virtual address. A memory mapping scheme then converts this 16-bit virtual address to a 20-bit physical memory address. Main physical memory may vary in size up to 2MB. Disc storage space limits the virtual memory size.

MAIN MEMORY.

The fourth area in which the processors differ, is memory. While both use metal oxide semiconductor (MOS) memory, the ABP 512KB memory may use a combination of read only memory (ROM), random access memory (RAM), programmable read only memory (PROM) with some qualification.

The ABP memory board contains 8,192 16-bit words arranged in 8 1024-word segments. These eight segments may be any combination of ROM, RAM, or PROM. The T16 memory is 8KB ROM with the remainder of 2MB being RAM.

LOGICAL MEMORY ORGANIZATION.

The fifth area of difference is the logical organization of memory. Memory in the ABP may be all program and data memory in any combination of ROM, RAM, or PROM. The user decides the division of memory during the program design phase considering the constraints imposed by the disc operating system, diagnostics, etc. However, in the T16, memory is logically divided into four address virtual spaces. These four address spaces are: (1) system code, (2) system data, (3) user code, and (4) user data. Code space is unmodifiable. Therefore, this unmodifiable code space inherently insures reentrant, recursive, and sharable code. Data space may be viewed as stack space or random access memory.

INPUT/OUTPUT.

The sixth area of difference is I/O. Three controllers provide all the ABP's I/O control for (1) serial data transfer, (2) peripheral interface, and (3) direct memory access. Each of these three controllers interface to the main data bus as does the memory, the Central Processing Unit (CPU), and the control panel. The maximum data transfer rate is 2MB. In the T16 processor, all I/O is direct memory access. The peripheral I/O channel is microprogrammed and block multiplexed. Individual controllers determine the block size. All controllers are buffered so that each data transfer occurs at a 4MB rate. Figure 6 shows the T16 I/O channel/processor module interface.

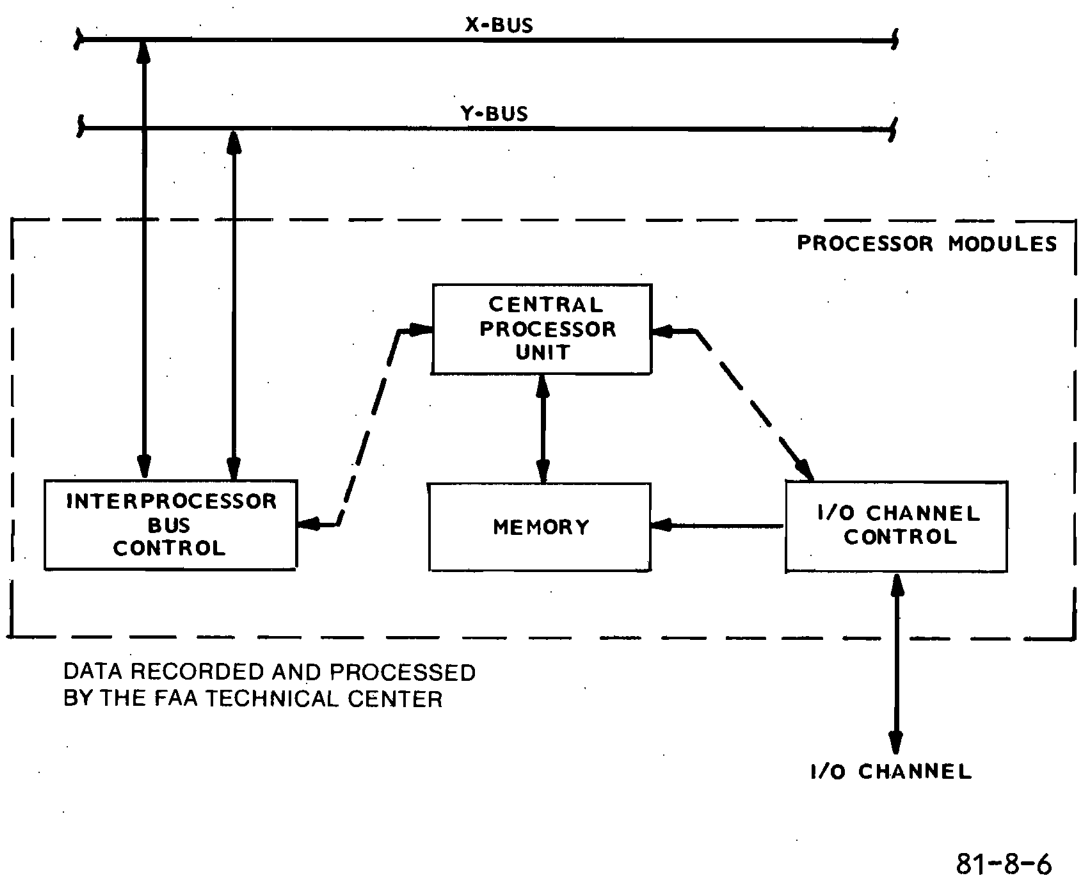


FIGURE 6. TANDEM 16 I/O PROCESSOR INTERFACE

SYSTEM SOFTWARE

GENERAL.

"Software design, development, and testing is the most highly labor-intensive component of computer systems, with software development costs now nearly 90 percent of total computer systems costs." See reference 2.

The inability to develop software with the same responsiveness to user demands, as is currently achievable with computer hardware, blocks realizing the actual potential of computers. In fact, incredibly rapid computer hardware advances accentuate difficulties that the Department of Transportation (DOT), Department of Defense (DOD), and industry find associated with software implementation. However, these same hardware advances in very high speed, very modular microcircuits, extendable memory, etc., and facilitate modularization of large complex systems. These advances also simplify software organization, making the software itself far more modular and expandable.

With this new software system and hardware system, the need to customize for each application becomes less and less. Certainly then, the more modular and off-the-shelf hardware and software become, the more the total costs can be reduced without sacrificing expected performance.

One way to reduce overall system cost is to buy off-the-shelf software. Since off-the-shelf software varies from vendor to vendor, it might be well to consider just what software vendors offer in general and then consider what two manufacturers offer specifically.

This general discussion will be limited to software offered by minicomputer manufacturers.

All during 1979, the Technical Center analyzed the current software offered by a representative sample of 10 vendors. During this work it became evident that minicomputer manufacturers, in general, furnish a limited selection of off-the-shelf system software.

The research in 1979 supports an earlier investigation by Mitre in 1977 (reference 3).

Generally, vendors now offer real-time operating systems which are multiprogramming, multitasking, event-driven disc operating systems or memory-based operating systems. These real-time systems manage all the physical resources including the processor, storage, and devices. They support:

1. System network architecture with

    a. System definition services.
    b. Network attachment activation/deactivation services.
    c. Session activation/deactivation.
    d. Session and message exchange.
    e. Synchronous data link control.

2. Program preparation

   a. Test editor.
   b. High order languages with some variations: FORTRAN, BASIC, COBOL, and PL/I.
   c. Mathematical and functional subroutine library.
   d. Job control language.
   e. Assembler unique to the system.
   f. Applications builder.

3. Supervisor services

   a. Operator interface management,
   b. Storage management.
   c. Partition management.
   d. Program management.
   e. Task management.
   f. Event management.
   g. Timer management.
   h. Interrupt management.
   i. Queue management.
   j. Interactive debugging.

4. Data base management with

   a. Data description.
   b. Data site management.
   c. Data base inquiry.

5. Communications

   a. Binary synchronous communications.
   b. Start/stop communications to switched and nonswitched point-to-point stations.

6. Utilities

   a. Stand-alone for system generation, save/restore, etc.
   b. System utilities that copy, compress, merge, patch, etc.

7. Sort/merge

8. System security

9. System integrity

10. Diagnostics

Though real-time operating systems provide all those services, an important function is still lacking. Even though real-time operating systems represent an extensive investment in software, this software still leaves distributed processing system design basically to the buyer or end user. Further, it does not supply a fail-safe system. The end user must configure a fail-safe system, write the configuration software and supporting distributed processing software for himself This means a fail-safe processing system still remains a custom-made and, therefore, very expensive system.

TIPS SOFTWARE.

Lockheed provided only a system development package off-the-shelf. Table 2 outlines the PACE disc operating system functions provided by Lockheed. All other software is custom software. Lockheed, specifically, will develop the TIPS common software consisting of an executive monitor and a message switch, plus all tower data processor (TDP), terminal flight data processor (TFDP), and TRACON data processor (TRDP) applications programs. Table 3 shows the software to be developed by Lockheed.

CCD SOFTWARE.

In comparison, Tandem offers off-the-shelf Guardian, a real-time executive/network monitor that provides a fail-safe, no data loss, system for all single component failures. The data base manager, query/report language communications manager, system performance monitor, spooler entry screen formatter, transaction processing monitor, and three high order languages — FORTRAN, TAL, and COBOL — all operate under the Guardian Operating System monitor. Table 4 outlines the real-time software supplied by Tandem. Appendix 4 outlines in more detail the major services supplied by Guardian.

It is Tandem's system software philosophy to provide the user with off-the-shelf fail-safe, distributed processing, networking executive, and support software. Therefore, the user need only write those unique application processes that tailor the system to his specific purpose.

In the CCD system, most central node software can be purchased off-the-shelf. Table 5 lists the remaining software to be developed by the systems contractor.

Since most of the real-time, on-line central node software can be purchased off-the-shelf and these individual programs operate together as a real-time system, the CCD system can be more responsive to changing user information, configuration, and algorithm demands.

TABLE 2. PACE DISC OPERATING SYSTEM (DOS)

A. Monitor

1. System configuration management
2. Debug subsystem
3. Paper tape loader
4. Card reader loader
5. Execute disc file

B. File Manager

1. File types

    a. symbolic
    b. main program
    c. load module
    d. data

2. Commands which provide:

    a. directory maintenance control
    b. disc file specification
    c. manipulation of data files to and from disc
    d. data file building
    e. retrieving and modifying disc data files
    f. disc file allocation and deallocation
    g. disc file protection

3. Commands

    a. copy
    b. delete
    c. duplicate
    e. locate
    f. pick
    g. protect
    h. rename
    i. space
    j. string
    k. trace
    l. undelete
    m. transfer control to main program

C. Assembler

D. Source Program Editor

E. Linkage Editor

F. Disc Drive and Diskette Diagnostic Program

G. Utility Program

1. Paper Tape Punch
2. Disc Patch

H. Firmware/Software Verification

1. Teletypewriter (TTY) absolute loader through DOS monitor
2. Debug
3. Source program editor
4. Assembler
5. Link editor

TABLE 3. TIPS SOFTWARE

A. TFDP Software

1. Executive*
2. Message switch**
3. Applications programs:
    a. input message processing
    b. intercomputer message processing
    c. IOT monitoring
    d. disc management
    e. system monitoring
    f. data recording
    g. time flight plan distribution

B. TDP/TRDP Software

1. Executive*
2. Message switch**
3. Applications Tasks
    a. TDP/TRDP display I/O
        1. interrupts
        2. input response
        3. input processing
        4. output processing
        5. buffer handling
    b. display applications
        1. quick action
        2. keyboard inputs
        3. common routines
    c. IOT processing
        1. I/O
        2. message processing
    d. intercomputer message processing
        1. input messages
        2. output messages

* Executive

1. Executive - Part I
2. Executive - Part II
3. System scheduler
4. Interrupt service routines
5. Executive time monitor
6. System startup

** Message Switch

1. Interrupt service routines
2. Output handler
3. Input handler
4. Output complete
5. Output start
6. Output message processing
7. Disc log of output message
8. Retransmittal check
9. Referent message processing

TABLE 4. TANDEM REAL-TIME SOFTWARE

A. Guardian/Expand Operating System

1. System integrity checking
2. File management
3. General utilities
4. System security
5. Traps and handling
6. Debug facility
7. Command interpreter
8. Process control
9. Checkpointing
10. Test editor
11. Peripheral utilities
12. File utilities
13. Update and program file editor
14. Sort/merge
15. Spooler

B. ENSCRIBE - data base manager

C. ENFORM - data base query language and report writer

D. PATHWAY - transaction processing throughout monitor

E. XRAY - system performance monitor and report system

F. TGAL - text formatter

G. ENVOY - communications monitor

H. ENTRY - screen formatter

I. High order languages

1. FORTRAN
2. COBOL
3. TAL

J. ACCESS - X.25/X.29 communications protocols for TELENET, TYMNET public packet switched networks

K. Data Definition Language

TABLE 5. CCD APPLICATIONS SOFTWARE

A. Data definition language for:

    1. Data base scheme description
    2. Data input format
    3. Data output format

B. Algorithms to present:

    1. Time from

        a. coded time source
        b. internal clock

    2. Barometric pressure
    3. Center field wind speed, direction and gusts
    4. Runway visual range
    5. Low-level wind shear
    6. Vortex advisory
    7. Runway equipment monitoring for

        a. instrument landing system (ILS)
        b. approach light system (ALS)
        c. sequence flashing lights (SFL)
        d. visual approach slope indicator (VASI)
        e. runway edge lights
        f. runway center line lights
        g. runway end identifier lights (REIL)

    8. Airport lighting control

C. Service A weather message cracking algorithms

D. Data recording and simulation

E. Event reconstruction

SYSTEM COST

This section addresses TIPS and CCD hardware and system software cost exclusive of display subsystem cost. No attempt was made to estimate application software cost for either system for two reasons: (1) The TIPS contract was cancelled. (2) To date, the CCD contract has not been awarded.

TIPS.

Table 6 summarizes TIPS cost for one Technical Center system and one field site system. Figure 1 shows this system configuration. These prices are one-time costs without fail-safeness. No production quantity prices are available currently because Lockheed Electronic Company (LEC) only markets the processors as embedded processors. (The word embedded refers to computers that are an integral part of a system, as contrasted with stand-alone computers providing management information services.) That is, LEC only sells these embedded in systems and not as off-the-shelf computers. In fact, LEC is closing its Computer System Division.

TABLE 6. TIPS COST

	Technical Center	Fieldsite
TFDP	$94,739.00	$61,762.00
TDP	20,796.00	15,150.00
TRDP	33,627.00	39,698.00
Peripheral Devices*	14,484.00	14,484.00
DOS and Diagnostics	90,107.00	--
Total	$253,753.00	$31,094.00

*Peripheral devices include: TTY, line printer, disc, tape and formatter, card reader.

CCD.

Table 7 summarizes the cost for a central processing system configuration recommended by Tandem. Figure 7 shows the recommended central processing system configuration. Appendix 5 itemizes cost for the recommended system.

Both CCD bidders proposed a central processing system costing significantly less than the optimal recommended configuration. Figure 8 shows the basic proposed system. Table 8 summarizes the proposed central processing system components. The proposed central processing systems cost $134,000 and $154,000, plus a one-time $36,000 software license fee. The difference in price between the optimal recommended system configuration and the two proposed system configurations occurs in the choice of microcode, disc subsystems, line printer, complement of asynchronous lines, system software, and partly because the bidders offer original equipment manufacturers (OEM) prices.

TABLE 7. SYSTEM COST SUMMARY

	List Price	Monthly Maintenance
Dual processor system	$85,375.00	$652.00
Microcode	24,000.00	80.00
Disc Subsystem	52,000.00	422.00
Peripherals*	47,450.00	338.00
System Software License Fee	49,000.00	580.00
Listings	757.50	--
TOTAL	$258,582.50	$2,072.00
Single processor with 384KB SEMI	$ 28,700.00	$ 221.00

*Peripheral device includes: 3 page-mode terminals, 24 asynchronous communications lines, 2 universal interfaces, and 1 600 LPM printer.

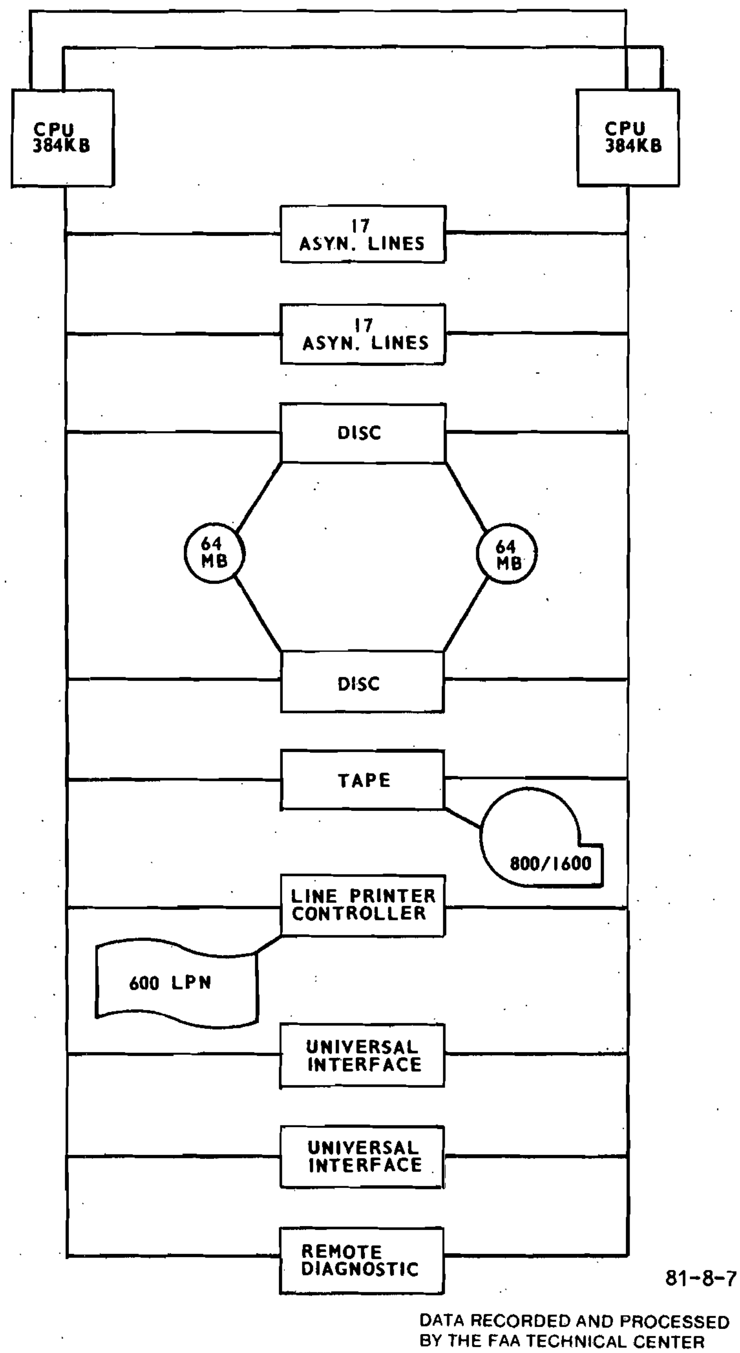


FIGURE 7. CCD RECOMMENDED SYSTEM CONFIGURATION

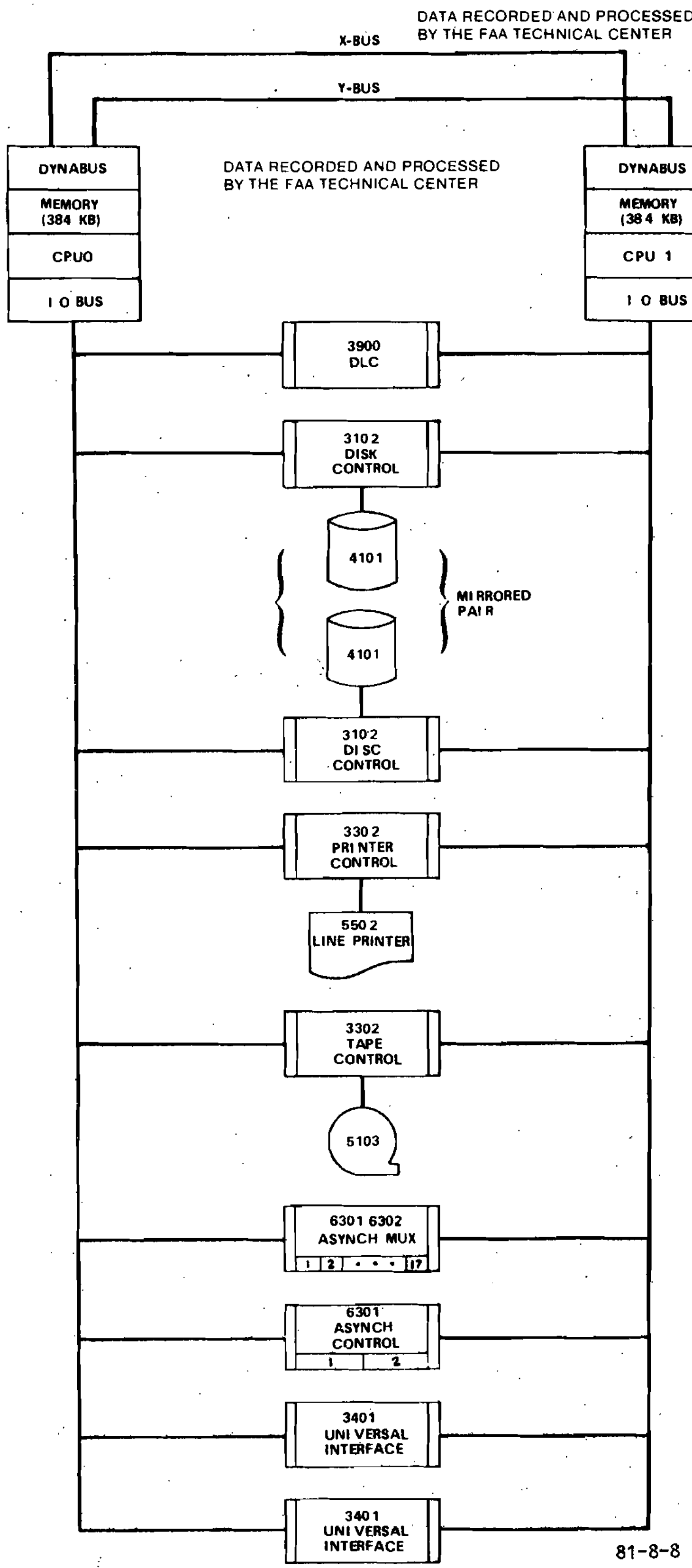


FIGURE 8. CCD CENTRAL PROCESSING SYSTEM CONFIGURATION

TABLE 8. PROPOSED SYSTEM CONFIGURATION

T16 Dual Processor

Microcode

floating point
decimal
arithmetic
FORTRAN
ENFORM
ENSCRIBE

Disc Subsystem

dual controllers
2 10MB discs

Peripheral Subsystem

1 300 LPM printer
1 line printer controller
1 asynchronous controller
1 asynchronous extension board
2 universal interfaces*

Systems Software

GUARDIAN
Sort/Merge
ENSCRIBE
FORTRAN
ENVOY
XRAY

*Included only by one bidder

ANALYSIS

SYSTEM PHILOSOPHY.

Both TIPS and CCD are data base management systems. Although the information manipulated and presented by both systems differ somewhat, data presentation and data manipulation can very well be addressed in a generalized manner. However, each specification approached these problems from a different direction. This section discusses, at some length, the impact of each approach to data manipulation and presentation on the system design.

The TIPS specification fixed the input and output message formats, sources of information and destinations, lists of information, quick-action functions, sequencing and resequencing actions, triggering mechanisms, system monitoring and control functions, response times, and so on. It specified particular data reduction and analysis programs. In addition, it required that all software be modular, flexible, and expandable so that, in the future, programmers could add new system functions easily. In response to these requirements, the TIPS systems contractor offered to provide a generalized executive program, generalized message switch and applications tasks to handle specific I/O messages, quick-action functions, disc management, system monitoring, timed flight plan distribution, data recording, IOT monitoring, and the like.

In examining more closely the design of the program modules for system monitoring, timed flight plan distribution and data recording, it was discovered that each of these modules provided a rigidly defined service. For example, the recording module only recorded data defined by a programmer at assembly time. Like the recording module, the system monitor module only monitors those channels and facilities defined by a programmer at assembly time. No generalized recording, monitoring, or distribution facilities are available to the system user in the real-time operational program. That means, any time the user needs to alter or modify those services, it will be necessary for a programmer to make those changes, reassemble the programs and then link the new modules into the operational program. This process becomes very cumbersome, costly and certainly not responsive to the system user's changing requirements.

These program modules were used as illustrations. The TIPS application tasks reflect this design philosophy almost exclusively.

The CCD system approached data manipulation and presentation as a generalization of a particular problem. This CCD specification not only required the software to be modular, flexible, and expandable, but also extended the flexibility and expandability to the user. The functional specification defined an operating system in which the user defined the data base of static and dynamic data. (Dynamic data are data which change either perodically or randomly.) Each new family of data elements may be defined by the user with its own unique set of characteristics. With this operating system, the user may also define new message inputs to the central processing system by defining the message format, source, and data base storage formats. Equally important in this operating system is the user's ability to define how (in what format) and where (on which display) and what information will be presented to each system user. It also gives the user some interactive control in response to the data presented. Furthermore, as in any software system, system throughput is of primary concern. Therefore, single linked tables are used for all dynamic data elements. The CCD operational program also offers basic data transformation capability (e.g., EBCDIC to ASCII, ASCII to EBCDIC, bit stripping according to a user defined pattern or a user defined transformation). It further offers generalized facilities for data recording, resource monitoring and query.

Flexible operating systems, such as the one described, help reduce the escalating cost of software. According to Dr. Ruth M. Davis, Deputy Undersecretary of Defense for Research and Advanced Technology, "software development is the most highly labor-intensive component of computer systems, with software development costs now nearly 90 percent of the computer systems costs." Of these total software costs, 75 percent occur after field deployment. Software costs occurring after field deployment can be divided into two major cost categories: (1) modifications to existing software, and (2) enhancements to the original design. Major elements in both categories are: (1) changes to the data base structure, (2) changes to the information display, (3) changes to the system input, and (4) addition of new functional software. With these facts in mind, the Technical Center designed the operational software requirements for the CCD to eliminate the programming changes in the three areas: data base structure, information display, and system input. Only new functional software will still require programming.

Even though such systems offer prodigious economies, one danger clearly exists. With the user controlling form and information presented, nonstandard information and information display may and probably will result. Therefore, all such systems will require information configuration control to standardize form and content of essential air traffic control data. One satisfactory method to manage essential information configuration control centrally would be similar to the configuration control presently used to manage the NAS operational software. For the purposes of this report, it will suffice to note that the control procedure described in A01100.134A, with minor modifications, could be expanded to include essential information.

RELIABILITY.

Probably no single factor influenced the design of both TIPS and CCD as much as their respective reliability requirements. The TIPS Engineering Requirement (ER) section 3.5.1 required a 500-hour system MTBF for the prototype system. Section 3.0 Requirements, Failure Mode Provisions, stated: "TIPS shall have the capability to be expanded to operate in a fail-safe mode (e.g. redundant equipment)." Section 3.2 enumerated the real-time operational program functional design requirements and initial and expanded system response-time requirements. Effectively then, this ER limited real-time operational tasks to a set of traditional tasks, not including all those tasks associated with fail-safeness, on-line real-time DR&A, and real-time diagnostics. To the extent that the number of tasks, kinds of tasks, and the system response-time requirement determine the size of the processor and system structure, the decision to include or exclude certain functions becomes very important to the total system scheme. In the TIPS system, the conscious decision to exclude fail-safeness from initial design phase and include an expandability clause had two serious consequences: (1) It allowed the TIP's contractor to choose a processor of a size and speed to meet the minimum response-time requirements; and (2) The contractor did not search the market for a commercially-available fault-tolerant system. As long as the contractor could expand the initial design with redundant equipment to a fail-safe design, the contractor could satisfy the engineering requirement.

In contrast, fail-safeness was a basic requisite for the CCD initial system design. Therefore, according to industry procedures, each CCD bidder searched the market for commercially available fault-tolerant systems. In searching the market, both CCD bidders found that Tandem offers a fail-safe system complete with software to support functional availability. Buying a commercially available fault-tolerant system offered both bidders and the FAA two immediate advantages: (1) reduced system design time, and (2) reduced software cost. Each bidder could have chosen any of several other computers costing significantly less for a CCD central processing system. For example, they could have purchased a minicomputer system with the following fail-safe configuration:

2 CPU with 64K memory	$34,000
4 cabinets	4,000
2 disc drives or controllers	22,000
1 tape drive	13,000
2 module drawers	4,400
6 16 channel MUX	36,000
2 real-time clocks	1,500
2 hardware floating points	1,500
2 hardware multiply/divide	1,500
2 extended instruction sets	2,000

1 printer	3,500
1 CRT terminal	2,000
1 operating system	2,000
1 programmable switch	8,400
Total	136,800

This particular system needed $102,000 for peripheral equipment. As can be seen, main CPU cost is minimal. However, all the other features added to make the system function acceptably, drove up the final hardware cost.

SYSTEM SOFTWARE

The TIPS contractor provided only a software development package with the system. Therefore, all TIPS operational software is essentially applications software including the common executive and message-switching programs. This, in turn, means FAA will absorb all TIPS software development costs including costs for generalized software, the executive, and message switch.

It is Lockheed's policy to develop software, as needed, when required by individual contracts. Lockheed will invest no funds of its own to develop generalized system software. Any system software enhancements become available to system users as they are developed under other contracts.

The Tandem system software package was one primary reason both CCD bidders chose Tandem for the central processing system. Tandem offers not only an on-line real-time software development system, but also a real-time executive, message switch, data base manager, etc. Table 5 lists real-time software provided by this vendor. Appendix D defines, in detail, the system software services available under the real-time executive. All real-time services are designed to support functional availability. Therefore, very little central processing software must be designed specifically for the CCD.

It is Tandem's policy to spend 10 percent of their gross annual revenue on research and development, the majority of which is invested in software development. They amortize the cost of new system software services over a period of years and expected number of users. This policy drastically reduces the cost of new and current service upgrades to the end user. The end user may, therefore, upgrade his own system at minimal cost.

EXPANDABILITY

Within a network node or a system, the question of expandability always arises. This section addresses expandability of computing power. Expandability in number of display devices and system interfaces is summarized in appendix A and appendix C.

Many manufacturers offer two or three levels of the same basic computer. For example, IBM has two levels of its System Series 1 computer, models 4953 and 4955, as can be seen in table 9. This table is presented solely to illustrate the concept of levels of computers available. IBM was chosen to illustrate this concept because Lockheed and Tandem offer only one basic processor.

TABLE 9. IBM MODELS 4953 AND 4955 CHARACTERISTICS

CHARACTERISTIC	Model 4953	Model 4955
Storage size	16-64KB	16-256KB
Interrupt levels	4	4
Storage cycle time	800 nanoseconds	660 nanoseconds
Instruction execution time (1)	7.4 microseconds	2.65 microseconds
I/O channel		
Average burst mode speed	1.33MB/sec	1.66MB/sec
Capacity	256 device addresses	256 device addresses
I/O feature locations		
Model A	4 (2)	4 (2)
Model B	13 (2)	3
Model C	4 (2)	10
Model D	13 (2)	7
Model E	(not available)	7
Packaging		
Full rack-width	Models B & D	All models
Half rack-width	Models A & C	(not available)
Basic console	All models	All models
Programmer console	Optional feature	Optional feature
Floating point	(not available)	Optional feature
Storage protection	(not available)	All models
Address translator	(not available)	Models B, D, & E (3)

(1) Average instruction execution time is based on an instruction mix of the IBM Series/1 Real-Time Programming System.

(2) The number of card sockets available for I/O features, on any model of the 4953, is reduced by one for each storage increment installed after the basic storage.

(3) The storage address relocation translator is an optional feature on Models B and D. This function is standard on Model E.

Primarily, a processor's own architecture limits its use in a distributed processing system. Therefore, most networks use single processors at a node. These nodes may not have a standby redundant computer with a bus switch to provide fail-safeness at a node.

So commonly, when a processor in a node or system functions too slowly to perform all the tasks within a given response time, the manufacturer will supply the next faster version of the basic machine. Using the IBM series 1 machine as an example again, if model 4953 is too slow, the user can replace it with a model 4955. However, when IBM's model 4955 cannot perform all the tasks in a given response time, what happens then? Often the user adds another node to the network and redistributes the workload or alternatively places a mainframe at that node. This approach to exandability seems to be the current industry standard.

Within TIPS, each node has a single basic processor. This processor performs all the information display, communications with other processors in the network, scheduling, organization/reorganization, and logging of data within a given response time. As TIPS is enhanced and the number and kinds of functions are increased beyond the initial system's capacity, TIPS could be expanded to meet the growing processing demand. One method to expand the processing power would be to add CPU's to the main bus. This would provide more compute seconds per second while also creating more memory, bus, and peripheral contention which reduces the available compute power. Another method would be to introduce more nodes into the network, and then redistribute the workload among the nodes. The redistribution of work among the nodes will require regenerating the operational software. Some combination of the two methods might be used to expand the TIPS processing capability. However, it is clear that TIPS can and will expand in a way typical of most systems today.

One manufacturer decided on a different approach to achieve expandability. Tandem Computers, Inc., offers (off-the-shelf) a distributed processing node expandable from 2-16 equal processors in 4 cabinets which can function in a distributed processing network of 2-255 nodes.

As the number of tasks grow beyond the processing capability of the basic two-processor node, the user may increase the number of processors in the node (up to 16) commensurate with his new processing requirements. Additional processors may be inserted in the system without interrupting real-time operations or regenerating the operational software. The addition of processors without interruption does, however, require some planning during initial system design.

As part of the approach to expandability/reallocation of resources, Tandem organized its system software with the concept of geographic independence. Therefore, programs may access any device and any file throughout the node and even the network. Application programs are no longer processor dependent; they may run on any processor in the node or network. The operating system sees all physical resources as logical files. Geographic locations of resource are known only to the message routing portion of the operating system. It is this facility to route data that permits the operating system to dynamically reallocate resources during failures.

This concept of geographic independence allows global networking. A network, as stated before, can grow to 255 nodes. Once a network has been established, nodes may be added or removed without reconfiguration. An expanded software package monitors this entire network. This monitor:

1. Chooses the fastest path between nodes.
2. Automatically reroutes data if a communication line fails.
3. Establishes communications paths to other nodes.
4. Maintains routing information.
5. Insures data integrity from node to node.
6. Logs network status.
7. Retries failed communications paths to determine if they are now up.
8. Can trace data paths through the network.
9. May use leased lines or X.25 public packet network.

All of these software facilities and the machine architecture combine to make a modularly expandable system, modular and expandable in a sense, quite different from nodes and networks employing other hardware/software.

COMMERCIALLY AVAILABLE/OFF-THE-SHELF SYSTEMS.

In an effort to reduce total system cost, government agencies (among them FAA), now require most new computer systems to be off-the-shelf equipment. However, only judicious choice of off-the-shelf systems minimizes total system cost.

Simply specifying that contractors may propose off-the-shelf or commercially available equipment, does not guarantee vendors will propose such equipment. To illustrate, consider TIPS.

The LEC offered the ABP as a commercially available processor for TIPS. The processor had been available from National Semiconductor as a military specification (MIL SPEC) processor. National Semiconductor had manufactured and sold DOD about 125 processors. Then they entered into a licensing agreement with LEC, whereby LEC would manufacture a commercial version of the ABP. To market the commercial version, LEC found it necessary to redesign the processor somewhat, replacing the MIL SPEC components with commercial quality components and making all I/O instructions interruptable after each word transfer on the main bus. When LEC became the TIPS contractor, they had not manufactured this redesigned processor in quantity. While National Semiconductors MIL SPEC processor was commercially available LEC was still developing a commercial version. Furthermore, it is company policy to market that processor embedded in system development packages only. This means (1) each time the company acquires a system development contract using the ABP, it starts a new production line; (2) each time that production line starts, the company incurs associated startup delay and risk; and (3) because LEC does not market the processor in direct competition with other commercial minicomputers, they have no standing inventory. So one cannot consider LEC's ABP commercially available or off-the-shelf.

In direct contrast, the CCD ER specified that the contractor use off-the-shelf central processing systems and field processing units; therefore both bidders proposed such equipment. This requirement insured for CCD (1) reduced system cost, (2) minimum system design time, and (3) compressed delivery and installation schedules. Those are the major reasons to choose off-the-shelf equipment for any system.

PROPRIETARY SOFTWARE.

As commercially available computer systems become more sophisticated, all users need to decide whether or not they will use proprietary software. Until recently, FAA never encountered this issue because all NAS software was specifically developed for the FAA ATC system. Now, within this past year or two, FAA awarded several contracts where part of the operational program is proprietary software. Therefore, it is advisable to explore in more detail the issue of proprietary software. For the purpose of this discussion, the use of proprietary software will be considered as it applies to the CCD system. Since TIPS software is all user developed software, the discussion does not apply to TIPS.

Using proprietary software for CCD offers advantages, but it also has drawbacks. This discussion explores most of them. The CCD operational software will include Tandem's Guardian operating system, enscribe data base manager, XRAY resource monitor, pathway transaction monitor, envoy communications manager and inform query language. So most central processing software will be complete and error free at the time Tandem delivers a CPS to the CCD contractor. The CCD contract will develop only the Information Management language and the field processing unit software. Table 5 provides an expanded list of routines included in these two broad categories. The advantages offered by this approach are minimized system development time and reduced system cost.

The disadvantages are not as well defined. With proprietary software, companies provide only service, not source code and listings. FAA requires companies to provide services with source code and listings so FAA may modify the services, if necessary. If FAA decides to modify these proprietary services, FAA then assumes responsibility for maintenance of these services. Under such circumstances, vendors no longer warrant their software's integrity. Vendors no longer insure software, upgrade compatibility, or provide enhancement compatibility. Therefore, any user choosing to modify proprietary software must be prepared to assume subsequent software maintenance costs and risk.

With CCD's Tandem system, the annual software maintenance fee for the recommended configuration would be approximately $6,000. This annual maintanence fee is in addition to a one time license fee of about $50,000. In general, these costs are very reasonable when compared to the cost to staff the software maintenance function.

Two more aspects in using proprietary software should be mentioned. Consider what happens if the operational program develops a bug, or worse, aborts becauses the system software has a bug. The initial problem is getting the operational program back on the air quickly. This can be resolved by a two-step process if the malfunction significantly degraded the programs operational acceptability. For these malfunctions, it would be advantagous to keep a previous acceptable version or versions available for use. At the same time, the vendor, by prior arrangement, could patch his software on a priority basis. Source code correction would be included in his next released update. For malfunctions which do not significantly degrade the system, simply patching around the problem or even "living" with the problem would do until the next scheduled software release. This process is similar to current NAS procedures with one exception, system software anomalies are handled by vendor rather than FAA staff.

The more complex problem, legal responsibility, should be resolved before incidents or accidents occur and the operational program is either directly or indirectly at fault. This report mentions legal reponsibility and proprietary software, only to point out that this topic is of great concern for each new ATC system or enhancement FAA contemplates implementing. The FAA should evaluate the risk and benefit of using proprietary software for each new system or enhancement, choosing the best implementation method in each case.

For TIPS, all software is development software. No proprietary software will be used because none is available. However, for CCD, most central processing software will be proprietary software. The benefits of using vendor software for CCD such as significantly improved system development time, reduced system development cost, and reduced system maintenance cost outweighed the associated risks.

RAW COMPUTE POWER.

Since both systems essentially are data base management systems, the instruction mix executed by each should be very similar. A data base management instruction mix will consist mostly of loads, stores, compares, branches, and moves with a few adds, subtracts, multiplies and divides. From table 2, Instruction Execution Times in Microseconds, it can be seen that the CCD Tandem processor executes instructions faster than the TIPS Lockheed processor. While any instruction mix will, by nature, execute faster with the CCD processor than with the TIPS processor, the CCD processor will offer a distinct advantage with a data base management instruction mix.

COMBINING SYSTEMS.

INCLUSION OF TIPS WITH CCD: To include the TIPS functions in the CCD system would mean:

1. Definition of a flight data base.

2. Addition of the ARTS/NAS protocols.

3. Addition of a sort/merge on data element function.

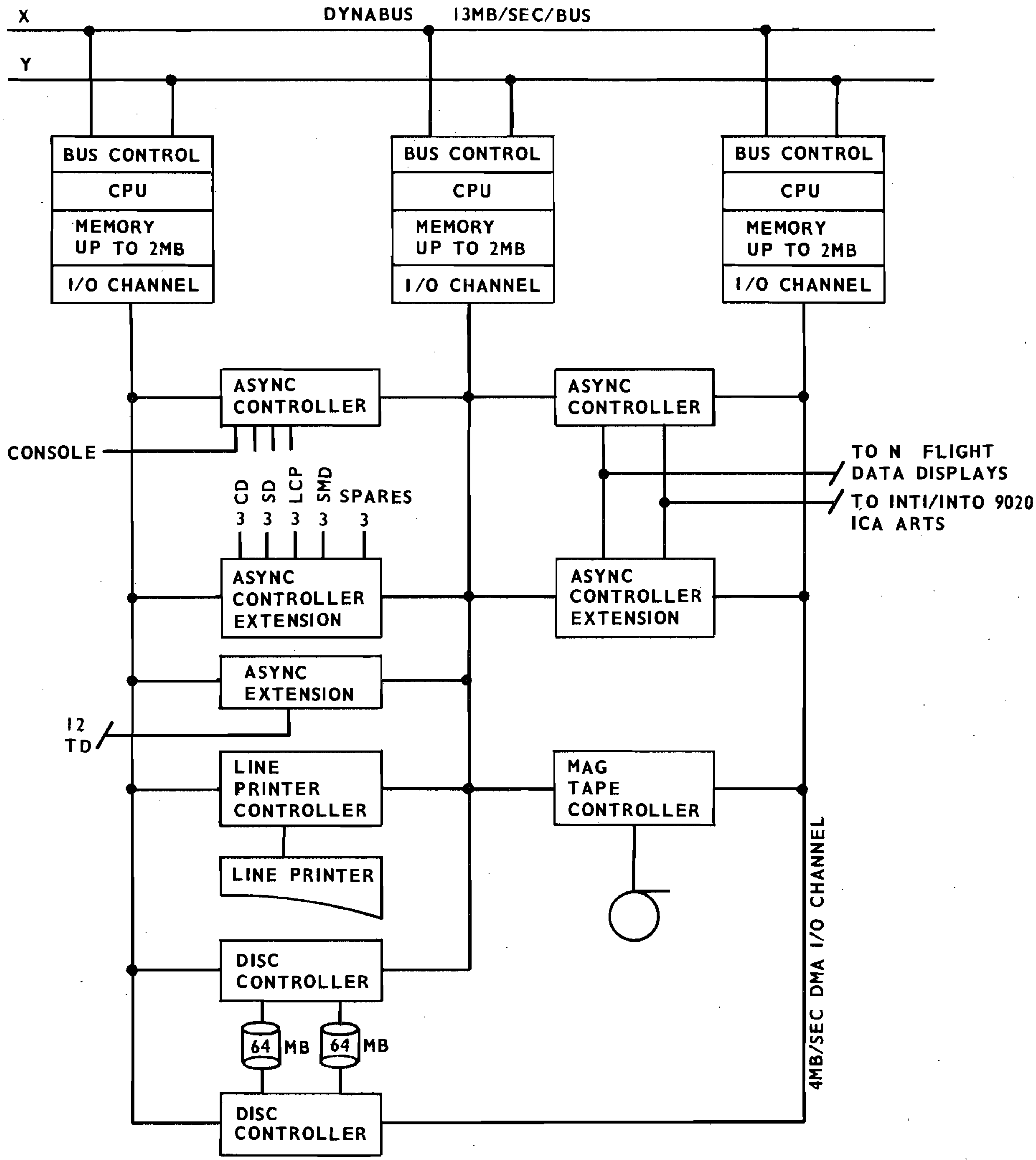
4. Addition of a local editing function.

5. Addition of a separate tower flight data display with entry capability.

6. Addition of a separate TRACON flight data display with entry capability.

7. Possibly purchasing one additional processor card with 384KB and reconfiguring the peripheral equipment (see figure 9 for TIPS/CCD configuration).

8. Addition of an interface box to recognize the NAS sync code.



TD - TRACON DISPLAY
LCP - LIGHTING CONTROL PANEL
SD - SUPPLEMENTARY DISPLAY
SMD - SUPERVISORY / MAINTENANCE DISPLAY
CD - CRITICAL DISPLAY

DATA RECORDED AND PROCESSED BY THE FAA TECHNICAL CENTER

81-8-9

FIGURE 9. TIPS/CCD CONFIGURATION

INCLUSION OF CCD WITH TIPS: To include the CCD functions in the TIPS would mean:

1. Addition of a fail-safe processing configuration with CCD/TIPS configuration (figure 10).

a. Additional two processors and commensurate memory.
b. Additional dual-ported disc controllers and two 10MB disc drives or substituting these for the present TIPS disc.
c. Addition of at least one universal I/O controller to handle 20 asynchronous communication lines.

2. Expansion of the executive and message switch to operate in a fail-safe system configuration including:

a. CPS integrity checking.
b. Fault isolation.
c. Mirrored discs.
d Alternate path selection.
e. Automatic disc data base restoration.

3. Addition of three supervisory maintenance displays.

4. Addition of three lighting control panels.

5. Addition of three critical displays.

6. Addition of three supplementary paged displays.

7. Addition of one field processing unit for tower interface.

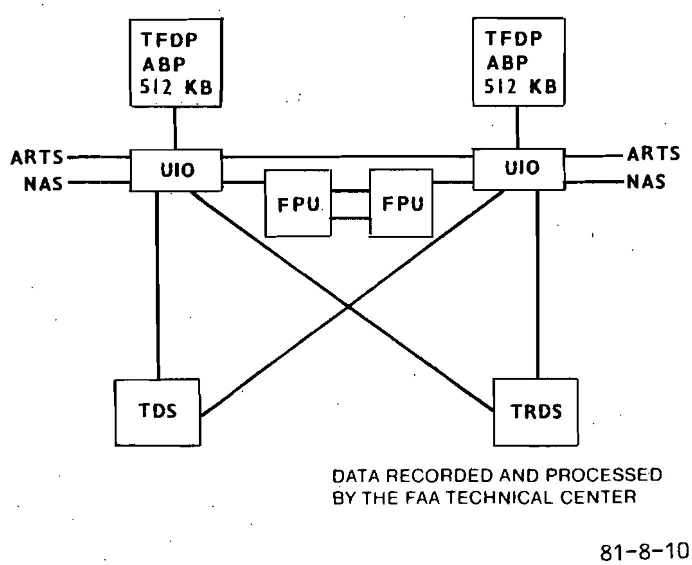


FIGURE 10. CCD/TIPS CONFIGURATION

8. Addition of tower interface sensors.

9. Addition of field control units.

10. Addition of FPU sensing, fault isolation, fail-safe software.

11. Addition of central processing data base Information Management language.

12. Addition of CPS query language.

13. Addition of a generalized CPS resource monitor.

14. Addition of Service A weather message cracking algorithms.

15. Addition of generalized data recording facility.

CONCLUSIONS

It is concluded from the foregoing information that:

1. The proposed Consolidated Cab Display (CCD) System provides more flexibility, expandability, modularity, and reliability than the Terminal Information Processing System (TIPS).

2. The user flexibility, inherent in the CCD's Information Management language, significantly diminishes the system life cycle cost by reducing the need for programmer support.

3. The Tandem-supplied system software greatly reduces programming effort and cost to initially develop and then maintain the CCD operational software.

4. The TIPS functions may be assimilated into the CCD system with minimum additional hardware/software cost and minimum development time. The CCD functions could be folded into the TIPS; however, the hardware/software cost and development time become prohibitive.

RECOMMENDATION

On the basis of the information gathered and the subsequent analysis, it is recommended that flight data management be included in the Consolidated Cab Display System.

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GLOSSARY

COMPUTER NETWORK. Two or more interconnected computers with the advantage of permitting geographical distribution, and thus economy, of computer operations. Such a network also permits parallel processing, time-sharing combinations of send/receive communications, multipoint remote entry and output, and locally controlled and maintained data banks and switching centers.

EXPANDABILITY. Allows the system to accommodate new users and new functions. After a system's initial success, two events typically occur:

1. More users want to use the system. A well-designed system must incorporate the ability to handle an increase in the number of users without affecting the current users.

2. New functions are requested. The ability to handle new user functions without affecting the current user functions must also be considered.

FLEXIBILITY. Determines how well the system reacts to change. If a system is designed properly with change in mind, changes can be applied quickly. Reaction time is reduced significantly.

INSTALLABILITY. A system can succeed only if it can be installed in a reasonable amount of time. Ease of installation also applies to any major enhancements or user functions.

MAINTAINABILITY. The ability to correct problems and "tune" the basic running application. Too often this consideration is overlooked in the original design. The problems that occur not only affect the existing functions but future functions, as well. If significant resources are required to maintain existing functions, the ability to provide changes and enhancements is reduced. The total reaction time increases and the probability of overall success decreases.

NETWORK NODE. One member of the set of interconnected computers in a network.

RELIABILITY. To ensure "service" to the user. In addition to being constantly available, the system must ensure the integrity of its data base.

APPENDIX A

ENGINEERING REQUIREMENTS CONCEPTUAL DIFFERENCES

	TIPS FAA-ER-D-120-006 Section		CCD FAA-ER-500-007 Section	
1. System reliability	3.5.1	MTFB = 500 HRS	1-3.1 3-3.1	Failsafe for single component failures
2. Interactive Input/Output Data Base description language		NONE	Appendix 1	Information Management language
3. System performance measurements	4.2.4.1	CPU ONLY	Appendix 1 1-20.1.5.35	System profile
4. System expansion	3.6		3-3.1	
max # TDS's		6		CPS processing = 65% CPS
max # TFDP Interfaces		4		No max # of displays specified
TFDP disc storage		100%		No max # of FPU's specified
TFDP memory		100%		
TDS 1/0 channels		4		
TDS displays		12		
5. Data display	3.2.2.1 3.2.3.1	Fixed format continuous display and fixed format paged display	1-31 2-3.3.2.1.1 Appendix 1 1-20.1.5	Online flexible format paged display
			2-3.3.1.1.1	Fixed format continuous display
6. System monitoring	3.2.1.5.2 3.2.2.4.2 3.2.3.4	TDS, TRDS, TFDS online service for: 1. Intercompute data channels 2. System peripherals 3. Hardware detected errors, e.g., parity	3-3.2 3-3.2.5 3-3.2.4	CPS online service for: 1. CPS integrity checking 2. Fault isolation 3. System and peripheral diagnostics 4. Base-line test program

ENGINEERING REQUIREMENTS CONCEPTUAL DIFFERENCES (Continued)

				FPU online services for:
			7-3.2.2.1	1. FPU fault isolation including, e.g., a. Memory error b. Arithmetic function error to the board level
7. Unit/Component Reliability	3.5.2 3.5.3	Specific MTFB Requirements for good design practice	2-3.3.1.2.2.1 2-3.3.3.2.13 2-3.3.5.2.10	Require use of "best" commercial practice and set a design goal MTBF
			2-3.6.10 3-3-5.2.1 3-3.5.2.2 7-3.3.10	These sections set minimum MTBF's
8. Data entry	3.3.2.4.12	a. Touch panels or pushbutton key b. Full keyboard for control positions	2-3.3.2	a. Pushbutton page selection b. Full keyboard for supervisory consoles only
9. Down loading processors	3.0	Down load of operational programs to TD's TRDS	3.3.4.2.1.7	Down load and display of parameters to and from FPU's
10. Ops program	3.2	Online functions: executive control FDH application I/O	3-3.2	Online functions: executive control CCD I/O diagnostics program development DR&A failsafeness

APPENDIX B

ENGINEERING REQUIREMENT CONCEPTUAL SIMILARITIES

	FAA-ER-D-120-006 Section	FAA-ER-500-007 Section
	3.4.2	1-3.3.1
1. Off-the-shelf Equipment	The contractor may propose the use of off-the-shelf equipment where indicated in this specification and where such equipment satisfies the following definition: off-the-shelf equipment is a unit which has been produced, delivered, and has performed its designated function for at least 1 year of the time of proposed submission. Off-the-shelf equipment shall meet all requirements of this engineering requirement except as noted.	It is the intent of the government to utilize off-the-shelf equipment where-ever possible. Each item of off-the-shelf equipment shall conform to those design and quality standards of its manufacturer in effect on the closing date of the request for proposal and all requirements stated in the ER
2. Maintenance Approach	3.5.5	1-3.2.1
	The preferred maintenance approach shall be to localize failures through use of software and hardware maintenance features and to replace the failed module elements or pluggable unit from spares. Actual repair of the replaced item should be accomplished at the convenience of maintenance personnel in a maintenance area.	The overall system maintenance approach shall be to localize failures through the use of software and hardware maintenance features and to replace the failed module element or pluggable unit from spares. The actual repair of the replaced item shall be accomplished off-line in a bench repair area.

	FAA-ER-D-120-006 Section	FAA-ER-500-007 Section
	3.4.9	1-3.3.2
3. Software Design	Modularity - The operational software shall have a modular structure. This shall include providing a separate module for each major function, and providing submodules to handle each peripheral device. The modular design of the operational software shall be such that individual programs and subprograms may be reassembled without requiring reassembley of the entire set of programs.	Modular - The software shall be designed modularly, with each separate task being an individual module capable of being compiled and/or assembled independently. The addition, deletion, or modification of a task shall have a minimum effect on the remaining software.
	Flexibility - The operational software shall be designed to meet, as a minimum, the following flexibility requirements: a. The design shall permit operating positions to be readily included or excluded from the operational system. b. The design shall provide for easily changing display formats and data entry sequences. The design shall also provide for the easy addition and deletion of data entry messages and TDS/TFDS communications messages.	Flexible - The software shall provide flexibility to adapt to specific remote sites and display subsystem configuration and requirements. The addition, deletion, or modification of remote site parameters to be monitored as the number and types of displays and display/terminals in the display subsystem shall have little or no effect on the software. Defensive - The software shall be designed defensively, with the communications software validating all messages and the command processing software validating all commands. An invalid message or command shall not hinder the performance on an FPU or the CPS. An inoperative FPU or a CPS single

ENGINEERING REQUIREMENT CONCEPTUAL SIMILARITIES (Continued)

	FAA-ER-D-120-006 Section 3.4.9	FAA-ER-500-007 Section 1-3.3.2
Software Design (Continued)	c. The design shall permit operational programs to be installed and operated in any tower cab facility without reprograming other than adaptation parameters.	processor and/or peripheral failure shall not degrade the performance of the remaining system.
	d. Where feasible, the operational software shall be designed to be table-driven, with the table entries corresponding to parameters which may be modified to provide different display formats and data entry sequences. No hard coded system constants or addresses shall be employed in the operational software.	Standardization - The software shall be written in the Fortran IV programing languages, to the maximum extent possible and must conform to the specification for the American National Standard Fortran (ANSI x 3.9-1966). Man-computer communications such as commands (input formats), error messages. and output data formats shall be standardized within each CCD/RMMS subsystem.
	Expandability - The operational software structure shall support the adding of new functions or the expanding of existing functions with minimum impact on other functions/modules.	
	Efficiency - The operational software shall be designed to operate efficiently with respect to computer processing time, memory storage utilization, and operator response time. The software shall also be	

	FAA-ER-D-120-006 Section	FAA-ER-500-007 Section
	3.4.9	1-3.3.2
Software Design (Continued)	designed to minimize the number of operator actions required for start-up or startover.	
	Data Base Integrity - Operational programs shall be designed to prohibit data base invalidation due to computer malfunction, power interruption or erroneous input data.	
	Timeliness of Execution - The computer program organization shall not permit execution of one function to prevent timely execution of a higher priority function.	

APPENDIX C

SYSTEM PROCESSOR SUMMARY

	LOCKHEED ABP	TANDEM T16
Logic	SCHOTTKY TLL	SCHOTTKY TLL
Architecture	Slight variation of single bus structure with stack capability and instruction overlap	Multiple bus structure, pipelined microprocessor with stack capability 2 interporcesssor busses 1 peripheral bus
Registers	4 accumulators 1 stack pointer 1 stack boundary 1 flag 1 program counter 1 base page offset 7 temporary store	8 general purpose 2 memory stack management 1 shifter 1 program counter 1 status 1 instruction 1 next instruction for prefetching
Interrupts	16 vectored interrupts	16 vectored interrupts and microinterrupt for e.g.
Instructions	75 instructions	123 instructions
	9 memory data transfer 7 register data transfer 9 stack manipulation 4 Boolean operations 9 register data operate 3 bit manipulation 7 shift and rotate 8 branch 7 Skip	15 16-bit arithmetic 8 32-bit signed arithmetic 5 16-bit signed arithmetic 14 branch 9 stack manipulation 8 Boolean Operations 9 Bit Deposit and Shift 1 Byte Test 16 Memory Stack - Register Stack

SYSTEM PROCESSOR SUMMARY (Continued)

Instructions (Continued)	5 I/O 5 miscellaneous	6 move, compare, scan 11 program register control 7 routine call and return 4 interrupt system 1 bus 5 I/O 3 map 2 miscellaneous 32 decimal arithmetic option 43 floating point option
Parity	single bit detection	single bit correction double bit detection
Addressing	direct, indirect, indexed	direct, indirect, indexed, virtual addressing
Memory expansion to	512KB	2MB
Real Time Clock Resolution	1 ms	10 ms
Memory organization	program data	user code area system code area user data area system data area virtual address space
Memory	MOS semiconductor any combination of RAM/ROM/PROM $\leq$ 512KBfer	MOS semiconductor ROM 2K 32-bit words RAM $\leq$ 2MB

SYSTEM PROCESSOR SUMMARY (Continued)

1/0	DMA 2MB/sec	DMA 4MB/sec all peripheral 1/0 is DMA with buffered dual ported controllers
Communications 1/0 Controller:	RS 232 C MIL-STD-188C 2400-19.2K based full duplexed asynchronous as synchronous	2 interprocessor buses: 13MB/sec/bus
Peripheral 1/0 Controller:	2 serial ports. 1 16-bit parallel port 2 8-bit parallel ports 110- 19.2K Based software selectable rate	
Maximum # of Controllers/ Processor	8 bit manipulation	32 /DMA 1/0 channel
Controllers	CRT line printer paper tape reader cassette floppy disc 5MB hard disc 9 track mag tape card reader	synchronous asynchronous disc 10MB-240 MB 7/9 mag tape card reader line printer

APPENDIX D

TANDEM SYSTEM SOFTWARE

I. Guardian/expand Real-time Monitor

A. System Integrity Checking

1. System Monitoring

a. Each processor transmits a test message to every other processor in the system.

b. Every processor checks to see if it received a test message from all other processors in system.

2. Processor failure mode

a. If guardian in one processor does not receive a test message from a processor in the system:

(1) The processor verifies it can end a test message through the dynabus to itself.

(2) If it verifies its own operation is good, the processor assumes the nontransmitting module is down.

(3) If it verifies its own operation is bad, the processor ensures its own module does not impair the operation of other modules.

B. File Management

1. File Types

a. Disc
b. Nondisc devices
c. Processes
d. Operator Console

2. Procedures

a. AWAITIO Procedure (all files)
b. CANCEL Procedure (all files)
c. CLOSE Procedure (all files)
d. CONTROL Procedure (all files)
e. CREATE Procedure (Disc files)
f. DEVICEINFO Procedure (all files)
g. FILEINFO Procedure (all files)
h. GETDEVNAME Procedure (Disc Files and nondisc Devices)
i. LASTRECEIVE Procedure ($RECEIVE File)
j. LOCKFILE Procedure (Disc Files)
k. NEXTFILENAME Procedure (Disc Files)

l. OPEN Procedure (all files)
m. POSITION Procedure (Disc Files)
n. PURGE Procedure (Disc Files)
o. READ Procedure (all files)
p. READUPDATE Procedure (Disc and $RECEIVE Files)
q. RECEIVE INFO Procedure ($RECEIVE File)
r. REFRESH Procedure (Disc Files)
s. RENAME Procedure (Disc Files)
t. REPLY Procedure ($RECEIVE File)
u. REPOSITION Procedure (Disc Files)
v. SAVE POSITION Procedure (Disc Files)
w. SETMODE Procedure (all files)
x. UNLOCKFILE Procedure (Disc Files)
y. WRITE Procedure (all files)
z. WRITEREAD Procedure (Terminal and Process Files)
aa. WRITEUPDATE Procedure (Disc and Magnetic Tape Files)

3. Errors

a. Error = 20-29 (coding error)
b. Error = 30-33 (system configuration problem)
c. Error = 40 (operation timed out)
d. Error = 43 (out of disc space)
e. Error = 50-58 (disc file inaccessible)
f. Error = 100-109 (device requires attention)
g. Error = 110-112 (terminal access failure)
h. Error = 120-199 (device hardware problem)
i. Error = 200-255 (path error)

4. Error Recovery

a. Device
b. Path Errors (nondisc devices)
c. No - Wait I/O

5. File Management Error Messages on the Operator Console

a. I/O Messages
b. Resource Allocation Messages

C. General Utility Procedures

1. CONTIME — takes 48 bits of a time stamp and provides a date and time in internal machine representation.

2. DEBUG — calls the debug facility.

3. LASTADDR — provides the golobal ('G'(0) relative) address of last word in the caller's data area.

4. NUMIN — converts the ASCII representation of a number into its binary equivalent.

5. NUMOUT — converts the internal machine representation of a number of its ASCII equivalent.

6. TIME — provides the current date and time in internal machine representation.

7. TIMESTAMP — provides the current value of the processor clock where this application is running.

8. BACKUP — used to create a backup copy of a particular disc file or group of disc files (i.e. fileset) on a magnetic tape. Files are copies in a special format that permits them to be read back into the system via the RESTORE program.

9. RESTORE — used to restore disc files back into the system from a tape (or group of tapes) previously created by the BACKUP program.

10. DIVER — causes a processor to fail and then makes the processor ready for RELOAD. It is typically used in conjunction with the Command Interpreter and the DELAY program.

11. DELAY — automatically causes repeated failures and reloads of the processors in a system. Thus, application processes running at the same time can be tested to ensure proper NonStop programming.

12. INSTALL — used to update Tandem supplied standard software; performs a restore for each of a system's Tandem supplied software file and then optionally runs a system.

13. EDITREAD — reads text records from an EDIT format file.

14. EDITREADINIT — initializes a file read and returns a status value.

15. FILEERROR — is a general purpose routine used to decide if an I/O operation should be retried.

16. FIXSTRING — is used to "edit" a string of characters based on information supplied in an editing "template."

17. FNAMECOLLAPSE — collapses an internal file name to its external form.

18. FNAMEEXPAND — expands a partial file name from the compacted form to the standard twelve-word internal form usable by file management procedures.

19. HEAPSORT — sorts an array of equal-size elements in place.

D. Security

1. System User Interface

   a. ADDUSER Command (of CI)
   b. DEFAULT Command (of CI)
   c. DELUSER Command (of CI)
   d. GIVE Command (of FUP)
   e. LICENSE Command (of FUP)
   f. LOGOFF Command (of CI)
   g. LOGON Command (of CI)
   h. PASSWORD Command (of CI)
   i. REVOKE Command (of FUP)
   j. SECURE Command (of FUP)
   k. USERS Command (of CI)

2. System Programmatic Interface

   a. CREATORACCESSID Procedure
   b. PROCESSACCESSID Procedure
   c. SETMODE Procedure
   d. SETSTOP Procedure
   e. USERIDTOUSERNAME Procedure
   f. USERNAMETOUSERID Procedure

3. User Classification

   a. Superid user
   b. Group manager user
   c. Standard user

E. Traps and Handling

1. 0 = illegal address reference
   1 = instruction failure
   2 = arithmetic overflow
   3 = stack overflow
   4 = process loop timer timeout
   11 (%13) = memory manager read error
   12 (%14) = no memory available
   13 (%15) = uncorrectable memory error
   14 (%16) = map parity error

2. Trap Handling

   a. If a process has previously made a call to the ARMTRAP Procedure, control is transferred to the process's own trap handling mechanism.

   b. If the process has not provided its own trap handler, the DEBUG Procedure is called for the application process by the operating system.

c. If a trap has occurred and another trap occurs before the process can call ARMTRAP again, the process is deleted and the creator of the process is sent a message indicating that an abnormal deletion occurred.

F. Debug Facility

1. Breakpoint Commands

a. Unconditional Breakpoint

(1) in a Procedure
(2) in a Subprocedure

b. Conditional Breakpoint
c. Trace Breakpoint

2. Display Commands

a. Display Variables

(1) Direct Form
(2) Indirect Form
(3) Table Format

b. Display Register Contents
c. Display Stack Markers
d. Display File Information

3. Modify Commands

a. Modify Variables
b. Modify Register Contents

4. Process Control Commands

a. Resume Process Execution
b. Pause Process Execution
c. Stop Process Execution

G. Command Interpreter

1. Modes

a. Interactive
b. Noninteractive Command File

2. Commands

a. ACTIVATE Command (standard user)
b. ADDUSER Command (group manager user)
Defining Groups/Users
c. ALTPRI Command (standard user)
d. ASSIGN Command (standard user)
e. BACKUPCPU Command (standard user)

f. CLEAR Command (standard user)
g. COMMENT Command (standard user)
h. CREATE Command (standard user)
i. DEBUG Command (standard user)
j. DEFAULT Command (standard user)
k. DELUSER Command (group manager user)
l. EXIT Command (standard user)
m. FC Command (standard user)
n. FILES Command (standard user)
o. INITTERM Command (standard user)
p. LOGOFF Command (standard user)
q. LOGON Command (standard user)
r. OBEY Command (standard user)
s. PARAM Command (standard user)
t. PASSWORD Command (standard user)
u. PAUSE Command (standard user)
v. PMSG Command (standard user)
w. PPD Command (standard user)
x. PURGE Command (standard user)
y. RELOAD Command (system operator user)
z. RENAME Command (standard user)

aa. (RUN(D)) Command (standard user)
bb. SETTIME Command (system operator user)
cc. STATUS Command (standard user)
dd. STOP Command (standard user)
ee. SUSPEND Command (standard user)
ff. SWITCH Command (standard user)
gg. TIME Command (standard user)
hh. USERS Command (standard user)
ii. VOLUME Command (standard user)
jj. WAKEUP Command (standard user)
kk. X Y BUSDOWN Command (system operator user)
ll. X Y BUSUP Command (system operator user)

H. Process Control

1. Types of Processes

a. Primary Process
b. Backup Process
c. Operation of the PPD
d. Ancestor Process

2. Process Control Procedures

a. AREND Procedure
b. ACTIVATEPROCESS Procedure
c. ALTERPRIORITY Procedure
d. CREATEPROCESSNAME Procedure
e. DELAY Procedure

f. GETCRTPID Procedure
g. LOCKDATA Procedure
h. LOOKUPPROCESSNAME Procedure
i. MOM Procedure
j. MYPID Procedure
k. MYTERM Procedure
l. NDWPROCESS Procedure
m. PRIORITY Procedure
n. PROCESSINFO Procedure
o. PROGRAMFILENAME Procedure
p. SETLOOPTIMER Procedure
q. SETMYTERM Procedure
r. SETSTOP Procedure
s. STEPMOM Procedure
t. STOP Procedure
u. SUSPENDPROCESS Procedure

1. Checkpoint Procedures

a. CHECKCLOSE is called by a primary process to close a file in its backup process.

b. CHECKMONITOR is called by a backup process to monitor the operability of its primary process. CHECKMONITOR performs two functions: (1) it performs the operations required when CHECKOPEN, CHECKPOINT, or CHECKCLOSE is called in the primary process, and (2) it returns control to the appropriate point in the backup process in the event that a failure of the primary process or processor occurs or if the primary calls CHECKSWITCH.

c. CHECKOPEN is called by a primary process to open a file in its backup process.

d. CHECKPOINT is called by a primary process to checkpoint its data stack, local file buffers, and/or file synchronization information to its backup process. The data stack and any combination of up to 13 data blocks or file sync blocks can be checkpointed in a single call.

e. CHECKPOINTMANY has the same function as CHECKPOINT except that it allows an unlimited number of data blocks and file sync blocks to be checkpointed in a single call.

f. CHECKSWITCH is called by a primary process to switch control to its backup process. A call to CHECKSWITCH is an implicit call to CHECKMONITOR so that the primary process becomes the backup process.

g. MONITORCPUS instructs Guardian to notify the caller if the operating state of a designated processor module changes from an operable to a nonoperable state or from a nonoperable to an operable state.

h. PROCESSORSTATUS returns a count of the number of processors in the system and the up-down state of each processor.

NOTE: The following procedures are called implicitly by the "CHECK" procedures and, therefore, are not normally called explicitly. However, they can be used by application programmers when writing application-dependent failure recovery tecniques:

i. GETSYNCINFO is called by a primary process to acquire a disc file's sync information so that it can be sent to its backup process.

j. RESETSYNC is called by a backup process, following a takeover from its primary, to clear a disc file's sync information on the backup side. RESETSYNC is called prior to reexecuting disc operations when the backup wants the operation to occur regardless of whether or not the operation has already been performed by the primary.

k. SETSYNCINFO is called by a backup process, following a takeover from its primary, to set a disc file's sync information on the backup side. SETSYNCINFO is called prior to reexecuting disk operations that may have just been performed by the primary so that already completed operations won't be repeated.

J. Text Editor

1. Modes

a. Interactive
b. Noninteractive Command File

2. Commands

a. Range

(1) <line number>
(2) <line>
(3) <simple range>
(4) <ordinal range>
(5) <range>

b. ADD

(1) Without <line>
(2) With <line>, Without <incr>
(3) To Existing <line>
(4) To Current <line>
(5) Quiet Option
(6) If No Current File Defined

c. BREAK
d. CHANGE
e. DELETE
f. EXIT
g. FIX
h. GET

(1) Making an EDIT File the Current File for Editing

(2) Using All or Part of an EDIT File to Create a New Current File

(3) Selecting All or Part of an EDIT File for Addition to the Current File

(4) Using a Non-Disc Device or Non-Edit Format Disc File to Create a New Current File

(5) Adding Text from a Non-Disc Device or Non-EDIT Format Disc File to the Current File

i. IMAGE Command
j. JOIN Command
k. LIST Command

(1) Display Text Lines
(2) Text Transfer via Magnetic Tape
(3) Write to Non-EDIT Disc File

l. MOVE Command
m. NUMBER Command
n. OBEY Command
o. PUT Command

(1) Copying all or part of the Current File into a New File
(2) Creating a New, more Compact Current File

p. QUERY Command
q. REPLACE Command
r. SET Command

(1) (NO) SHIFT Option
(2) (NO) CONTROL Option
(3) (NO) TABS Option

(4) INLEN Option
(5) OUTLEN Option
(6) JOIN Option
(7) FREQ Option
(8) QUIET Option
(9) Block Option

s. XEQ

3. Page Mode Editing Capability

a. ADD BLOCK Command
b. REPLACE BLOCK Command

K. Peripheral Utilities

1. Modes

a. Interactive
b. Noninteractive Command File

2. Commands

a. Device Designation

(1) Configurations

(a) (Form 1) Primary Path Designation
(b) (Form 2) Logical Device/Volume Designation
(c) (Form 3) Disc Device (drive) Designation
(d) (Form 4) Controller Path Designation

b. ADDRTOCYL
c. ALLOWOPENS
d. CONSOLE - Procedure for Switching to a New Log File
e. COPY
f. CYLTOADDR
g. DOWN
h. EXIT
i. FORMAT - Format Execution Times
j. LABEL
k. LISTBAD
l. LISTDEV
m. LISTFREE
n. LISTSPARES
o. MOUNT
p. ARO, ARU
q. FEFRESH
r. REMOVE
s. REVIVE
t. SPARE
u. STOPOPENS
v. UP

L. File Utilities

1. Modes

    a. Interactive
    b. Noninteractive

2. COMMANDS

    a. ALLOCATE
    b. ALLOW
    c. ALTER
    d. BUILDKEYRECORDS
    e. COPY: Copy Form
    f. COPY: Display Form (1) Display Format
    g. CREATE
    h. DEALLOCATE
    i. DUP(LICATE)
    j. FILES
    k. GIVE
    l. INFO
    m. LICENSE
    n. LOAD
    o. LOADALTFILE
    p. PURGE
    q. PURGEDATA
    r. RENAME
    s. RESET
    t. REVOKE
    u. SECURE
    v. SET
    w. SHOW
    x. SUBVOLS
    y. VOLUME

M. Update: Program File Editor

1. Modes

    a. Interactive
    b. Noninteractive

2. Commands

    a. ADD
    b. BUILD (1) Listing Format
    c. DATA
    d. DEL
    e. DUMP
    f. EXIT
    g. FILE
    h. LIST (1) Listing Format
    i. MAIN

j. MOD
k. SET

N. Sort/Merge
O. Spooler

II. ENSCRIBE DATA BASE MANAGER

1. Data File Structures

   a. Key-sequenced
   b. Relative
   c. Entry sequenced

2. Access Methods

   a. Multikey access to records
   b. Relational access among files
   c. Sequential access buffering option

3. Compression

   a. Data compression for key sequenced files
   b. Index compression

4. Automatic maintenance for all keys

5. Multiple volume partitioned files

6. Cache Buffer

7. File Manipulation Procedures

   a. AWAITIO
   b. CANCEL
   c. CLOSE
   d. CONTROL
   e. CREATE
   f. DEVINCEINFO
   g. FILEINFO
   h. FILERECINFO
   i. KEYPOSITION
   j. LOCKFILE (file locking)
   k. LOCKREC (record locking)
   l. NEXTILENAME
   m. OPEN
   n. POSITION (relative and entry-sequenced files)
   o. PURGE
   p. READ (sequential processing)
   q. READLOCK (sequential processing, record locking)
   r. READUPDATE (random processing)
   s. READUPDATELOCK (random processing, record locking)
   t. REFRESH

u. RENAME
v. SETMODE
w. UNLOCKFILE (file locking)
x. UNLOCKREC (record locking)
y. WRITE (insert)
z. WRITEUPDATE (random replace and delete)

aa. WRITEUPDATEUNLOCK (random processing, record locking)

8. File Creation Commands

a. Set
b. Create
c. Reset
d. Info

9. File Loading Commands

a. Load
b. Loadaltfile
c. Buildkeyrecords

III. ENFORM QUERY/REPORT LANGUAGE

1. Query Features

a. English-like query language

b. Retrieves data from multiple files which may be related differently than originally conceived during the data base design

c. Usable with Expand to allow query on distributed data bases

d. Automatically develops the most efficient strategy to extract data from the data base

e. Keywords may be redefined

f. Uses Tandem's data definition languages to define the data base

2. Report Generation Features

a. Sort and summarize information according to user defined evaluation criteria

b. Automatically spaces information on a page and supplies headings

c. Reformat data items

d. Change default display column headings or create report page headings

e. Standard aggregate functions

(1) Average
(2) Count
(3) Maximum
(4) Minimum
(5) Sum
(6) Percent
(7) Cumulative total

f. Accumulate information according to a user specified formula
g. Callable from TAL, COBOL, or FORTRAN

IV. PATHWAY TRANSACTION PROCESSING MONITOR

1. Pathmon - pathway monitor provides all systems programming for multiple terminal control and communications from the terminal to the server process.

a. Controls existence of terminal control processes and server processes.
b. Controls state of terminal control processes and server processes.
c. Controls interrelation of processes and device.
d. Log errors
e. Manager links between terminal control processes and server processes.

2. Pathcom - pathway user communications interface to the pathway monitor pathmon. With pathcom, the user may:

a. Define system parameters for:

(1) Terminal control processes
(2) Server processes
(3) Terminal control
(4) Pathway system

b. Starts terminal control processes, terminals and server processes.
c. Display system status information
d. Shutdown the pathway system
e. Control terminal states
f. Define terminals

3. TCP - terminal control processes provide terminal functions for one or multiple terminals, general terminal control, and sends messages to server processes. Specifically, it provides:

a. Terminal I/O support

(1) IBM 3270 type terminals
(2) Tandem 6510 terminals
(3) Tandem 6520 terminals

b. Interpretation of Screen COBOL which defines:

    (1) Display format
    (2) Application of editing checks and data conversion
    (3) Relationship between screen fields and internal data items
    (4) Control statements for data flow

c. Field validation

V. XRAY PERFORMANCE MONITORING SYSTEM

1. System Performance Monitoring Levels

    a. Mode
    b. Network

2. Modes of Operation

    a. Interactive
    b. Noninteractive Command File

3. Measurement Definition Command

    a. CONF Command

        (1) Configuration file format

            (a) Configuration file sections
            (b) Configuration file entity sets
            (c) Subentry list format

        (2) Null configuration files
        (3) Nonedit configuration files
        (4) The Home Terminal as configuration file

    b. DATA Command
    c. GO Command
    d. EXIT Command
    e. LIGHTS Command

4. Report Definition Commands

    a. Units of Measurement
    b. Overflow and Underflow
    c. BUFFER Reports
        BUFFER Items
    d. BY Clause
    e. COPY Command
    f. CPU Reports
        CPU Items
    g. DELTA Command
    h. DEVICE Reports
        DEVICE Items

i. DISC Reports
   DISC Items
j. DISCOPEN Reports
   DISCOPEN Items
k. FILE Reports
   FILE Items
l. IF Clause
m. LINE Reports
   LINE Items
n. NETLINE Reports
   NETLINE Items
o. NEWPLOT Command
p. OUTLEN Command
q. PLOT Command
r. POOL Reports
   POOL Items
s. PROCEDURE Command
t. PROCESS Reports
   PROCESS Items
u. SCALE Command
v. SYSTEM REPORTS
   SYSTEM Items
w. TERMINAL REPORTS
   TERMINAL Items
x. WINDOW Command

5. Output Formats:

a. Report
b. Plot
c. Histogram

VI. TGAL: TEXT FORMATS

1. Mode

a. Interactive
b. Noninteractive

2. Commands

a. Basic Command

(1) CENTER Command
(2) SPACE Command
(3) NEW Command
(4) HEAD Command
(5) SUBHEAD Command
(6) DBL Command

b. Format Control

(1) POFF Command
(2) ALT Command
(3) SECT Command
(4) PAGELEN Command
(5) OUTLEN Command
(6) NEED Command
(7) OV Command

c. Final Draft Production

(1) LINENO Command
(2) PAUSE Command
(3) ERRORS Command
(4) OUT Command
(5) IN Command

d. Special Purpose

(1) BOX Command
(2) ARROW Command
(3) COMMENT Command
(4) UPSHIFT Command
(5) FOOT Command
(6) VERSION Command
(7) TAG Command
(8) CHANGES Command

e. Conditional Printing

(1) SET Command
(2) IF Command

VII. ENVOY COMMUNICATIONS MANAGER

1. Protocols Provided

a. Binary synchronous (BISYNC or BSC)
b. ADM-2/Burroughs
c. TINET

2. Autocall Facility

3. Line Types

a. Point to point (BISYNC protocol only)
b. Centralized multipoint supervisor (all protocols)
c. Centralized multipoint tributary (BISYNC protocol only)

4. Synchronous Protocol Automatic Features

   a. Multipoint polling
   b. KSC II/EBCDIC translation
   c. Transparent text recognition

5. Trace Facility

6. Line Usage/Error Statistics Performance Monitoring

7. Line Testing Program

8. File Management Procedures

a. AWAITIO - waits for completion of an outstanding I/O operation pending on an open file.

b. CANCEL - cancels the oldest outstanding operation pending on an open file.

c. CHANGELIST - is used by a process acting as a multipoint station. For a supervisor station, CHANGELIST is used to enable/disable polling of a particular station. For a tributary station, CHANGELIST is used to set the station into an active/inactive state.

d. CLOSE - stops access to an open communication line or autocall unit.

e. CONTROL - is used to perform various line control operations, such as setting Data Set Ready (DSR), sending an EOT character, disconnecting the line, and temporary text delay.

f. DEFINELIST - is used by a process acting a multipoint supervisor or tributary station. For a supervisor station, DEFINELIST is used to designate the polling address and selection address of each tributary station to be polled. For a tributary station, DEFINELIST is used to designate which polling and selection address(es) the tributary station will respond to when the line is polled or selection occurs.

g. DEVICEINFRO - provides the device type and physical record length of a (closed or open) file.

h. FILEINFO - provides error information and characteristics about an open file.

i. HALTPOLL - is used by a multipoint supervisor station to stop continuous polling and by a BISYNC point-to-point station to terminate an outstanding read.

j. OPEN - provides access to a data communications line or an auto-dial unit.

k. READ - is used to accept data from a remote station. For a multipoint supervisor station, READ is additionally used to initiate polling of the tributary stations (polling stops with the first station to respond to the poll. Subsequent polling begins with the next station in the multipoint network.) For a multipoint tributary station, READ is used to enable the station to respond to polling or selection.

l. WRITE - is used to transmit data to a remote station. For a point-to-point station, WRITE is used to bid for the line. A multipoint tributary station uses the WRITE procedure to transmit data to the supervisor station when polled. A multipoint supervisor station uses the WRITE procedure to select and transmit data to a tributary station. For an auto-dial unit, WRITE is used to dial a remote station.

m. WRITEREAD - is used by point-to-point stations when performing a conversational exchange of data. The WRITEREAD procedure is also used by point-to-point lines when performing an "id exchange."

n. SETMODE - is used to alter various line characteristics, such as number of times that ENVOY is to retry a message when an error occurs, set intermediate block size, set line statistics threshold, and arm the Trace Facility.

APPENDIX E

DETAILED TANDEM SYSTEM COST

Product Ident	Description	List Price	Discount Portion	Install Charge	Maint./ Month
T/16/244-3	System, Packages, 384KB	$85,375	$58,400		$652

Contains the following modules:

1. Two T/16/1412-1 processors each containing 384KB (192K words) of 500 ns semiconductor (MOS) memory mapping, bootstrap loader, interval timer, and DMA for all I/O. Each processor may be expanded to 2MB of memory.

2. Dual dynabus redundant interprocessor link (13MB/sec each).

3. Two block multiplexed I/O channels (4.0MB/sec each).

4. Thirteen unassigned I/O slots for system expansion.

5. System cabinet T16/7104. The cabinet provides the capability to add two additional processors for a total of four processors.

6. One console T16/6604 (hard copy, 30 cps, 132 column, C/L connected).

7. One dual channel connected asynchronous controller, T16/6303 with two ports.

8. One terminal patch panel, T16/7501.

9. Magnetic Tape Controller T16/3202 with dual channel connections which can control up to two (2) magnetic tape drives.

10. Magnetic tape drive T16/5103, 45 ips, dual density 800/1600 bpi, includes cabinet. 800 NRZI, 1600 PE.

11. Two T16/7303 Batter Packs for backup of semiconductor memory.

Specify voltage when ordering.

DETAILED DISC SUBSYSTEM COST

Quan.	Product Ident.	Description	List Price	Discount Portion	Maint/ Month
2	T16/4105	DISC, MOVING HEAD, 64MB Pedestal mounted, uses one removable 5-high pack, 64KB formatted, 30 ms average seek 8.33 ms latency, 1.2MB transfer rate. Specify length for daisy (10' or 25') and data (if not 25', but not to exceed 80') cables. Each drive is shipped with one disc pack.	$15,500	$8,000	$158
2	T16/3105	DISC CONTROLLER (COMBO) Dual channel connected, can be powered from either processor, can control 1 to 8 drives of T16/4103, takes 2 I/O slots.	$10,500	$10,500	53
2	T16/7504	DISC PATCH PANEL - STD This panel provides connection between large disc drives (T16/4103/4104/4105) and the large disc controller (T16/3105). Up to 16 ports or 4 controllers can be supported by one disc connection panel.	$775	______	N/C
	T16/7608	CABLE SET, BACKUP CONTROLLER, DRIVE 0 Same as T16/7604 for 64MB disc drive.	N/C	______	N/C
	T16/7609	CABLE SET, BACKUP CONTROLLER, DRIVE 1-7 Same as T16/7605 for 64MB disc drive.	N/C	______	N/C

DETAILED MICROCODE OPTIONS COST

Product Ident.	Description	List Price	Discount Portion	Maint/ Month
T16/2001	DECIMAL ARITHMETIC PACKAGE Extension to standard instruction set which provides 20 additional instructions for scaled decimal arithmetic including ASCII conversion, ADD/SUB/MPY/DIV and scaling. Note that this option is required on each processor which will run COBOL or FORTRAN object code.	$2,000	$2,000	$20
T16/2005	FLOATING POINT ARITHMETIC PACKAGE Extension to standard instructions set which provides 40 additional instructions for floating point arithmetic, both normal (23 bits) and extended (55 bits) precision. This option is required by FORTRAN object programs.	$2,000	$2,000	$20
T16/2002	ENSCRIBE MICROCODE Extension to processor unit to allow ENSCRIBE Package to execute on that processor. Note that this option also requires a software license (see SOFTWARE).	$1,500	______	N/C
T16/2006	FORTRAN MICROCODE Extension to processor unit to allow FORTRAN compiler to execute on that processor. Note that this option also requires a software license (see SOFTWARE). Object code produced by the FORTRAN compiler does not require the FORTRAN MICROCODE option but does require the FLOATING POINT ARITHMETIC and DECIMAL ARITHMETIC options.	$500	______	N/C

T16/2007	GUARDIAN/EXPAND MICROCODE Extension to processor unit to allow EXPAND package to execute on that processor. Note that this option also requires a software license (see SOFTWARE).	$2,000	______	N/C
T16/2008	ENFORM MICROCODE Extension to processor unit to allow ENFORM package to execute on that processor. Note that this option also requires a software license (see SOFTWARE).	$2,000	______	N/C
T16/2010	PATHWAY MICROCODE Extension to processor unit to allow PATHWAY package to execute on that processor. Note that this option also requires a software license (see SOFTWARE).	$2,000	______	N/C

PERIPHERAL SUBSYSTEM

Quan.	Product Ident.	Description	List Price	Discount Portion	Maint/ Month
1	T16/3302	LINE PRINTER CONTROLLER, MULTI	$2,800	$2,800	$18
		Dual channel connected, can be powered from either processor, controls one of the following: T16/5502/5503,5504/5505.			
1	T16/5503	LINE PRINTER, 600 LPM	$14,000	$4,000	$162
		132 columns, 300 LMP drum printer, 64 character ASCII set, 12-channel VFU, paper receptacle, 25' cable.			
2	T16/3401	UNIVERSAL INTERFACE	$2,800	$2,000	
		Dual channel connected, can be powered from either processor, controls two devices having 16 line parallel interface. Line drivers and receivers are TTL logic for one device and differential for the other. Maximum transfer rate is 950KB.			
	T16/6303	ASYNCHRONOUS CONTROLLER	$3,600	$3,600	$16
		Dual channel connected can be powered from either processor to which it is connected. Controls up to two terminal lines which can be current loop or RS232 local or modem connected. Line speed is programmable from 50 to 19.2K BPS. Programmable continuous read option allows attachment of simplex lines. Accommodates up to two extensions (see T16/6304). Requires T16/7501 terminal connection panel.			
2	T16/6304	ASYNCHRONOUS EXTENSION BOARD	$4,300	$4,300	$20
		Can be powered from either processor to which it is connected. Provides control for an additional 15 asynchronous lines. Each line may be current loop or RS232 local			

		or modem connected. Line speed is programmable from 50 to 19.2K BPS. Programmable continuous read option allows attachment of simplex lines. The second T16/6304 extension attached to a T16/6303 controller requires an additional T16/7501 terminal connection panel. Prerequisite: T16/6303.			
3	T16/6524	TERMINAL CRT, MULTIPAGE	$3,150	$1,600	$22
		5 or 10 displayable memory pages of 24 x 40 or 80 characters with memory parity. Operational modes include certain combinations of asynchronous, synchronous, character or block, RS-232 or 20 ma current loop, point to point or multipoint at speeds from 110 to 19.2K BPS. Full complement of video and data attributes, local editing, program function keys, and 25th status display line. Additional RS232 communications port for serial output. Specify cable option T16/6D or T16/6E.			
1	T16/3900	DIAGNOSTIC LINK SUBSYSTEM	$3,400	______	N/C
		Includes a control panel that mounts in a patch panel space, a printed circuit board that mounts in an I/O controller board slot, and all required cabling. This basic subsystem is designed for a Tandem two-processor system.			

SYSTEM SOFTWARE

Product Ident	Description	One Time License Fee	Processor Option	Maint./ Month
T16/9002	ENSCRIBE - Data Base Record Manager Provides structured files (key-sequenced, relative and entry-sequenced), multi-key access, cache buffering, automatic disc error recovery. Requires T16/2002 ENSCRIBE microcode per processor.	$6,000	T16/2002	$60
T16/9006	XRAY A software subsystem which monitors system performance. Assists in balancing of processor and I/O channel loading for optimum performance. Requires T16/3900 Diag Link.	$2,500	________	$25
T16/9007	GUARDIAN/EXPAND OPERATING SYSTEM A Network operating system. Permits interconnection of up to 255 Tandem T/16 systems. Requires T16/2007 EXPAND microcode per processor.	$15,000	T16/2007	$150
T16/9010	X25AM-X.25 AXCESS METHOD A communication access method which implements the X.25 communications protocols. Provides Application program and Expand Line Handler Interface to X25 virtual circuits. Control panel included contains a modem equivalent to a Bell 113B for use with a DAA. It also has provision for connection to an external modem supplied by the customer.	$2,000	________	$20

	Included at no extra cost in all systems with Tandem service contracts.			
T16/9202	FORTRAN - ANSI 78	$6,000	T16/2006 T16/2005 T16/2001	$60
	Requires T16/2006 FORTRAN micro code and T16/2005 Floating Point Arithmetic and T16/2001 Decimal Arithmetic packages per processor.			
T16/9101	SPOOLER	$2,000	T16/2002	$20
	A software subsystem allowing files to be passed from application programs to holding areas for later retrieval. Requires T16/9002 ENSCRIBE software, and T16/2002 ENSCRIBE microcode per processor.			
T16/9102	ENFORM	$7,000	T16/2002 T16/2008 T16/2001	$70
	A query/report writing system designed for relational data bases. Requires T16/9002 ENSCRIBE software and T16/9002 ENSCRIBE and T16/2008 microcode per processor.			
T16/9103	PATHWAY - TRANSACTION PROCESSING SYSTEM	$8,500	T16/2010	$85
	Provides transaction processing system software capability which includes screen formatting, data conversion and validation, and transaction routing through the use of a Screen COBOL language, Application Monitor, Screen builder, and Terminal Control Process. Requires T16/2010 PATHWAY microcode, T16/2002 ENSCRIBE microcode, and T16/2001 DECIMAL ARITHMETIC PACKAGE per processor.			

LISTINGS

Quantity	Product Ident	Description	List Price
1	T16/9801	GUARDIAN I/O LISTING Source listing of GUARDIAN I/O for customers needing to interface to the File System. Includes PIOCOM, PIOPROC, PTERM, PPRINT, and PTAPE. Includes T16/9803 "GUARDIAN I/O System Internals." Requires Nondisclosure agreement.	$250
1	T16/9802	ENVOY LISTING Source listing of ENVOY for customers needing to interface to the File System. Includes ADRIVER, COMMDEC, DIALS, PROCSRC, PROTO0, PROTO1, PROTO2, and SDRIVER. Requires Nondisclosure agreement.	$250
1	T16/9803	GUARDIAN I/O System Internals A User Guide for writing custom I/O interfaces. Should also order T16/9801 and/or T16/9802 listings. Requires Nondisclosure agreement.	$7.50
1	T16/9804	ENTRY LISTING Source listing of ENTRY for customers needing to interface to the screen formatter. Requires Nondisclosure agreement.	$250
		Total	$757.50