EPA-650/2-75-035

April 1975

Environmental Protection Technology Series

APPLICATION OF AUTOMATIC DATA PROCESSING TECHNOLOGY TO LABORATORY PROBLEMS

U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

EPA-650/2-75-035

APPLICATION OF AUTOMATIC DATA PROCESSING TECHNOLOGY TO LABORATORY PROBLEMS

by

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Contract No. 68-02-1436
ROAP No. 21BCC54
Program Element No. 1AB014

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Prepared for

U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D. C. 20460

April 1975

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Publication No. EPA-650/2-75-035

ABSTRACT

This report describes the design, acquisition, programming and installation of a multiprogramming data acquisition system. Two multichannel experiments and a high speed laser doppler velocimeter were interfaced. The laser velocimeter is interfaced by a bi-directional ASCII communication link. The mini-computer operating system supports several foreground data acquisition programs with concurrent background data processing.

PREFACE

This report covers work accomplished for the U.S. Environmental Protection Agency, Control Systems Laboratory, Research Triangle Park, North Carolina, by the Aerotherm Division of Acurex Corporation under Contract 68-02-1436. The work was performed between June 10, 1974 and August 31, 1975. Mr. William B. Kuykendal was the Environmental Protection Agency project officer for the program.

We wish to express our appreciation to Frank Briden, Nelson Butts, and Bill Lowans, of the Control Systems Laboratory, for their active and enthusiastic assistance during the installation phase. We would also like to thank Mr. John Barry, of Modular Computer Systems, San Jose, for his invaluable assistance in a number of problem areas.

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1.1 CONCLUSIONS

A complete data acquisition system has been designed, integrated and installed within the Control Systems Laboratory high bay area. The system design is based on a third generation mini-computer utilizing a modern multiprogramming operating system, cartridge disc storage media, high speed floating point arithmetic hardware, and wide range analog-digital conversion equipment. The initial application programs were based on discussions with EPA engineers concerning their future test programs and later modifications by the EPA project officer. While the inital start-up encountered the usual problems, such as instrument nosie, incorrect conversion coefficients, revised thermocouple types, that seem to hamper any major interfacing task, the system is meeting the needs of the experimental programs. As the use of the system increases, there will undoubtedly be changes and modifications to the program and options prompted by both internal and external forces.

The basic system is a flexible and capable tool and has the capacity for future growth and expansion to meet new and changing requirements.

1.2 RECOMMENDATIONS

Aerotherm makes the following recommendations for future expansion and improvement of the original data system as currently installed.

1. The addition of floppy disc as a data storage device should be seriously considered. The system currently has no archival data storage device.
2. The reduction of data in the background would be considerably enhanced by addition of a faster printing device than the 10-character/second teleprinters now installed.
3. The flexability of the system would be materially enhanced by 8,000 or 16,000 words of additional memory.
4. Several new system software modifications have recently become or will shortly become available from Modular Computer Systems. Using the new asynchronous communications handlers, the data acquisition programs could be combined into one program per experiment at a net savings in memory and a decrease in complexity. It may be profitable to revise the data acquisition programs completely at some future time. A new revision of the operating system has been released with several new capabilities which may be useful later. This change could be extremely useful if combined with an increase in memory on the system.

SECTION 2

INTRODUCTION

The Control Systems Laboratory (CSL) at the EPA National Environmental Research Center (NERC), is the primary center within EPA for stationary source air pollution control technology development. In support of this program, CSL operates a number of pilot scale research faciliites in the G wing of the EPA Research Triangle Park Center, North Carolina. These facilities include several combustion research furnaces, two wet scrubbers, a medium scale wind tunnel and a hot baghouse test facility.

The full utilization of these facilities is limited by manpower restrictions. A need became evident for an automatic data acquisition system designed to eliminate the clerical tasks of data logging, conversion to engineering units, calculation of air/fuel ratios and other parameters of interest, and correction of data to standard conditions.

The Aerotherm Division of Acurex Corporation was contracted to develop a laboratory data acquisition system for CSL. This program covered the design, implementation and installation of an automated turn-key data acquisition system which gathers analog and digital data directly from the process instrumentation installed on selected test facilities in the G wing of the EPA Research Triangle Park Center. The work was accomplished during the period from June 10, 1974 through March 15, 1975.

The contract scope of work was divided into three major phases:

- Phase I – A survey of system requirements culminating in a feasibility study and design report to the Management Information and Data Systems Division of EPA.
- Phase II – The acquisition of the system hardware. This phase included programming and testing at Acurex Corporation, Mountain View, California.
- Phase III – The installation of the equipment at CSL's pilot plant experimental facilities in Research Center at Research Triangle Park, North Carolina. This phase included operator training and program documentation and reporting.

The initial implementation of this system includes data acquisition from one of the CSL combustion units, the particulate aerodynamic test facility and a laser doppler velocimeter. However, the system design is expandable to meet the requirements of the entire experimental area.

The first experimental facility serviced by the data acquisition system is the multisegment furnace used by the Combustion Research Section for NO_x control studies. This facility has 40 analog channels which are connected to process instrumentation measuring O_2, NO, NO_x, CO, CO_2, unburned hydrocarbons, air and fuel flow rates and a number of temperatures at various locations in the system. The majority of the instrumentation is set up to produce 0-1 volt signals while the thermocouples are read directly at the low millivolt levels.

A typical test involves some 16-24 hours of initial warm up of the instrumentation and the furnace itself. A given set of conditions is set in the furnace and the system allowed to equilibrate for 30 to 40 minutes. The data acquisition system can display an engineering unit conversion for any data channel and compute excess air to assist the operator in making these adjustments. The test operator may select an "equilibration" mode whereby the system will monitor the furnace for equilibration stability during the waiting period.

After equilibrium is reached, the operator can select the log data mode and acquire data on all channels for a period of time. Typically, this is some 20 to 30 minutes and may involve some 50 to 100 data sets depending on the data rate selected. After the data is required, a pause is selected, the furnace resets for a new set of conditions, and the cycle repeats. Typically, some five or six sets of these tests are completed each day. A complete test sequence may involve 30 or 40 tests over a three-week period.

The testing done in the particulate aerodynamic test facility follows a similar pattern in that the major portion of the testing is accomplished under approximately steady state conditions.

The laser velocimeter and its associated electronic produce two sets of eight BCD coded digits representing position, x and y velocity and particle size. These data sets occur in bursts depending on the particulate loading of the air stream being measured. Typically, some 40 or 50 data sets are taken at a given location and set of conditions. These data are converted to velocity and statistically analyzed. By analysis of x and y velocity vectors at a number of points, a two-dimensional flow map is built up. Normal analysis of a group of data sets will be to analyze for mean and normal values and truncate outliers. Analysis of individual values, including outliers, can give fine scale turbulence measurements.

This report describes the work accomplished on the three contract phases previously listed. Section 2 presents the work done on Phase I, the requirement survey and system design.

Section 4 presents the system implementation, Phase II. The system installation, Phase III is summarized in Section 5. Section 6 considers expansion capability of the system.

3.1.2 Proposed System Usage

The initial implementation of the data acquisition system covers one of the combustion research furnaces, the particulate aerodynamic test facility and the laser doppler velocimeter. The system has sufficient expansion capability to serve the three remaining combustion facilities, the two wet scrubber units and the high temperature fabric filter test unit. The use of a multiprogramming operating system makes it possible to independently serve many projects with the principal current constraint being the memory requirements of the application programs.

3.1.3 Data Source and Data Bases

As currently implemented, the data acquisition system utilizes a 72-channel multiplexed analog to digital connector as its primary data input device. This unit operates at 100 samples/second and auto-ranges between ±5 millivolts and ±10.24 volts full scale. Conversion accuracy is 0.05 percent or 11 bits plus sign. As installed, 47 analog channels are allocated to the segmented furnace facility and 24 channels are assigned to the particulate test facility. The multiplexer is capable of expansion to 512 channels.

Acquired data is currently written on a series of disc partitions. These partitions will hold 256 data sets of both raw and converted data. The furnace experiment is allocated 12 of these partitions and the particulate test facility is allocated 6 partitions.

There are no current provisions in the system for archival or hierarchial storage of data. This task may be more properly assigned to the Univac 1110 system via a data link.

SECTION 3

FEASIBILITY STUDY AND DESIGN

3.1 FEASIBILITY STUDY

In late August 1974, Aerotherm submitted a feasibility study and design report (Reference 1) to EPA's Management Information and Data System Division in accordance with EPA Policy Order 2800.1. This feasibility study and design report covered the aspects of interaction with other EPA (Electronic Data Processing) systems, proposed system usage, data sources and data bases, scheduling, environmental and design constraints, and overall system requirements. Some of the major items covered in the feasibility study are discussed below.

3.1.1 Interaction with Existing Systems

As a first level real-time data acquisition system, this system does not impact any existing EPA EDP systems. The system is designed to be self sufficient in its primary data acquisition and primary analysis tasks. As CSL's data analysis requirements expand to a more extensive usage of the on-line data acquisition system, the unit is designed to allow remote job entry into the EPA Univac 1110 via a Univac 1004 terminal emulation. This option will allow ready access to the 1110 for data reduction and storage consistent with its capabilities while retaining the real time response and flexibility of the data acquisition system.

3.2 SYSTEM CONSTRAINTS

The overall system design was influenced by four major constraints, which are identified below.

3.2.1 Contractual Requirements

1. Approximately 70 analog input channels
2. An interrupt driven, multilevel priority multiprogramming operating system featuring foreground and background modes of operation
3. Program generation software that operates in the background mode
4. A FORTRAN compiler, assembler and necessary utility programs
5. An operating system that is capable of generating and storing random files

3.2.2 Environmental, Physical, and Electrical Constraints

The physical environment in the Wing G High Bay Area is a typical enclosed pilot plant operation where the noise, dust, temperature and humidity levels can be somewhat elevated, particularly during the summer months. The electrical distribution networks of 440 volt 3-phase power along with frequent motor or pump switching, creates an electronically noisy environment for sampling.

3.2.3 Expansion Capability

The system must be modularly expandable by adding incremental amounts of core memory, random access discs, interfacing additional numbers and types of instruments, increasing types and numbers of terminals and modifying, and adding or changing application programs.

3.2.4 Schedule

The system must be installed and operational not more than nine (9) months after the signing of the contract.

3.3 A-D CONVERTER SELECTION

The first design parameter addressed the selection of an analog to digital converter. Primary consideration in this area were the ability to reject transients and noise, protection from over voltage damage, wide range (5 mv to 10 volts) capability and auto-ranging capability. The minimum sampling speed desired was 50 to 100 channels/second.

An intergrating type of A-D converter was chosen for its immunity to high frequency and switching type nose since it integrates the signal over several noise periods. The choice of a relay over a solid state multiplexer was made principally for the relay system's relative ability to reject overvoltages which might burn out the usual solid state type multiplexer. The selection of mercury wetted relays minimizes contact bounce and switch contact nose associated with dry reed relay multiplexers and contributes to an extended operational lifetime at the cost of limiting the unit to a 100 sample/second sampling rate.

An alternative type of analog-digital converters is the "flying capacitor" type which uses relays to isolate a small capacitor and switch the capacitor from voltage source to the converter input.

3.4 COMPUTER SELECTION

3.4.1 Computer Requirements

The choice of an operating system was somewhat limited by the scope of work requirement that the system "shall efficiently execute operational programs in an interrupt driven, multilevel priority foreground and provide a background mode for mathematical analysis and program generation. The operating system must support a FORTRAN compiler."

After a careful review of the overall system requirements, the following general system specifications were proposed:

1. A 16-bit mini-computer with hardware integer and floating point arithmetic, 24,000 to 32,000 words of core memory expandable to at least 64,000 words, and equipped with direct memory access from dual 1 million-word capacity (or greater) cartridge discs, one of which must be removable. The CPU must be equipped with hardware memory protect and have a real-time clock of a least 100 milliseconds resolution. Memory parity checking is a desirable option.

2. The operating system shall be an interrupt driven, multiprogramming system capable of execution of at least 10-disc-resident independent programs in a multilevel priority structure. Since experiments may be run completely asynchronously, it is required that the foreground data acquisition programs servicing each experiment be truly independent and not overlays of a single foreground root task. As the system must also contain a background of varying size for analysis and software preparation, it is desireable that the system be capable of dynamic core allocation from operator assignable core pools. These pools should be changeable under run time conditions. The background core pool should be checkpointable under foreground priority demand.

3. The FORTRAN run-time system should be a memory system resident element and must provide intertask control capability. The FORTRAN system should meet the requirements of ISA Standard S61.1, "Industrial Computer System FORTRAN Procedures for Executive Functions and Process Input-Output."

4. The operating system must provide a random access file capability and such file must be capable of read/write protection on a global or task only basis.

5. The operating system and hardware must provide hardware memory protection for the executing program, both for other programs and the resident portion of the operating system. Outside boundary memory access shall be on a task by task priviledge basis which shall be operator programmable or selectable.

6. The system must be readily expandable for closed loop real-time process control using standard modules.

3.4.2 Equipment Selection

After surveying the broad field of mini-computer vendors, the more restricted field of multiprogramming operating systems and the still more restricted field of process control and data acquisition oriented systems, we selected three systems for final consideration. They were the Digital Equipment Company's PDP-11/40-RSX-11D system, DEC's PDP-11/40-RSX-11M system, and Modular Computer System's MODCOMP II/220-MAX III system (see Table 1).

All of these systems offer these common features: interrupt driven multilevel priority, multiprogramming operating systems, wide range relay muliplexed A-D converters, FORTRAN

TABLE 1. SYSTEM COMPARISONS

Parameter	Digital Equipment Co.	Modular Computer Systems
Equipment	PDP 11/40	MODCOMP II/220
Operating System	RSX-11/M or RSX-11/D	MAX III
Multiprogramming (Tasks)	Yes 256	Yes 256
Memory Protection	Yes	Yes
File Protection	G, R, W, Task Only	G, R, W, Task Only
Random Access Files	Yes	Yes
Parity Memory	No	Yes
Foreground/Background	Multilevel Priority	F, M, B
Cataloged Procedures	No	Yes
FORTRAN IV with ISA Extensions	Yes	Yes
FORTRAN – Task Control Extensions	Yes	Yes
Local Software Office	Yes	No
Local Maintenance Office	Yes	Yes
Local Users	Yes	Yes
<u>Software Supplied</u>		
Operating System	RSX 11/M or RSX-11/D	MAX III
FORTRAN IV Compiler	Yes	Yes
Macro Assembler	Yes (Macro-11)	Yes Macro
Link/Edit	Yes (Task Builder)	Yes (Link-Edit)
Source Editor	Yes (Edit-11)	Yes (Source Update)
Source Librarian	Yes	Yes (Source Maint. Control)
Binary Librarian	Yes (LIB-11)	Yes (Library Update)
Copy Utility	Yes (PIP)	Yes
File Utility	Yes (Files-11)	Yes (DAMP)
Diagnostics	Yes (All Hardware)	Yes (All Hardware)

IV compiler with ISA S61.1 real-time extensions, modular expansion including process control equipment, resident reentrant FORTRAN run time system, hardware floating point and integer arithmetic units, core memory, real-time clocks, task and memory protection on a task by task privilege basis, file protection and support random access files.

Both vendors maintain maintenance service offices in the Research Triangle Park area and DEC supports a full scale sales, software and maintenance office in the Durham area. After extensive investigation, we concluded that any of these three systems would fully support the requirements of CSL's pilot facilities in the initial implementation and all contain sufficient modularity and growth potential to be fully adquate over an extended life span (Table 2). Table 3 shows the hardware cost comparisons among the three systems. The first system considered is based on DEC's PDP-11/40 and the RSX-11D operating system. RSX-11D offers a full scale multiprogramming system which is engineered for very fast response times and highly dynamic task swapping. It accomplished this by having a large portion of the system memory resident and making maximum use of defined single program partitions. This leads to a highly responsive system at the cost of additional memory requirements. It also offers an extensive file management system. RSX-11D is a mature operating system with several hundred installations over an 18-month period. User reports were very satisfactory as to the hardware, software and company support.

The second system considered is the Modular Computer System's MODCOMP II/MAX III system. This combination offers a full scale multiprogramming system which was designed as an IBM 1800 replacement for process control work. Since it uses a more dynamic core allocation procedure than RSX-11D (from a pool instead of fixed partitions), it is somewhat slower (60-70 millisec to load a task instead of 20-35 millisec

TABLE 2. SYSTEM COMPARISONS EXPANSION CAPABILITY

CURRENT/MAXIMUM	DEC 11/40	MODCOMP II	APPROXIMATE PRICE ($)	
MEMORY INSTALLED/MAXIMUM	32K/64K	32K/64K	6,500	6,500
DISC UNITS INSTALLED/MAXIMUM	2/8 SINGLE	2/4 DUAL	5100	10,000(DUAL)
A/D CONVERTER INSTALLED/MAXIMUM	72/320	72/512		
CHANNELS				
EXPANSION FRAME	32	128	2,050	500
MPX CARDS	8 CH	8 CH	415	500
D/A CONVERTERS	UDC 11 SYSTEM MODULES	IOIS MODULES	795	500
LINE PRINTER	60 LPM	50-150 LPM	5,600	7,000
TERMINAL INTERFACES (20 MA, RS232C)	YES	YES	500	1,250/2
TERMINALS (TTY)	ASR 33	ASR 33	1,600	
DIGITAL I/O	UDC 11 FRAME	IOIS FRAME	2,300	1,800
	VARIOUS MODULES	VARIOUS MODULES	250	150
MAGNETIC TAPE INSTALLED/MAXIMUM	0/8	0/4	1st 11,000	
			2-8 8,000	

TABLE 3. HARDWARE COST COMPARISONS

PDP 11/40-RSX 11D

Basic System

DEC 1142D	$48,150
2 Teletypes	4,100
AFC11 A/D & 72 Channels	11,990
Floating Point & EIS	2,700
Card Reader	4,860
LDV Interface	1,830
	$73,630

Basic Unit Includes:

- 48 K Memory
- Dual Disc
- Bootstrap
- Necessary System Features
- Console Terminal

MODCOMP II/MAX III

Basic System

II/220	$32,000
2 Teletypes	3,750
Console Term.	1,800
A/D & 72 Channels	9,500
LDV Interface	2,600
Floating Point	4,000
Card Reader	4,000
	$57,650

Basic Unit Includes:

- 32 K Memory
- Dual Disc
- Bootstrap
- Necessary System Features

PDP 11/40-RSX 11M

Basic System

11-40/BH	$16,100
2 Discs	16,100
16 K Memory	4,900
Bootstrap	540
2 Teletypes	4,100
AFC 11 & 72 Ch.	11,990
Floating Point & EIS	2,700
Card Reader	4,860
LDV Interface	1,830
RSX 11M License	3,000
	$65,920

Basic System Includes:

- 16 K Memory
- Console TTY

with RSX-11D). MAX III's file management requires that disc partitions be preassigned and is somewhat less extensive than RSX-11D. MAX III supports a full scale background batch processor which is capable of operating under procedures for ease of operation. Each task receives individual hardware memory protection during execution. There are several levels of file protection – read only, write only, read-write by owner, read only by others, global access, system only access and several other combinations.

The MAX III/MODCOMP II system, is a mature stable system which has several hundred installations over a 3-year period. User reports were very satisfactory regarding hardware, software and vendor support.

The third system considered, was the Digital Equipment Company's PDP-11/40-RSX-11M system. This system combines the proven PDP-11/40 hardware in combination with a new operating system called RSX-11M. This new system was announced for first release in November 1974. Since at the time of the design study period (August 1974) RSX-11M had not yet been released, we did not have any user background on the system. Background operation for program preparation and mathematical analysis will not be available until May 1975, when Version 2 is released.

Delivery schedule and economics were critical factors in system selection. At the time of the system design, DEC was quoting 120- to 130-day delivery dates placing potential equipment delivery in late December. Since the contract required installation of the complete turn-key system by February 10, 1975, this schedule did not allow much time for program debugging and changes. The MODCOMP hardware was quoted for 45-day delivery.

The second consideration was economic. Table 3 is a cost comparison of the three candidate systems. A PDP-11/RSX-11D system would consume so much of the program budget as to make any application programming minimal. The choice of a PDP-11/RSX-11M system offered a better economic balance to the program. However, we were reluctant to rely on a first release of a new operating system, especially when programming changes would be necessary in the following spring when version 2 was released.

Aerotherm recommended in the design report that the Modular Computer System's MODCOMP II/MAX III system offered substantive advantages to EPA in this program and should be purchased. The final decision table is shown in Table 4. In early September, the EPA project officer approved the purchase of the recommended system (Tables 5 and 6).

The computer system was delivered to Aerotherm on October 8, 1974. Figure 1 shows the complete system hardware configuration.

TABLE 4. FINAL DECISION TABLE

	ADVANTAGES	DISADVANTAGES
DIGITAL EQUIPMENT COMPANY	1. LOCAL SOFTWARE & MAINTAINANCE OFFICE 2. EXTENSIVE FILE SYSTEM 3. MANY LOCAL USERS (80-100) DUKE, UNC, EPA 4. MORE DYNAMIC SYSTEM 5. LARGE COMPANY - FUTURE IMPROVEMENTS MORE RAPID	1. MINIMUM SYSTEM FOR BUDGET 2. DELIVERY TO AEROTHERM DEC-JAN 3. RSX-11/M VERSION 1 RELEASE NOV 18 4. BACKGROUND BATCH SUPPORT IN VERSION 2 (APRIL-MAY) 5. FORTRAN COMPILER OUTPUTS THREADED CODE (DIFFICULT ERROR TRACING) 6. NON PARITY MEMORY
MODULAR COMPUTER SYSTEMS	1. COMPUTER & SOFTWARE DESIGNED FOR PROCESS APPLICATIONS 2. LOWER COST ALLOWS ADDITIONAL FEATURES 3. DELIVERY DATE - OCTOBER ALLOWS MORE PROGRAM TESTING 4. MATURE OPERATING SYSTEM - VERSION E, 3 YRS OPERATING EXPERIENCE 5. FOREGROUND/MIDDLEGROUND/BACKGROUND 6. PARITY MEMORY 7. CANNED PROCEDURES	1. LOCAL SUPPORT IS MAINTAINANCE ONLY. SOFTWARE (ATLANTA) 2. PREASSIGNED FILES - MINIMUM SYSTEM 3. ONLY 2 LOCAL USERS (BURLINGTON MILLS & UNC) 4. SMALLER COMPANY - MAJOR ADDITIONS WILL OCCUR MORE SLOWLY

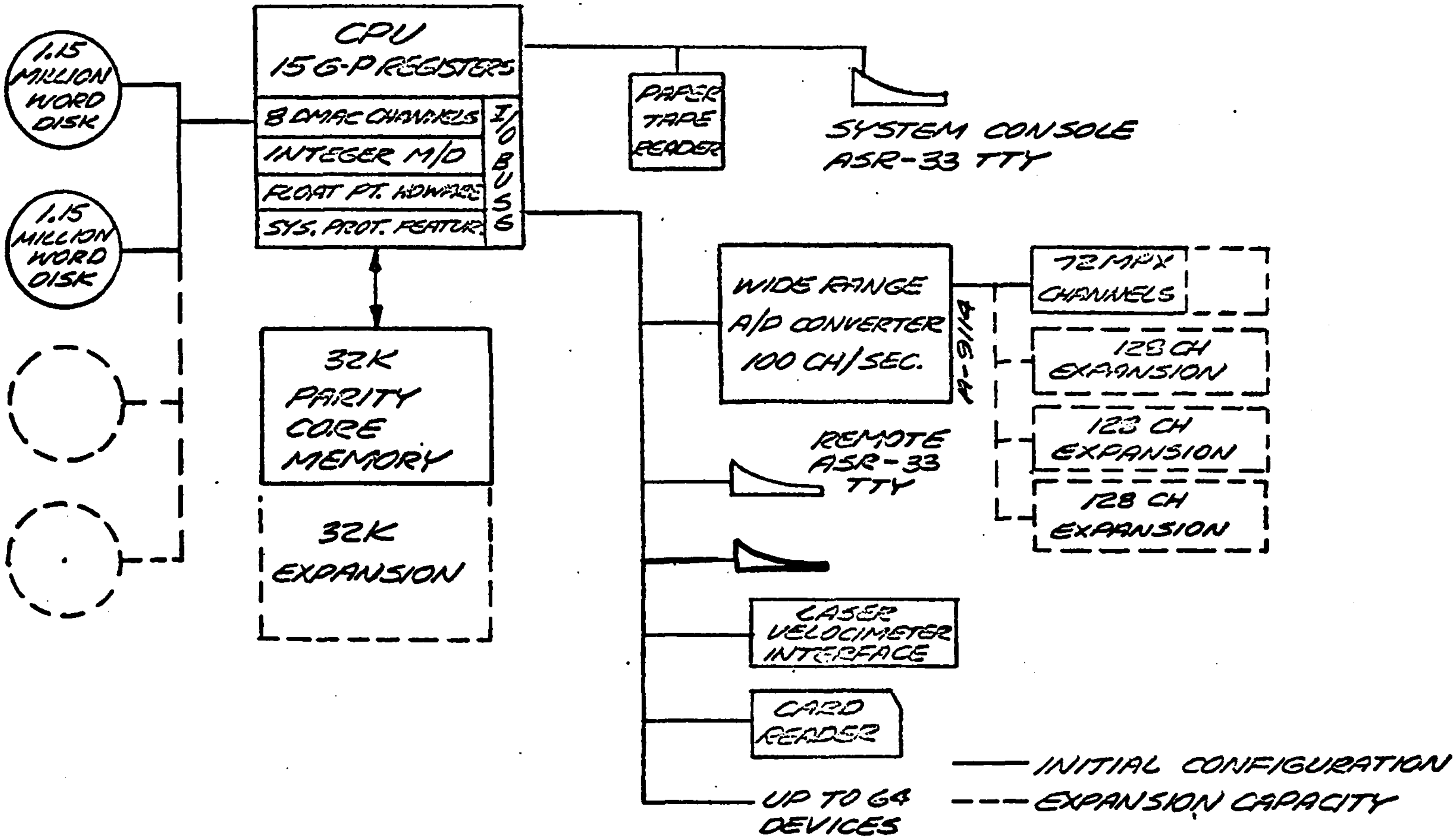

Figure 1. System hardware configuration.

Table 5. MOD COMP II/MAX III SYSTEM HARDWARE

Item	Model	Qty	Description
1	II/220	1	Computer System Consisting of: . MODCOMP II 16 Bit CPU . 32,768 Words of Core Memory 800 nsec Cycle Time . Memory Expansion to 65,536 Words . Direct Memory Processor . Executive Features . System Protect . Multiply/Divide . Hardware Fill . Power Fail Safe/Auto Start . Memory Parity . 4903 Peripheral Controller Interface . 3751 Controller for TTY & Paper Tape Reader . 4128 Moving Head Disc . Two 0001 Cabinets
2	3512	1	Hardware Floating Point
3	4233	1	ASR-33 Console Teletypewriter
4	3747	1	Programmable Power On/Off Switch for TTY
5	4903	1	Peripheral Controller Interface
6	4810AA	1	Asynchronous Communications Interface Two 110 Baud Channels
7	481066	1	Asynchronous Communications Interface 4800 Baud Channel
8	4223	2	Remote ASR-33 Teletypewriter
9	4411	1	Card Reader - 300 CPM
10	1406	1	Wide Range Analog Input Subsystem
11	1421	9	Wide Range Analog Multiplexer Switch 7.4 Hz Filter $\pm$ 10.24V Input

TABLE 6. ANALOG TO DIGITAL SYSTEM CHARACTERISTICS

INPUT - ± 5 MV TO ± 10.24V FULL SCALE	SPEED - 100 SAMPLES/SECOND
RESOLUTION - 1/2048 OR 0.05%	TYPE - DUAL SLOPE INTEGRATION
CHANNELS - UP TO 512	NOISE IMMUNITY - DC - INFINITE 60 Hz-86DB MINIMUM

SPECIAL FEATURES

AUTOMATIC RANGE SELECTION OR PROGRAM CONTROLLED

INVALID DATA FLAG

AUTOMATIC DISCONNECT ON OVERVOLTAGE

MERCURY WETTED 3 WIRE RELAYS - LOW NOISE
- LOW VOLTAGE OFFSET
- 10 BILLION CYCLE LIFE

TRANSFORMER ISOLATION - NO DIRECT ELECTRICAL CONNECTION TO COMPUTER

SECTION 4

IMPLEMENTATION

Implementation of a multiprogramming data acquisition system is at its simplest a resource allocation problem. There are certain hardware resources which must be "dedicated" to a particular task. For example, analog-digital converter channels must be physically rewired to change from one project, location, instrument to another. Of the 72 channels available on the system, 48 are assigned to the furnace experiment and 24 to the aerodynamic particulate test facility (wind tunnel). Similarly, the teletype output ports represented by the dual channel 4810 interface, are allocated (by physical wiring) to the same two experiments. A third 4810 interface channel is allocated to the laser velocimeter interface, but this has three potential locations where it can be plugged into the system.

The remaining resources of the machine are under the "command" of the operating system and thus may be reassigned dynamically to meet the immediate needs of the system. For example, the two cartridge disc units are split into a number of "partitions" which are used by specific programs. The first disc (called the system disc) is primarily used as a repository for programs, libraries, program sources, and also contains several large reusable scratch areas for program generation and data analysis. The second disc is divided into 20 identical partitions for data storage by the data acquisition programs. These disc partitions are dynamically assigned as required by different programs.

The principal limiting resource on the system at this time is the amount of memory available. The system has currently installed 32,000 words of a possible 64,000 words of memory. the operating system requires approximately 13,000 words of this space which leaves about 19,000 words for dynamic assignment to programs as required. Within this 19,000 words of memory, we must fit various combinations of furnace data acquisition, wind tunnel data acquisition, and program generation.

The program generation programs are a part of the operating system and are furnished by Modular Computer Systems. The FORTRAN compiler is furnished in two forms; one requires 10,000 words of memory to execute and is heavily overlayed and rather slow. The extended compiler is quite fast (I/O limited) but requires 14,700 words of memory to run. The output of both compilers is identical. All program generation software except the extended compiler will execute in 10,500 words of memory or less.

4.1 DATA ACQUISITION PROGRAMS

In order to conserve memory, the data acquisition programs are written in the form of a root task plus four overlays which represent mutually exclusive functions.

With the exception of I/O unit numbers, and the A/D channels to be sampled, the data acquisition programs for the furnace and wind tunnel experiments are identical. The data acquisition task for each experiment is handled by two programs called "COMMAND" and "RUN-TIME." COMMAND acts primarily as a communications interface to the test technician allowing him to enter commands and comments. The program interprets the command and passes various flags to the "RUN-TIME" program via a segment of global common which is accessible to both programs. The RUN-TIME program operating asynchronously under its own timing loops actually performs most of the work such as data taking, converting and logging to the disc.

The division of labor between the programs was required by the inability of the "asynchronous communications I/O handler" within the operating system to correctly handle the full duplex hardware installed on the system. The manufacturer states that a new "asynch" handler will be available later in 1975 which will correctly use the full duplex hardware. When this is available, we recommend that the programs be revised and combined since this will simplify and shorten the programs and use less memory.

The "RUN-TIME" program is broken into a root area and four exclusive overlays. The root area contains the code to acquire and convert the data, write it on the disc and keep its timing loops. The various overlays (which are loaded during specific times) are "INITIALIZE," "DISPLAY," "COMMENT," and "EQUILIBRATE."

"INITIALIZE" is used only once at the start of the program to load the instrument calibration, etc., from the configuration file and to assign a disc partition for data storage. "COMMENT" is used whenver the command "COMMENT" or "CO" is intended. The overlay is loaded and asks the operator to enter any one line comment which is tagged with time and data and written on the comment disc file. "DISPLAY" is loaded in response to the operator's request to type out the current readings on certain channels. The program will print the millivolt A-D readings and the engineering units for each selected channel on a one time basis. "EQUILIBRATE" can be used by the test operator to survey the stability of his experiment. Up to 10-operator-selected channels will be compared from reading to reading with operator-input range values to determine whether the experiment is in equilibrium after adjustments. The program will signal when equilibrium is reached or when the unit is not equilibrated.

Figure 2 reproduces a page from the operating manual (Reference 2) which details the various commands available to the operator. The specific internal details of these programs are given in Section I and II of the program documentation (Reference 3) and will not be discussed further here. The program pairs for each experiment require approximately 6000 words of memory per pair. The overall program relationships are indicated in Figure 3.

4.2 DATA REDUCTION PROGRAM

The data reduction and analysis programs fall into three categories: utility, generalized and specific. All data reduction programs operate in the background under the jurisdiction of the background Job Control processor. Most of the programs will operate in a background size of 6000 words or less.

The utility programs serve the function of being general interfaces between the data files and the data reduction programs. There are two programs (REFORMAT and GET DATA) which will interogate the raw or engineering unit data files and extract specific channels, sequences of channels, etc., and write them on a scratch disc file in a card image format tailored to specific data reduction programs. "COMMENT PRINT" and "DATA PRINT" are two programs which exist mainly to print the contents of the data file in a understandable manner.

The generalized data reduction program include a linear regression, a multiple linear regression, general statistics, a polynomial curve fit, and specific programs for multirange NO_x and hydrocarbon monitoring instrumentation. These programs are all general in their usage and will read card image data from punched cards, scratch disc file, and the operator console. The programs are fully described in the program documentation and operators manuals.

C. RUN TIME OPERATIONS

Valid commands are:

LOG - starts the data taking cycle at the normal rate

FAST - take data at the FAST rate defined in the configuration

NORM - take data at the NORMAL rate defined in the configuration

PAUSE - have everything going but don't take data for awhile

RESUME - start taking data again after a pause

COMMENT - I want to write a comment in the records. The program will answer TYPE. Type in any message you wish up to 70 characters long.

DISPLAY - type out the current values for up to 5 data channels

The program will answer "CHANNELS?". Type in the desired channel numbers (up to 5) in I3 format. Example: 00100200300 9022. Include the zeros as necessary, no spaces please. The program will print the raw and converted data for each channel requested.

EQUILIBRATE - will keep an eye on up to 10 chennels and check for steady state. The program asks "ENTER CHANNEL AND RANGE". You may input up to 10 channels in the following manner:

XXXYYYYY where XXX is the channel # and YYYYY is the acceptable range in engineering units. (020 5.7)

End the list with a $$ (end of file) marks. The program will ask "SURE?". If you answer $$ again, it will go into the equilibrium wait mode. If you answer anything else, it will start over asking for channels again. When it begins checking for equilibrium, it reads the specified channels at the data rate selected. The program will print "HR:MIN:SEC EQUILIBRIUM STATUS = X" every time the equilibrium status changes. If X = 0, the system is not in equilibrium. If X = 1, the system is equilibrated. The equilibrium mode may be terminated at any time by entering the command LOG or Resume.

TIME - prints out the current time

EOT - End of Test - prints out the current record numbers on the data files for information stops taking data. You can now set new conditions on the equipment and wait for it to equilibrate, then begin taking data again.

QUIT - QUIT for the day - prints out record numbers on the data files. Writes an end of file on the disc files. Shuts down the data program.

This completes the real time portion of the experiment.

Figure 2. Typical instruction manual page.

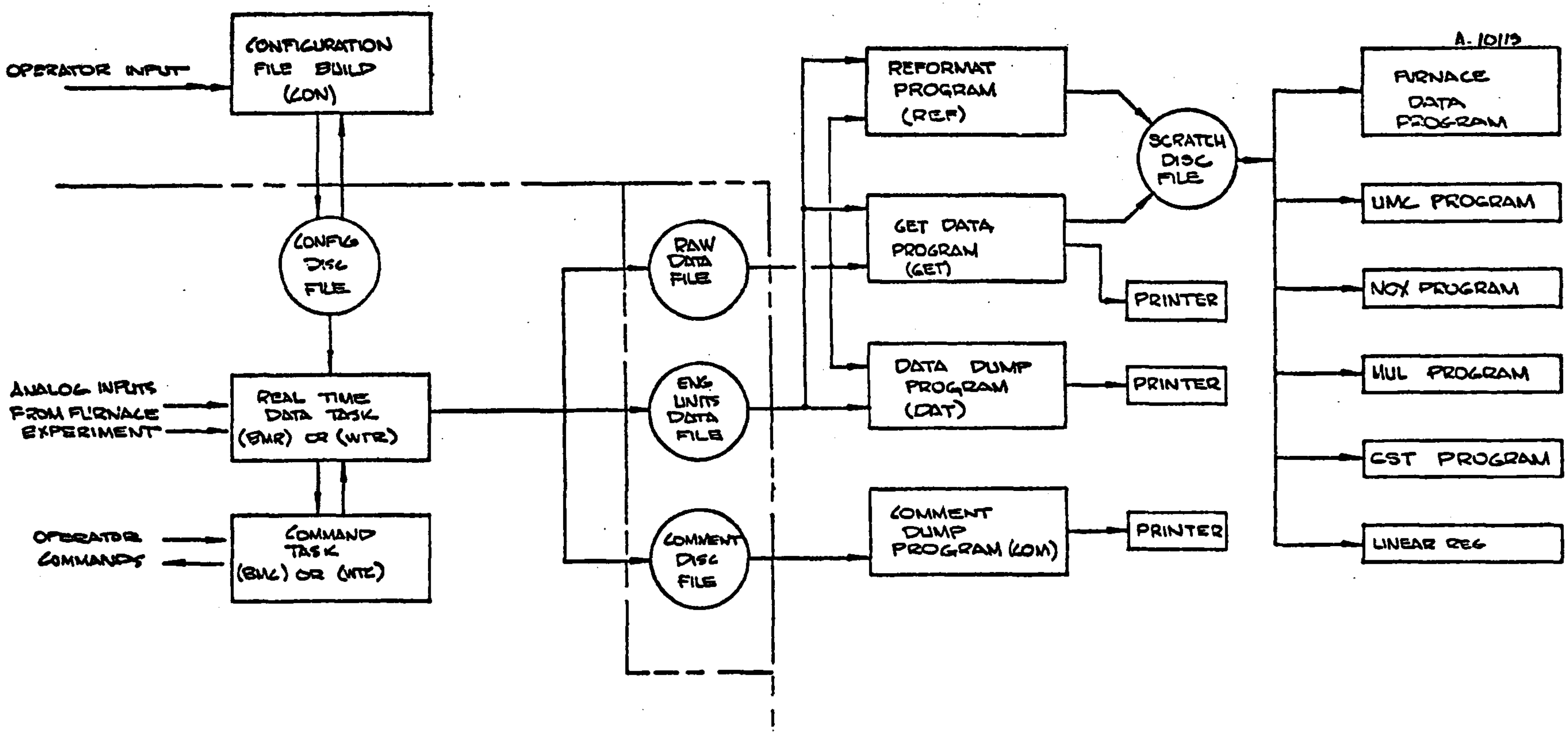

Figure 3. General multichannel experiment.

There are several specialized data analysis programs available in the system. Program BMF is a program to perform specific data analyses on data from the segmented furnace experiment. Emissions are corrected for excess air and a number of process variables are printed in a tabular format.

4.3 LASER VELOCIMETER DATA ACQUISITION

The laser doppler velocimeter is connected to the data system via a two-channel asynchronous interface and a Digital Equipment Company PDM-70 interface unit (Figure 4). The PDM-70 receives an ASCII character string from the computer and performs certain electronic functions depending on the commands contained in the message string (Table 7). Its basic function is to indicate a ready or busy status to the LDV operator and to receive, convert and transmit to the computer two 8-digit BCD messages from the LDV's data multiplexer. The first 8 digits represent a 4-digit position and the next 4 digits the x plane velocity. The second 8 digits are 1 marker digit, 3 size parameter digits (future expansion) and 4 y plane velocity digits. The marker digit is used to identify the first and second messages returned by the LDV multiplexer. The first digit of the position is always 0 or 1 (3-1/2 digit DVM) and the marking digit is set with a thumb wheel to 2-9 thus providing an easy separation. Data messages not meeting the x-y sequence criteria are discarded.

There are two LDV data acquisition programs used with the LDV. The LDV test program uses a nearby teletype to interact directly with the operator to assist him in setting up the LDV for use. The program will ask how many data sets are required, obtain the data and print means, standard deviations, and maximum and minimum readings on the teletype. No data is saved other than the printed output.

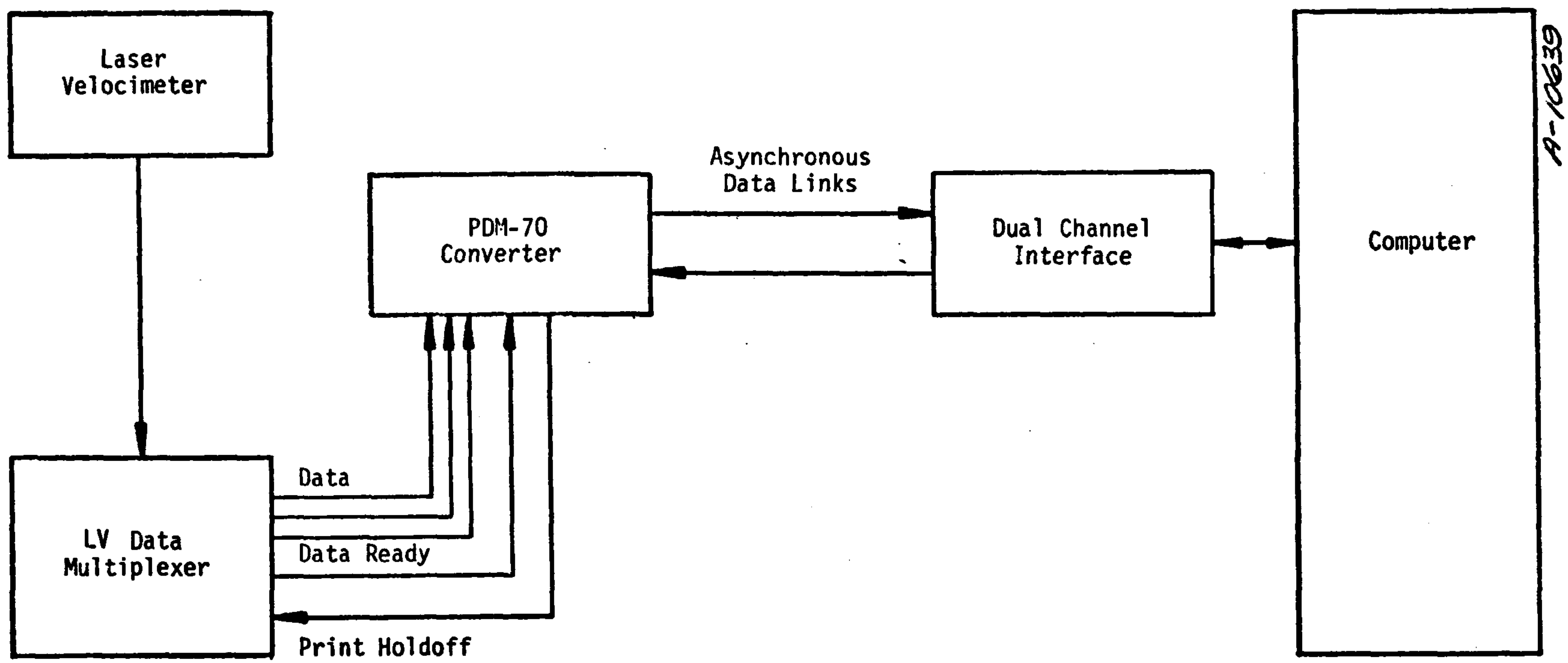

Figure 4. Velocimeter interface.

TABLE 7. LDV COMMAND AND DATA MESSAGES
(ASCII Characters)

Computer Command	LDV Reply or Action
LF, DC1, 3, SOH, 1, DC3, NULL (wait for reply)	"EOT" or "D EOT" toggle in by operator
LF, DC2, 3, DC3, 7, Ø, EOT	(Turn on busy light, turn off ready lights)
LF, DC1, Ø, SOH, 3, DC3, NULL	PPPPXXXXEOT First data string X Velocity Position
LF, DC1, Ø, SOH, 3, DC3, NULL	MSSSYYYYEOT Second data string Y Velocity Size Marker
LF, DC2, 3, DC3, Ø, 7, EOT	Turn off busy lights and turn on ready

The normal data acquisition program operates without a remote teletype and will acquire 50 data sets and writes the data and time date information on a selected disc partition. the LDV operator must enter (via the PDM-70 console switches) (Figure 5) either an "EOT" (04) character or a "D" (44) character to signal the program to take another data set or to quit taking data and exit. The system signals the operator of the "busy" or "waiting" status via the front panel lights.

There are two data reduction programs which operate in the background. The first program was written by Mark Wagman at EPA and uses punched cards to enter data and truncation and limit parameters before calculating means and standard derivations and printing histograms before and after truncations beyond selected data limits. The second data analysis program is an adaptation of the first to read data sets from the disc file where they were stored. The operator is asked for range setting information and whether or not to print a histogram for each data set. These options provide a quick look form of the data analysis without excessive waiting time because of the low speed of the teletypewriter used for printing.

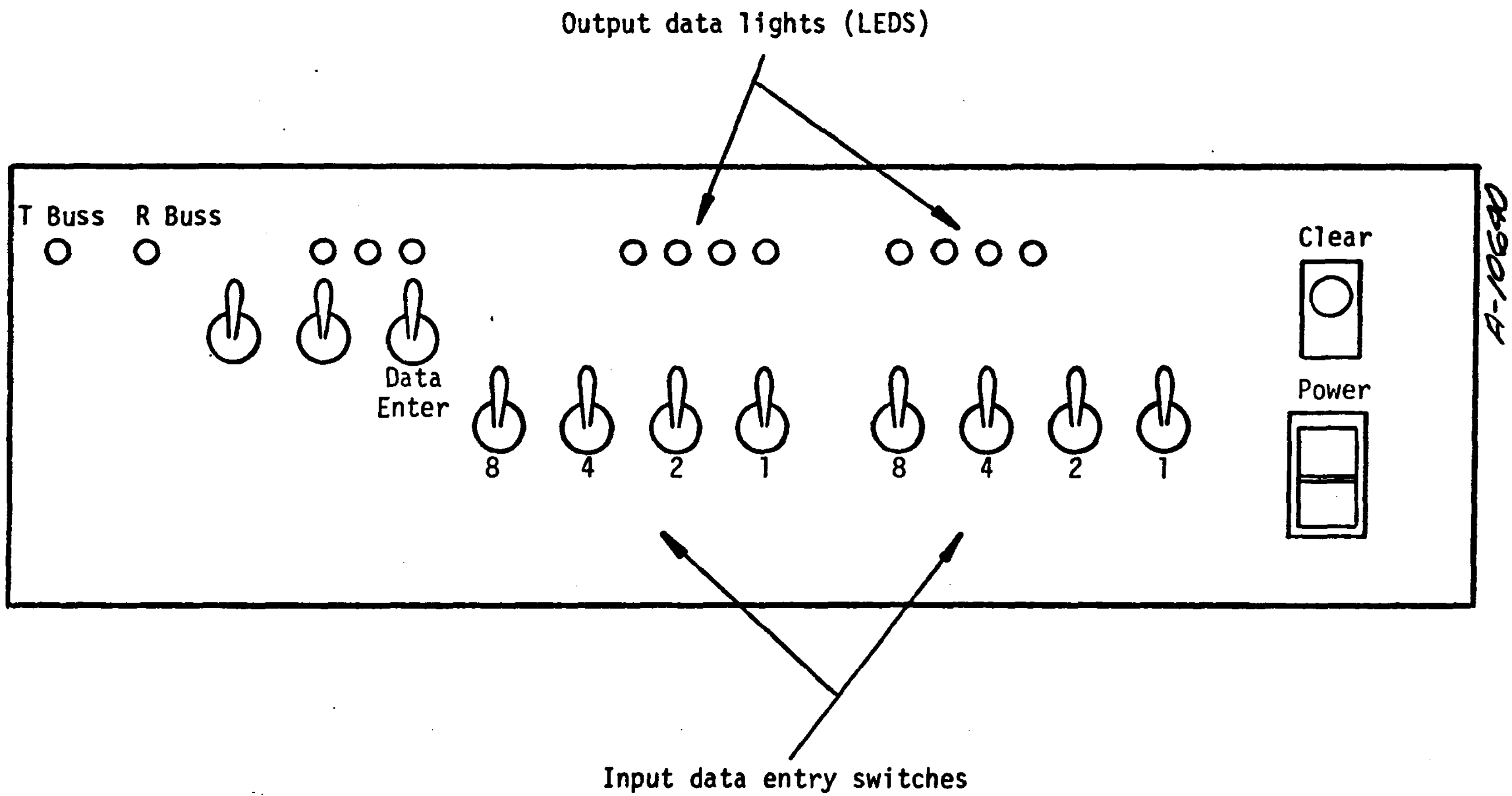

Figure 5. PDM-70 front panel.

SECTION 5

INSTALLATION

This data acquisition system was shipped to EPA in mid-January 1975. The installation phase of the program began on January 25, 1975, and except for the laser velocimeter, was completed on February 14, 1975. The installation consisted of emplacing the system in a room on the mezzanine of the high bay area and installing conduits, cabling and termination panels at several locations in the high bay area (Figure 6). With the active assistance of the EPA co-project officer and several of the EPA test technicians, the installation phase was accomplished with only minor hitches. A room air conditioner was azquired and installed to prevent overheating in the computer rooom since the central air handling system in the area was inadequate. The only major problem encountered during the installation was involved with the laser velocimeter interface. The LV interface problems were associated with the computer hardware and software. The first problem was associated with the 4800 Baud communications channel which would not return a data interrupt on the receive channel. The problem was subsequently corrected by a Modular Computer Systems field service engineer. The second problem was in the asynchronous communcations data handler, a part of the operating system software. The LDV interface apparently was capable of receiving a down-link channel command and replying with the data on the up-link channel faster than the program could be ready to receive the data. This problem was solved by separating the channels on the dual interface and installing the new program on a return trip to EPA. At the time of the return a number of minor revisions were made to several of the data acquisition and reduction programs. After a initial period of operating correctly for several weeks the analog to digital connection developed an apparently random zero drift of 1 to 2 millivolts. Repeated service by the manufacturer has failed to disclose any apparent cause for this behavior which is still under investigation. The data acquisition sections of several programs were modified to read channel 48 at the beginning of each AD channel scan. Channel 48 is permanently shorted so its reading should represent the instantaneous value of the zero offset. This value is then subtracted from the other channel readings to correct the zero offset pending a conclusive hardware solution.

Another problem which has occurred periodically is that occasionally a single data point will read a very high unusual value. This is probably due to a recurrent nonperiodic noise spike or pulse somewhere in the center getting into the A/D connection at the crucial time. The source of the noise is unknown and is not periodic or frequent enough to track down at this time. Since all the current data programs in use compute averages from all the instantaneous data readings, the occasional periodic bad value is not significant in the overall data reduction scheme. It would be simple to pass the data through a simple screening program prior to data analysis if the problem persists.

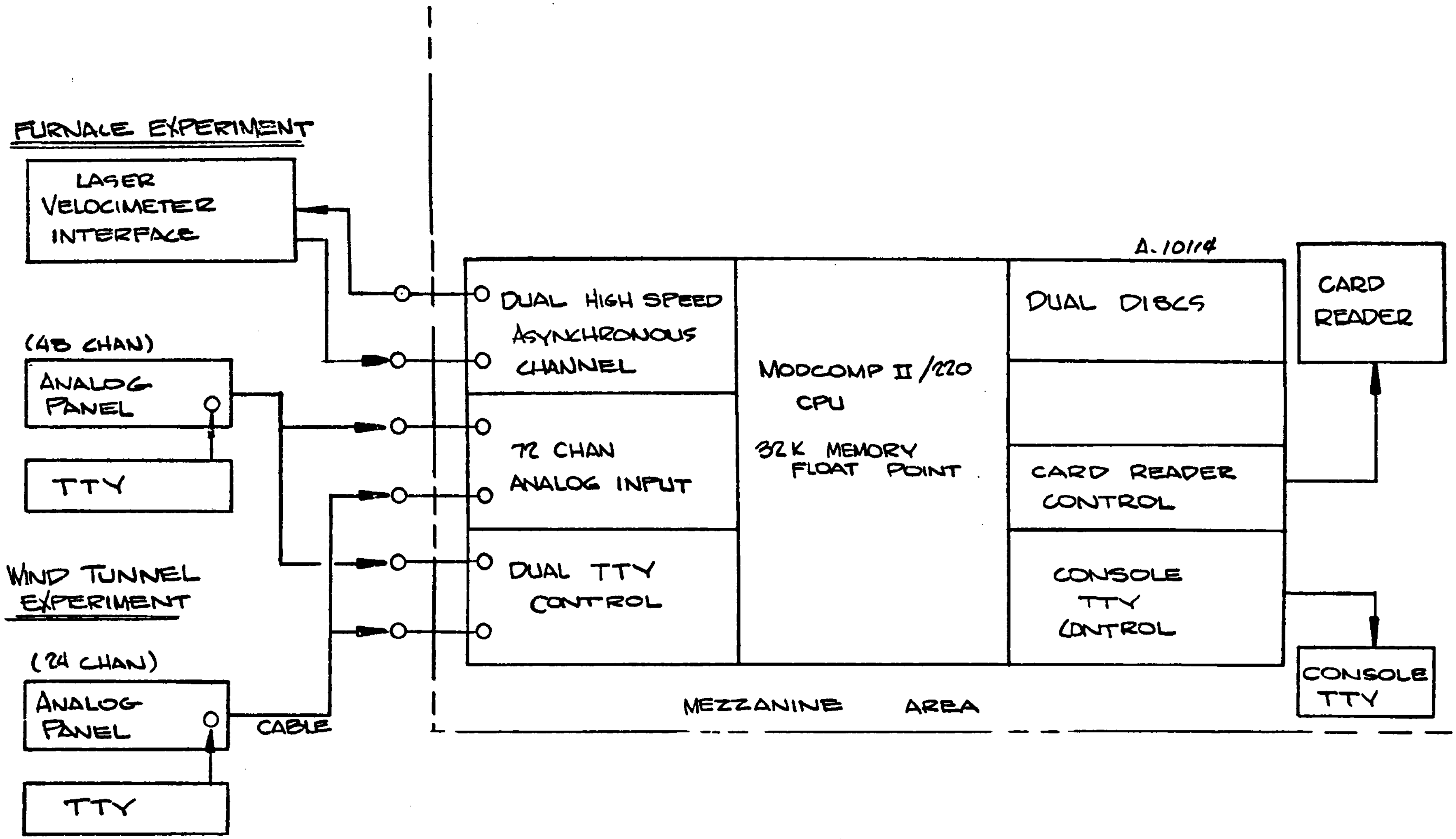

Figure 6. System outline.

SECTION 6

EXPANSION CAPABILITY OF THE SYSTEM

The Modular Computer System, Model II/220 computer system, was selected as the basis of this data acquisition system in part because of its expansion capability. The MODCOMP II computer is designed specifically as a process control computer to be a replacement for the IBM 1130, 1500 and 1800 series of process computers. As such, MODCOMP offers a wide variety of process control peripheral units on a standard equipment basis. These units are fully supported with software. The first area of expansion covers the analog and digital control interfaces available.

6.1 ANALOG - DIGITAL INTERFACES

The unit as installed has a wide range A-D converter with 72 multiplexed input channels. This can be expanded to 128 channels by plugging in additional 8-channel multiplexer cards. Addition of another multiplexer card frame will hold an additional 128 multiplexer channels. The unit can be expanded to 512 channels with more expander frames and multiplexer cards. This system can also contain additional high and low speed A-D converters, each of which may service 512 channels.

The addition of process control capability requires that one additional cabinet be added to the system along with an Input-Output Interface System unit. This unit is essentially a frame with power supplies into which a wide variety of printed circuit cards are plugged. These cards include relays, power controllers, digital switches in and out, timers and digital to analog converters. Expanders for this unit are readily added. This option is fully supported with software via the ISA Standard S61.1 extension to FORTRAN. Through this interface unit and its modules, the system could support almost any forseeable process control function.

6.2 DATA STORAGE

The data storage facilities of the system are currently limited to the partitions available on the second disc unit. This approach is adequate for the current real time needs of the system, but are not convenient for longer term storage of data. There are four options which could increase the system capacity and capability in this area. The system can support the addition of up to two more cartridge disc units. These may be removable or fixed discs. This approach would also add additional capability for data manipulation since these are moderately high speed units. A second option which is considerably less expensive, is the addition of a "Floppy" disc controller and unit to the system. The floppy disc offers a convenient method of saving data in external files. The floppy disc cartridges are about $8 each and may be readily kept in a file cabinet or desk drawer much like a 45 RPM record which they physically resemble.

Data can be readily copied from large discs to and from the floppy quickly and conveniently, for storage data, retrieval and access.

A third approach would add a Model 4811 interface, a modem and a Univac 1004 emulator program to the system. In this manner, the system could act as a remote job entry terminal to the control EPA Univac 1110 facility. Presumably, the 1110 could be used for data storage, large scale data manipulations, plotting, etc. The 4-6 thousand words of memory required by the 1004 emulator program is the only major drawback to this approach.

The last data storage approach is the addition of magnetic tape to the system. The tape transports are available in a variety of industry-compatible speeds, density and track combinations. All are fully supported by system software. This option is the most expensive of any except the additional high speed disc units and is not recommended unless other data acquisition equipment on hand currently produces data records on tape. In this case, tape may be a desirable interchange media between systems. The system can support up to four magnetic tape drivers in any combination on each controller unit.

6.3 DATA PRINTOUT

The remaining major expansion capability in this system is concerned with those options which act to increase the throughput or output of the system. One of the major bottlenecks in the system is the lack of a moderate or high speed device for generating hard copy data output. Currently the system uses 10-character/second teleprinters as output devices. A background data analysis typically takes 5 to 10 seconds to get all the data from the disc, 2 to 3 seconds to analyze it and 5 to 10 minutes to print the results. The addition of a small medium speed printer in the 100- to 150-character/second region would increase system efficiency radically.

6.4 MEMORY EXPANSION

The other throughput expansion option is the addition of memory from the 32,000 words now installed to the maximum 64,000 words. This expansion may be done in 8,000 or 16,000 word modules. Since most of the data acquisition programs occupy about 6,000 words of memory (as do many of the data reduction programs), it is generally possible to run any three of the four major programs concurrently, such as Data Reduction/Background, Furnace Data Acquisition, Wind Tunnel Data Acquisition, and Laser Velocimeter Data Acquisition.

It is presently possible to run only one major data acquisition task while doing program generation in the background. The addition of even 8 or 16,000 words of additional memory would eliminate this potential bottleneck.

REFERENCES

1. "Feasibility Study and Design of an Automated Data Acquisition System," Aerotherm Interim Report 74-110, August 30, 1974.

2. Users Manual: "Data Acquisition System," Aerotherm UM-75-59, January 1975, revisions, March 1975.

3. "Program Documentation, Data Acquisition System," Aerotherm UM-75-61, March 1975.

4. MAX II/III Reference Manaul, "Modular Computer Systems," 210-600303-001 and -002, May 1973.

APPENDIX A

GLOSSARY OF TERMS

ASCII

1. American standard code for Information Interchange
2. A code used to transmit symbolic characters
3. A mode of transmission to and from an I/O device

Asynchronous

1. Not in step with
2. A term which specifies that an event has no time relationship with another event.
3. Not synchronized with time

Background

1. The MAXII task operating at software priority level 255, used for batch processing (nonreal-time) operations
2. A special area of the MAXIII core pool which is set aside and used to execute the background task.

Batch Processing

1. Processing of programs sequentially
2. A method of program execution where control passes from one overlay program to another as specified by a control statement processor (called Job Control) which is loaded itself as an overly between other programs.

Cataloging

The process of storing object programs or other data in a random access disc partition. A directory is maintained in a central place that allows the cataloged item to be found quickly elsewhere on the disc.

Direct Access

A method of locating a particular record on a device without passing through other records to find it; sometimes called random addressing.

Directory

An ordered data array in core or on disc which contains pointers and keys to the location of other data items on disc or in cores.

Driver

1. A section of program code directly connected to an interrupt.
2. In MAXIII, a driver is usually the section of code between an interrupt entry point and an I/O device handler.

Executive

1. A collection of programs and data bases whose sole purpose is to control other programs and provide services for them. Sometimes called a monitor
2. The resident core elements of an operating system

Foreground

1. The highest priority group of multiprogram levels in MAXIII
2. A collection of privileged tasks
3. A region of memory in which foreground tasks and overlay programs execute

Full Duplex

A method of interconnecting a computer system and a peripheral device so that both the input and output data paths are unique and can be operated asynchronously and concurrently

Global

1. Capable of being shared by more than one program
2. Global common - a public core area which may be concurrently accessed by several tasks

Half Duplex

A method of communicating with an I/O device in which input and output operations must share a common data path and must be programmed alternately

Job Control

The name of the root overlay program of the background test. This overlay processes Job Control statements or directives which set up I/O devices and files and then transfers control to and loads other background programs on top of itself. It is reloaded automatically any time a background program exits or is aborted.

Multiprogramming

The concurrent execution of two or more programs on a single computer by means of switching between them as certain events occur, or as particular programs need to wait for an external event.

Object

A representation of a program which is in a data format suitable for processing by a loader or editor. In addition to being a specification of machine instructions, data arrays, addresses, it also has information which permits the program to be relocated into any area of memory.

Partition

1. Core Partition – a contiguous area of memory defined for a specific purpose
2. Disc Partition – a defined contiguous area of disc medium (integral number of tracks) which is given a unique name and made to take on the characteristics of a unique logical device

Physical Device

The device hardware integrated with its physical recording or transmission medium; as opposed to a logical device which is the entity to which a programmer can assign his files

Procedure

1. A precise step by step method for solving a problem or producing a result
2. A named symbolic skeleton or prototype that basically defines a step by step Job Control sequence, with variables are supplied by the parameters of the calling statement ($DO) which specifies the name of the procedure

Real-Time

1. Pertaining to program elements which are executed during (or close to) the time a physical process is actually being performed

2. The processing of information in a sufficiently rapid manner so that the results are available quickly enough to allow another program element or human operator to influence the process being investigated

TECHNICAL REPORT DATA
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1. REPORT NO. EPA-650/2-75-035	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Application of Automatic Data Processing Technology to Laboratory Problems		5. REPORT DATE April 1975
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Larry Babb and Fredric Jaye		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Aerotherm/Acurex Corporation 485 Clyde Avenue Mountain View, CA 94042		10. PROGRAM ELEMENT NO. 1AB014; ROAP 21BCC-054
		11. CONTRACT/GRANT NO. 68-02-1436
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development NERC-RTP, Control Systems Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 6/74-3/75
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

The report describes the design, acquisition, programming, and installation of a multiprogramming data acquisition system. Two multichannel experiments and a high-speed laser doppler velocimeter were interfaced. The laser velocimeter is interfaced by a bi-directional ASC II communication link. The mini-computer operating system supports several foreground data acquisition programs with concurrent background data processing.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Data Processing	Stationary Sources	9B
Lasers	Laboratory Problems	20E
Speed Indicators	Process Instrumentation	14B
Combustion		21B
Research Projects		

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 53
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)