**SIMPL-1:
SIMULATION IMPLEMENTING MACHINE
PROGRAMMING LANGUAGE—VERSION 1**

OCTOBER 1968

**AEC RESEARCH &
DEVELOPMENT REPORT**

BATTELLE

NORTHWEST

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORY
BATTELLE BOULEVARD, P. O. BOX 399, RICHLAND, WASHINGTON 99352

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PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

PRINTED BY/ FOR THE U.S. ATOMIC ENERGY COMMISSION

BNWL-878

UC-32, Mathematics and Computers

SIMPL-1: SIMULATION IMPLEMENTING MACHINE
PROGRAMMING LANGUAGE—VERSION 1

Edited and Assembled By

R. D. Benham

Control and Instruments Department
Systems and Electronics Division

Principal Contributors

C. R. Cole
P. J. Dionne
H. F. Foote
L. H. Gerhardstein
W. F. Lenzke
G. R. Taylor
G. A. Worth

FIRST UNRESTRICTED
DISTRIBUTION MADE

OCT 16 '68

October 1968

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

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PREFACE

Two of the most difficult problems impeding the scientific revolution relate to education of computer users and control of inflationary computer costs. Many recognized authorities have publicly stated, "Computerized solutions are costing 100 times too much."

This report does not claim to completely solve both the educational and economics problems facing science and engineering. However, it does point to an area where cost savings of 100-to-1 and time savings of 500-to-1 can be realized. The techniques for realizing such savings are illustrated with tutorial examples of varying complexity from the main report through each appendix.

Hybrid Computer System

ABSTRACT

SIMPL-1 is a hybrid operating software system for a fixed point PDP-7 digital computer and a Beckman 2133 analog computer. The programming method associated with SIMPL-1 belongs to the same family of continuous simulation language as MIDAS and PACTOLUS. The method is a dialect of the Digital Equipment Corporation's PDP-7 assembly language. When used on our most sophisticated nuclear plant simulation the hybrid processes information about 400 times faster than more conventional programming methods employing a UNIVAC 1108 digital computer equipped with floating point hardware.

When SIMPL-1 programming methods are used without including the analog computer as part of the system, the effective speed of the system is decreased. However, the SIMPL-1 programming method increases the effective computing speed by factors up to 1000 as compared to software floating point FORTRAN.

The digital computer replaces the following analog elements on our largest hybrid simulation:

- 180 amplifiers
- 17 integrators
- 35 variables
- 120 POTS
- 30 function generators
- 8 variable time delays.

The computing frame time for this simulation is approximately 20 msec, which corresponds to processing speeds 10 times faster than real time.

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SIMPL-1: SIMULATION IMPLEMENTING MACHINE PROGRAMMING LANGUAGE-VERSION 1

I. WHAT IS SIMPL-1?

SIMPL-1 is a hybrid operating software system for a fixed point PDP-7 digital computer and a Beckman 2133 analog computer. It was developed by modifying and augmenting the (Digital Equipment Corporation furnished) basic PDP-7 software system. With the exception of the program library given in Appendix B, the 31 different programs that comprise the SIMPL-1 system are categorized (Appendix F) into the following functions: DECTAPE INPUT/OUTPUT, PAPER TAPE INPUT/OUTPUT, CARD INPUT/OUTPUT, EDITOR, ASSEMBLERS, DEBUGGING PROGRAMS, MEMORY DUMPS, and ANALOG SETUP and CHECK OUT.

The programming method associated with SIMPL-1 belongs to the family of continuous simulation languages such as MIDAS⁽⁵⁾ and PACTOLUS⁽⁸⁾. The acronym SIMPL-1 (Simulation Implementing Machine Programming Language-Version 1) was chosen because it is somewhat descriptive of the programming method. That is, it implies that the method is simple to learn and apply, and that a lower level language (i.e., machine language) is necessary. However, the acronym is deceiving because assembly language rather than machine language is used. The programming method used with the SIMPL-1 system is not new. Rather, it is a dialect of the Digital Equipment Corporation's PDP-7 assembly language with rules and symbols added for programming convenience (: . * \ + ' \$) (See Appendix A). Five hardware instructions were also added to the PDP-7, and the teletype interface was modified (See Section XI).

In most hybrid systems the analog is considered a peripheral device to the digital. However, the SIMPL-1 programming methods allow consideration of the digital as peripheral to the analog. Nevertheless, SIMPL-1 programming methods can be used without including the analog computer as part of the system. When used this way, the result is that problem solution times are decreased by factors of 10 to 1000 as compared to software floating point FORTRAN methods, (i.e., greater time decreases are realized as problem complexity increases).

If the SIMPL-1 concept is implemented on a fixed point digital computer, the size of the computer is reduced by a factor of two and this should reduce computer cost [according to an indirect application of Grosch's Law⁽²¹⁾] by a factor of four. Furthermore, it opens an area where cost savings of 100-to-1 can be realized.

In the following sections SIMPL-1 and FORTRAN are compared in general. The "Pilot Ejection Study" is then used as a basis to compare the use of SIMPL-1 with other languages on various machines. Programming principles, practices and computer operation are illustrated in the main body of the

report. Finally, the appendices contain detailed programming and operating instructions as well as more detailed examples.

Further work on implementing simulation methods with assembly language is continuing in areas such as (1) MACRO assembly language, (2) magnetic tape, and (3) drum interacting systems. These variations will be noted by different version numbers (i.e., SIMPL-2, etc.).

II. HOW DO SIMPL-1 AND FORTRAN COMPARE?

Most scientific programming for large digital computers is through FORTRAN. The main advantages of FORTRAN are that it is easy to use because it accepts statements which resemble algebraic mathematical formulas, and that the programmer need not concern himself with the manual operation of the machine.

For small to medium size scientific problems, FORTRAN does an adequate job. However, as problems become more complex, memory requirements and computer running time become excessive. Some scientific problems require over 65 K fast memory locations and from 10 min to 10 hr of running time to completely produce the desired answers.

When this happens, it becomes necessary to re-evaluate the problem-solving method. In fact, analog and recent hybrid computers have been used to overcome the economic penalties associated with FORTRAN and large expensive digital computers.

Most commercial and privately built hybrid computers use an altered FORTRAN package. This, of course, retains the basic equation-oriented advantages of FORTRAN. Long computer running times are decreased by solving the "high frequency" problems on the analog computer. In the hybrid environment the slowest processor is the digital computer (because the digital is a serial processor and an analog is a parallel processor). Since speed and memory are critical, changes in philosophy that decrease memory requirements and increase processing speed are desirable. (Of course, it is also desirable to maintain simple programming methods.)

In this respect it is useful to point out the disadvantages of FORTRAN compilers. First, the transformation of FORTRAN statements to machine language (called compiling) is very inefficient (approximately 33% for fixed-point computers). That is, the compiler produces three times more instructions than necessary to do the job, which in effect creates two problems. First, more core memory is required to hold the machine language (compiled) program, and second, more computer time is required to process the program.

High level interpreter programs, such as MIDAS, are even more wasteful of memory and processing time. For example, MIMAC⁽¹¹⁾ requires 25 K core locations to hold the interpretive program. However, simulator programs are easier to program than FORTRAN.

The SIMPL-1 method retains much of the programming simplicity of interpretive languages (like MIDAS) and significantly reduces the memory and computer running requirements to solve a problem (by factors of 5 to 500).^{*} A SIMPL-1 program is prepared by interconnecting mathematical building blocks with assembly language.

The relocatable feature of the SIMPL-1 assembler allows an assembled main program to call previously assembled hybrid subroutines through a linking loader. (Absolute hybrid programs are also possible.) By using the features of Hybrid DDT (Digital Debug Tape),⁽²⁴⁾ modifications to an assembled program can be made on-line without the need for reassembling.

The disadvantages of SIMPL-1 as implemented on the EASE 2133 analog computer (150 + amplifiers) and PDP-7 digital computer (8 K of 18 bit words) are:

- (1) The necessity to scale problem variables to overcome the fixed point characteristics of the digital computer. (In general, this is not a severe limitation because scaling is required for the fixed point analog computer.)
- (2) The necessity of programmer interaction with the computers.

Because of an unfamiliarity with scaling and machine operating procedures, most FORTRAN-oriented scientists and engineers could regard these as intolerable limitations. However, the economics of solving complex problems have shown that significant cost and time savings (up to 100 to 1 over modern large digital FORTRAN methods) can be realized through hybrid simulation. This should be adequate justification for learning and applying new hybrid techniques to large scientific simulation problems.

III. GENERAL COMPARISONS OF MACHINES AND METHODS

Very little published work is available on comparing machines and methods for solving scientific problems. It is therefore difficult to select a comparison criterion acceptable to all scientific computer users.

The Pilot Ejection Study used as an example in the MIDAS and MIMIC programming guides is being used by R. D. Brennan⁽¹⁾ of IBM as an industry-wide "bench mark" problem. Others, such as the MONSANTO^(2,3) and PHYSBE⁽⁴⁾ bench mark problems, require much more computer capability than the Pilot Ejection Study. However, they are not as widely used.

Since the Pilot Ejection Study was the easiest to program and most widely known bench mark problem, it was used to evaluate the relative efficiencies shown in Table 1 for the SIMPL-1 method. (The programs are shown in Appendices M and N.)

^{*} Programs like PACTOLUS⁽⁸⁾ and DES-1⁽⁷⁾ have been developed for on-line digital simulation. PACTOLUS is at least an order of magnitude slower than DES-1 and SIMPL-1.

TABLE 1. *Comparison of Speed and Efficiency for the Pilot Ejection Study*

<u>Method of Solving Problem</u>	<u>Minimum Computer Time Required to Give Equivalent Accuracy, sec</u>	<u>Relative Efficiency</u>
FORTTRAN		
PDP-7	7	1
UNIVAC 1108	1.4	5
MIMIC		
IBM 7090	45	0.155
UNIVAC 1108	2(a)	3.5
SIMPL-1 (all digital)	0.0615	110
SIMPL-1 (hybrid)	0.043	160
AD/4 analog computer	0.00043	16000

(a) *Neglects 26 sec input/output time (the IBM 7090 required 95 sec of I/O time). Five parameter runs were made to determine effect of DTMIN (minimum computing interval) on running time. A DTMIN of 0.0001 requires one more second than DTMIN of 0.001 and two more seconds than DTMIN of 0.01 sec.*

For this relatively trivial problem SIMPL-1 is from 110 to 160 times more efficient than FORTRAN as implemented on the fixed point PDP-7 computer.

In comparing digital computer speeds it is also necessary to compare accuracies. The PDP-7 FORTRAN computing time* listed in Table 1 utilized a rectangular integration scheme with a 0.01 sec step size. Since the problem only requires 0.43 sec of real-time to run, 43 time steps were taken. The maximum error in any variable was 1.8%. Parameter studies were then made to determine running time as a function of step size and accuracy. To obtain the same accuracy as real-time SIMPL-1 (both hybrid and digital) and the predictor-corrector integration methods used by MIMIC, a step size of 0.0013 sec and a computer time of 52 sec are required. The time required to process 0.43 sec of real-time with FORTRAN on the fixed point PDP-7 computer is:

$$T = \frac{0.0767}{(\text{Step Size})^{0.98}}$$

When FORTRAN was used on a UNIVAC 1108 (with floating point hardware) the problem required about 6 sec to compile and from 1.4 to 3 sec (depending on step size) to execute.

In ten times real-time, the hybrid method produced 41 updates, which is roughly equivalent to the 43 steps produced by FORTRAN with 0.01 sec time steps. Twenty percent more hybrid speed could have been realized by individually programming analog-to-digital and digital-to-analog conversion. In ten

* It took over 15 min to compile

times real-time the all digital SIMPL-1 method produced 29 time steps and was in error by 7.5%. By ratio, 44 time steps could be accommodated in about 7 times real-time to produce answers with a maximum error of 1.8%. Most values were within 0.5%, but in real-time, the overall accuracy is within 0.2%.

The FORTRAN memory requirements were not determined. However, the PDP-7 assembled FORTRAN compilation generated 3.3 times the number of instructions required by the hybrid SIMPL-1 program and 1.5 times the number required by the SIMPL-1 all digital program. The hybrid SIMPL-1 problem required 9.3%, and the SIMPL-1 all digital problem required 23.3% of the digital computers 8192 word memory. If the output variables are directly plotted (on a scope, X-Y plotter, or strip chart recorder), the memory requirements of the all digital problem are reduced by 7.6%.

To the novice, the detailed analysis of computing times given above may appear to be an unnecessary exercise. For a problem like the Pilot Ejection Study there is little gained in speeding up the problem solutions (even above the 52 sec required by FORTRAN when using an 0.001 time step).

From the above speed comparisons the relative speed advantages of SIMPL-1 are demonstrated. This speed advantage is realized even for nontrivial problems which require 10 min to 10 hr of large computer processing times. SIMPL-1 offers speed advantages up to 500 over all digital FORTRAN methods (implemented on machines with floating point hardware).

To the experienced hybrid programmer it may appear that an attempt was made to compare "apples and oranges" by comparing software floating point with hardware floating point methods. Also, no attempt was made to estimate the necessary planning and educational costs for implementing the SIMPL-1 concept on a larger scale (i.e., company-wide basis). Criticism of this nature is indicative of the need for additional R & D on computer utilization.

Since such amazing speeds can be realized through hybrid techniques, there is ample justification for wider use of hybrid problem solving methods, especially when large multimillion dollar digital computers are made obsolete every 3 or 4 years by merely increasing the hardware speeds by factors of 2 to 10.

IV. SUMMARY OF SIMPL-1 OPERATING TECHNIQUES

Figure 1 summarizes the steps required to solve a hybrid computer program. It is generally recommended that programs first be punched on cards for editing convenience and more effective computer utilization. However, the computer's

* See Appendix G, page 5

** See Appendix G, page 6

FIGURE 1. Overall Programming and Operation Procedures

editor program is usually required, especially for nonstandard key punch characters, such as a backward slash (\).

The typical computer operating instructions shown in the blocks describing the EDITOR, ASSEMBLER, and DDT are for illustrations only. Conditions of programs in-core will necessitate variations from the given operating instructions. Finally, as a programmer becomes more proficient, he will discover and master specialized techniques for increasing his effectiveness.

V. PROGRAMMING PRINCIPLES

A SIMPL-1 program (like an analog computer) is composed of numerous computing blocks with inputs and outputs. The building blocks (or operational elements) are listed in Appendix B. Each element has the following characteristics:

- (1) A symbol for use in block diagrams. This can merely be a box with the mathematical symbol included.
- (2) A calling sequence. Generally one of the inputs must be loaded in the accumulator before the subroutine is called with a JMS instruction. (Other descriptive information is included in the remarks column of Appendix B.)
- (3) An output in terms of the inputs. The output is generally left in the accumulator following the last calling sequence instruction.

VI. DRAWING THE BLOCK DIAGRAM

The equations to be solved determine the method of ordering the building blocks. For example, consider the system described by the following differential equations.

$$\frac{dV}{dt} + KV^2 + g \sin \theta = 0$$

$$\frac{d\theta}{dt} + g \frac{\cos \theta}{V} = 0$$

The block diagram (see page 10) can be drawn by utilizing the principle of repeated integration.

- (1) Solve equations for highest order derivatives

$$\frac{dV}{dt} = -KV^2 - g \sin \theta$$

$$\frac{d\theta}{dt} = -g \frac{\cos \theta}{V}$$

- (2) Assume that the highest order derivative for each equation is available as the output of an operational element and integrate successively until each of the lower derivatives and the functions themselves are available. (Note analog integrators invert the sign.)

- (3) Note that the values for forming the highest order derivatives are now available as the output of operational elements.
 (4) Form as the output of computing elements the highest derivatives by using additional computing elements as necessary.

The final block diagram is formed by connecting the units in (2) and (4) above together with digital-to-analog and analog-to-digital conversion trunks after allowance is made for sign reversal of the analog components.

VII. SCALING

Since both the analog and digital computers used in the hybrid system are fixed point machines it is necessary to amplitude scale the equations. (Time scaling may also be necessary, which usually involves changing the gains on all integrators by the same factor.) All analog numbers range between ± 100 , and all variables transmitted to and from the digital computer must range between ± 99.99 . However, once a number is in the digital computer, it can range between ± 1599.99 .

Analog computing variables should be scaled for operating in a range above 10 V. Digital variables, on the other hand, give better results if their magnitudes are above 50 V. If warranted, digital programs like MIDAS⁽⁵⁾ and APACHE⁽⁶⁾ can be used to obtain preliminary scaling information.

The derivative calculations for dV/dt and $d\theta/dt$ will illustrate the scaling technique.

$$\frac{dV}{dt} = -KV^2 - g \sin \theta$$

$$\frac{d\theta}{dt} = -g \frac{\cos \theta}{V}$$

where

$$K = 1.699 \times 10^{-3}$$

$$V(0) \approx 900$$

$$\theta(0) \approx 0.043 \text{ (radians)}$$

It is clear that K and θ are too small and V is too large. Since V and θ are analog variables, scaling factors of 0.1 and 1000 seem reasonable. That is

$$0.1 V = 90$$

$$1000 \theta = 43$$

Since K is entirely a digital variable, a scale factor of 10^5 is reasonable, or

$$10^5 K = 169.9$$

The scaled block diagrams for the derivative calculations are:

The scale factors written above take into account the division by 100 of SIMPL-1 multiply routines. A scale factor of 0.05 was chosen for $\frac{dV}{dt}$ because $0.05 \frac{dV}{dt} \approx 61.0$. Since a scale factor of 0.1 was chosen for V on the analog

computer, the gain on the analog integrator must be 2. The scale factor for θ was chosen to be 1000 ($1000 \frac{d\theta}{dt} \approx 43.0$).

The completed scaled block diagram for this system of equations is:

VIII. CODING THE PROGRAM

Once the scaled block diagram is completed the problem is ready for coding. (See Appendix A and Appendix B for explanation of SIMPL-1 and assembly language coding.) Like MIDAS programming (or analog computer programming) coding is accomplished by interconnecting the computing elements. This procedure is explained by: (1) showing how individual blocks are connected, (2) showing the program sequence for the main program loop, (3) showing the analog-to-digital and digital-to-analog conversion program sequence, (4) showing the completed program, and (5) summarizing the necessary elements of every SIMPL-1 program.

METHOD FOR CONNECTING BUILDING BLOCKS

The term $10^{-1}KV^2$ shown in the block diagram is generated with the following coding sequence:

```
LAC V
JMS HSQ$
JMS HMPY2$
LAC K
DAC SAVE1#
```

The first instruction (LAC V) loads the accumulator with the value of V. The second instruction directs the value of V left in the accumulator to a

JMS HMPY2 \$
LAC K

MAIN PROGRAM SEQUENCE (Without A/D and D/A Conversion)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42									
												LAC V																																						
												JMS HSCF\$																																						
												JMS HMPY2\$																																						
												LAC K													/-0.1KV**2																									
												DAC SAVE1#																																						
												LAC THETA																																						
												JMS HMPY2\$																																						
												LAC (63.66																																						
												JMS X.01\$																																						
												DAC SAVE2#																																						
												JMS HSLN\$																																						
												JMS HMPY2\$																																						
												LAC G																																						
												JMS X.01\$																																						
												ADD SAVE1																																						
												JMS X.5\$																																						
												DAC VDOT														/-0.05VDOT																								
												LAC SAVE2																																						

A/D AND D/A CONVERSION

The analog-to-digital transfer of V and θ is accomplished with the following sequence:

```
LAC (Ø
JMS ADC$
1
DAC V
DAC THETA
```

The digital-to-analog transfer for $-0.05 \frac{dV}{dt}$ and $-1000 \frac{d\theta}{dt}$ is accomplished by:

```
LAC (Ø
JMS DAC$
1
LAC VDOT
LAC DTHETA
```

THE COMPLETED PROGRAM

The program coding for this example can be completed as shown in Figure 2 by adding a title, inserting program constants, initializing the computer, performing a computing termination check, and adding JMP BGN, and a PAUSE statement at the end of the LISTING.

SUMMARY SHOWING NECESSARY ELEMENTS OF SIMPL-1 PROGRAMS

Every program should have the following sections:

- (1) A title
- (2) A program constants section which includes
 - (a) Storage of program constants (such as G and K)
 - (b) Function generator storage (if required)
 - (c) Time delay table storage (if required)
 - (d) Instructions for automatic priority interrupt channels
 - (e) Teletype header messages
- (3) Computer initialization for
 - (a) Modified instruction set (MIST)
 - (b) Clearing software flags
 - (c) Setting up teletype subroutines
 - (d) etc.
- (4) CALCULATION of analog computer initial conditions (if required)
- (5) Main program loop
 - (a) Analog to digital conversion
 - (b) Interconnecting of mathematical building blocks
 - (c) Digital-to-analog transfer
 - (d) End of compute test (if required)
 - (e) Jump to starting address of main computing loop

(6) PAUSE

By comparing the summary given above with the listing in Figure 2, it is obvious that:

- (1) The title is: EXAMPLE TITLE
- (2) The program constants are G and K (no other constants are necessary)
- (3) The only computer initialization required is to select the modified instruction set with the instruction MIST
- (4) Calculation of analog initial conditions are not required
- (5) The starting address of the main programming loop is BGN. The main computing loop contains all essential elements which include changing the analog computer mode to initial conditions when computing is terminated.
- (6) It has a PAUSE statement

IX. COMPUTER OPERATION

For convenience, the program was first keypunched on cards for hand editing. (Two or three errors were found and corrected.) A paper tape of the program was then obtained by using the PUNCH DECK program (see SIMPL-1 System Program Index, Appendix F). After calling the EDITOR into core memory from DECTAPE, the paper tape source program was read in for final editing and listing. The first block in Figure 3 shows the editor's program listing. The A and comment "append the following to the editor" is included to show what the listing would look like if the program were typed directly into the EDITOR. The N typed at the end of the program is a punch and paging command to the EDITOR.

Normal assembler operating instructions were then followed to obtain a binary (actually called funny format) assembled tape. Since # symbols were not used in the program for defining DTHETA, THETA, V, and VDOT, an error message was printed. The assembler automatically corrected the error and proceeded with the assembly. However, if other errors had been made, additional diagnostics would have been printed. Following the error diagnostics is an alphabetic and numeric listing of tags and subroutines. (Note SIMPL-1 library routines are listed without address specification.) Addresses for library routines are assigned by the linking loader as indicated in the next block. A symbol table for running the program under control of DDT is also punched at this time. A minus sign (-) typed out with the DDT symbol table indicates a missing subroutine.

The symbol table tape was read in by typing TABLE\$. After that the teletype responded with the octal numbers 743 and 13503. (The space between 743 and 13503 is unused core.)

A (append the following to the editor)

```

EXAMPLE TITLE
100/
/PROGRAM CONSTANTS
G, 32.2
K, 169.9 /10**5(K)
/INITIALIZE COMPUTER
BGN, MIST
/MAIN PROGRAM LOOP
LAC (0 /ANALOG TO DIGITAL TRANSFER
JMS ADC$
I
DAC V
DAC THETA
LAC V /MAIN COMPUTING LOOP
JMS HSO$
JMS HMPY2$
LAC K
DAC SAVE1#
LAC THETA
JMS HMPY2$
LAC (63.66
JMS X.1$
DAC SAVE2#
JMS HSIN$
JMS HMPY2$
LAC G
JMS X.1$
ADD SAVE1
JMS X.5$
DAC VDOT /-0.05VDOT
LAC SAVE2
JMS HCO$
JMS HMPY3$
LAC G
LAC V
DAC DTHETA /-1200 DTHETA
LAC (0 /DIGITAL TO ANALOG TRANSFER
JMS DAC$
I
LAC VDOT
LAC DTHETA
LAC THETA
CAS (0 /DONE COMPUTING
JMP BGN /NO
NOP /YES
LAC (3 /YES, SET IC MODE
JMS SMODE$
JMP BGN
  
```

PAUSE

" (Punch paper tape of source program)

Normal assembler operating instructions were followed)

Assembler error messages:

```

EXAMPLE TITLE
DTHETA 155
THETA 156
V 157
VDOT 158
  
```

symbols were not used when defining these symbols in main program. The assembler corrected this error and proceeded with the assembly

Assembler Output Contd

```

EXAMPLE TITLE
ADCS 172
RGN 172
DAC$ 155
DTHETA 155
G 170
HCO$ 181
HMPY2$ 153
HMPY3$ 154
HSIN$ 156
HSP$ 157
K 160
SAVE1 181
SAVE2 153
SMODE$ 154
THETA 156
V 157
VDOT 160
X.1$ 157
X.5$ 160
  
```

(Alphabetic listing of tags and subroutines)

storage locations

```

G 172
K 181
RGN 172
SAVE1 153
SAVE2 154
DTHETA 155
THETA 156
V 157
VDOT 160
HSP$ 157
DAC$ 155
HCO$ 181
ADCS 172
SMODE$ 154
HMPY2$ 153
HMPY3$ 154
HSIN$ 156
X.1$ 157
X.5$ 160
  
```

(Numeric listing of tags and subroutines)

address assignments are made by linking loader

Normal instructions for loading relocatable program through linking loader and running program under control of DDT were followed:

Hybrid and user subroutines loaded by linking loader

```

SMODE 742
HSIN$ 430
ADCS 531
HSP$ 265
HSIN$ 362
HMPY2$ 157
X.1$ 256
X.5$ 247
HCO$ 312
HMPY3$ 273
DAC$ 651
SMODE$ 475
  
```

a minus sign (-) typed out with listing indicates a missing subroutine

TABLES (Called DDT and read in symbol tape)

next open address 743 13503

BGN Bottom of DDT

INPUTS To punch a new binary tape call PUNSY\$ DDT by addressing 16000, pressing START and then typing the instructions shown.

FIGURE 3. Teletype Output from Editor, Assembler and Linking Loader

The next instruction typed was the starting program TAG' (BGN'). Since the program ran, no debugging with DDT was necessary. (Appendix L gives an example of how to debug with DDT and Appendix H lists typical operating and programming errors.)

The last block of Figure 3 shows the instruction sequence for obtaining a single assembled funny format tape. This is an especially useful feature of DDT because funny format patches to the assembled program can be made without reassembling the entire program. The disadvantage is that a new typed source program listing is not available.

Of secondary importance is the ease in reloading the program. The single tape is loaded by calling DDT, typing DEBUG\$, and the starting TAG' (BGN'). If a tape had not been punched, the library would have to be reloaded through the linking loader and the DDT symbol tape reloaded.

X. RESULTS

Figure 4 is a strip chart recording of V and THETA versus TIME. For comparison, the same problem was simulated using FORTRAN. Figure 5 shows the FORTRAN statements, the compiled assembly language, and three strip chart recordings.

FIGURE 4. SIMPL 1 Solution to Example Problem

FORTRAN Listing

```

EXAMPLE TITLE
G=32.2
AK=0.001699
CONTINUE
CALL INPUT(2,V,THETA)
V=10.*V
THETA=0.001*THETA
DVDI=0.05*(AK*V+2+G*SINF(THETA))
DTHETA=1000.*(G*COSF(THETA)/V)
CALL OUTPUT(2,DVDI,DTHETA)
GO TO 100
STOP
END
  
```

FORTRAN Assembled Listing

```

EXAMPLE TITLE
DECIMA  FIODEC
        EXTERNAL .101,.102,.103,.104,.105,.106,.107,.108,.109
        EXTERNAL .1057A,.10DEC

        CALST
        EXTERNAL EARTH
        JMS EARTH
        EFM
        LAC .AAA
        DAC $G.

        LAC .AAB
        DAC $AK.

.100,
        EXTERNAL INPUT.

        CAL INPUT.
        ARX (2
        ARF $V.
        ARF $THETA.

        EFM
        LAC .AAC
        FMP V.
        DAC $V.

        LAC .AAD
        FMP THETA.
        DAC $THETA.
  
```

FORTRAN Assembled Listing Continued

```

EXTERNAL XPN,EXP

LFM
LAC (2
FLO
DAC TEM+0
LAC V.
JMS EXP
LAC TEM+0
FMP AK.

EXTERNAL SINP.

CAL SINP.
ARF $THETA.
DAC TEM+3
LAC G.
FMP I TEMAD
ADD TEM+3
FMP .AAE
DAC $DVDI.

EXTERNAL COSF.

CAL COSF.
ARF $THETA.
LAC G.
FMP I TEMAD
FDP V.
FMP .AAI
DAC $DTHETA.

EXTERNAL OUTPU.

CAL OUTPU.
ARX (2
ARF $DVDI.
ARF $DTHETA.

LFM
JMP .100

LAC (0 HLT
JMP .-1

HLT
6 65945 -104857
-3 114017 -10501
4 81920 0
-8 67108 -35651
-3 104857 -104857
10 128000 0
TEM,
TEM+6/
START
  
```

FIGURE 5. FORTRAN Solution for Example Problem

The first strip chart shows the results obtained by solving the problem in real-time (Analog Integrators). Since the FORTRAN frame time was only 0.1 sec the solution did not converge. The second figure shows the result for 0.1 sec real-time. The solution converged, but it required 10 times as much time as the SIMPL-1 program, and the stair-step for DVDT is noticeable. When solving the problem in 0.01 times real-time, the solution converges without stair-stepping of DVDT. The conclusions are that the FORTRAN on a fixed point machine is slow. For this particular example, it is 10 times slower than the SIMPL-1 method.

Additional examples of varying complexity are explained in Appendices L through O.

XI. DESCRIPTION OF COMPUTING SYSTEM

The PNL Hybrid Computing System (see References 22 through 35) consists of a Beckman Model 2133 analog computer, a Digital Equipment Corporation PDP-7 general purpose digital computer, Adage Inc. data conversion equipment, and the associated control interface. The system provides complete hybrid capability for both data and control.

ANALOG COMPUTER

The Beckman Model 2133 analog computer contains 156 amplifiers (72 are integrators), 32 multipliers, and 16 function generators. It has 240 servo-set pots that utilize the DO/IT system. This computer contains two iterative mode controllers (IDACAS). The Model 2133 may be coupled to a Beckman Model 1132 analog computer for added hardware capability to solve large problems. Peripheral devices for the Model 2133 analog computer include an X-Y plotter, a Brush eight-channel strip-chart recorder, a cathode-ray tube display, a Friden flexowriter, a Tektronix 564 storage oscilloscope, and a digital logic system.⁽³²⁾

The digital logic system extends the capability of the analog computer by adding up-down counters, preset counters, buffer and shift registers, gates, analog comparators, and analog switches. The digital logic provides program interrupt signals that are dependent on the value (voltage) of an analog variable. It also provides analog computer "flags" that will initiate, upon flag searching, a digital computer program branch.

DIGITAL COMPUTER

The PDP-7 is a binary, fixed point digital computer containing an 8192 word random access core memory, hardware multiply/divide, two clocks, and 16 levels of automatic priority interrupt. The 18 bit word allows the user to directly address 8192 core locations while executing a memory reference instruction. The computer has a basic read/restore cycle time of 1.75 μ sec, and an average divide time of 11 μ sec.

It is difficult to precisely size the digital computer in terms of analog computing blocks. However, the digital computer replaces the following analog elements on our largest hybrid simulation:

- 180 amplifiers
- 17 integrators
- 35 variable product multipliers
- 120 POTS
- 30 function generators
- 8 variable time delays (which could not be done by all analog means)

CENTRAL PROCESSOR MODIFICATIONS

The central processor has been modified to perform added arithmetic functions.⁽²⁹⁾ Changes include the addition of the instructions, Compare and Three-way Branch (CAS), One's Complement Subtract (SUB), and Increment the Accumulator (IAC). These three instructions are referred to as the modified instruction set. Their use is controlled by two IOT instructions: MIST and MICL (modified instruction "set," and modified instructions "clear").

Two clocks have been installed in the central processor. The first is crystal controlled with a frequency of 5 kHz, and the second operates from line frequency of 60 Hz. Both clocks operate through the Automatic Priority Interrupt as interval times.

PERIPHERAL DEVICES

The PDP-7 has associated with it peripheral devices that allow input and output of user programs and data. A simplified block diagram of the system is shown in Figure 6.

A model KSR 35 Teletypewriter is interfaced to the computer and operates in simplex or duplex mode and off-line.* Standard PDP-7 programs using the KSR 35 have been modified to use automatic vertical and horizontal tabulation and form feed.

A 300 character per second paper tape reader and 63 line per second paper tape punch provide high speed paper tape input/output with the PDP-7. These units use fan-fold paper tape having eight channels of data processed in either alphanumeric or binary modes.

A dual Dectape, Type 555, is coupled to the digital computer. Each reel of tape contains three million bits of information, and data is transferred at the rate of 90,000 bits per second.

* A 300 line per minute line printer will be incorporated into the system by January of 1969.

FIGURE 6. Hybrid Computer System Simplified Block Diagram

A 25,000 word drum memory (having an average access time of 20 msec, and a transfer rate of 50,000 words per second) is used for bulk storage of user programs. The drum transfers blocks of data to and from core memory via the Data Break facility of the PDP-7.

Source program card decks and data cards may be input to the PDP-7 through an IBM 713 card reader. It reads cards under program control at the rate of 150 cards per minute. Cards are used when off-line program preparation or on-line program modification is desired.

HYBRID CONTROL INTERFACE

The data interface includes a 24-channel high-speed multiplexer, an analog-to-digital converter, and 24 digital-to-analog converters. In addition, the interface allows the digital computer to perform the following control functions: (1) set analog computer modes, (2) sense analog computer mode status, (3) address variables in the analog computer, (4) read the value of a variable into core memory using the digital voltmeter, and (5) set analog computer potentiometers.

ACKNOWLEDGMENTS

The work reported in this document is the result of a team effort by the Process Simulation and Analysis Section. The efforts of Mr. L. H. Gerhardstein in conceiving, designing, and developing the major portion of the software system is of paramount importance. Second to Mr. Gerhardstein's efforts, are those of Mr. W. F. Lenzke who developed the POT Editor, List Deck, Punch Deck, Card Read, and assisted in the development of several other systems programs. Mr. Lenzke also provided support to Mr. M. D. Erickson and Mr. K. M. Busness in designing and fabricating the computer hardware for the card reader, magnetic drum, and hybrid control interface.

Mr. C. R. Cole developed four SIMPL-1 subroutines, solved the illustrative example problems, and contributed valuable ideas on organizing the appendix. Mr. H. F. Foote developed one of the SIMPL-1 subroutines and Mr. P. J. Dionne provided the MIMIC computer running times for comparison with SIMPL-1. Mr. G. R. Taylor developed the analog computer maintenance routines and the AD/4 analog simulation of the Pilot Ejection Study for comparative purposes. Finally, Mr. G. A. Worth supplied the discussion on assembly language methods for multiplication and division.

LITERATURE

BENCH MARK PROBLEMS

1. Brennan, R. "Digital Simulation," presented at National Simulation Councils Meeting, Atlantic City, New Jersey. May 3, 1968.
2. Giese, C. "Determination of Best Kinetic Coefficients of a Dynamic Chemical Process by On Line Digital Simulation," Simulation, vol. 8, no. 3, pp. 141-145. March 1967.
3. Nesbit, R. A., and R. D. Engel. "An Example Program for the Determination of Chemical Rate Coefficients from Experimental Data," Simulation, vol. 8, no. 3, pp. 133-137. March 1967.
4. McLeod, J. "PHYSBE--A Physiological Simulation Bench Mark Experiment," Simulation, vol. 6, no. 7, pp. 324-329. December 1966.

AMPLITUDE SCALING AIDS

5. Harnett, R. T., F. S. Sansom, and L. M. Warshawsky. "MIDAS--An Analog Approach to Digital Computation," Simulation, vol. 3, no. 3, pp. 16-43. September 1964.
6. Borgin, G. H. "APACHE--Some Encouraging Experiences," Simulation, vol. 6, no. 1, p. 16. January 1966.

SOME DIGITAL ANALOG SIMULATORS

7. Levine, L. "The DES-1, A New Digital Computer for Solving Differential Equations," Simulation, vol. 4, no. 4, p. 264. April 1965.
8. Brennan, R. D. "PACTOLUS--A Simulator Language Which Makes a Digital Computer Feel Like an Analog Computer (Sorta Kinda)," Simulation, vol. 3, no. 2, pp. 13-19. August 1964.
9. Sansom, F. J., and H. E. Petersen. Mimic Programming Manual, SEG-TR-67-31. Research and Technology Division Systems Engineering Group, Wright-Patterson AFB, Ohio. July 1967.
10. Strauss, J. C. "The SCi Continuous System Simulation Language (CSSL)," Simulation, vol. 9, no. 6, pp. 281-303. December 1967.
11. MIMAC--A Digital System for Continuous Simulation, McDonnell Automation Company. February 1968.

RECOMMENDED ANALOG COMPUTER REFERENCES

12. Strong, J. D. and G. Hannauer. "A Practical Approach to Analog Computers," Instruments & Control Systems, vol. 35, pp. 60-71. August 1962.
13. Parisot, P. E. "Analog Computers," Chemical Engineering, p. 137. September 1959.
14. Johnson, C. L. Analog Computer Techniques, Second Edition, McGraw-Hill, New York, 1963.
15. Truitt, T. D., and A. E. Rogers. Basics of Analog Computers, Rider, Inc., New York. 1960.
16. Rogers, A. E. and T. W. Connolly. Analog Computation in Engineering Design, McGraw-Hill. 1960.

RECOMMENDED DIGITAL COMPUTER REFERENCES

17. Benrey, R. Understanding Digital Computers, Rider, Inc., New York. 1967.
18. Murphy, J. A. Basics of Digital Computers, vol. 1, 2, 3, Rider, Inc., New York. 1958.
19. McCracken, D. D. Digital Computer Programming, John Wiley & Sons, Inc., New York. 1963.
20. Stein, M. L., and W. D. Munro. Computer Programming, Academic Press, New York. 1964.
21. Knight, K. E. "Changes in Computer Performance," *Datamation*, vol. 12, no. 9. September 1966.

LITERATURE APPLICABLE TO SIMPL-1

22. Instructions--2100 Series Operator's Manual, Beckman Instruments, Inc., Berkeley, California. August 1964.
23. PDP-7--Users Handbook, F-75, Digital Equipment Corporation, Maynard, Massachusetts. 1965.
24. "PDP-7--Symbolic Tape Editor," Digital-7-1-S, Digital Equipment Corporation, Maynard, Massachusetts. 1965.
25. "PDP-7--DDT Debugging System Programming Manual," Digital-7-4-S, Digital Equipment Corporation, Maynard, Massachusetts. 1965.
26. "PDP-7--FORTRAN II," Digital-7-2-S, Digital Equipment Corporation, Maynard, Massachusetts. 1965.
27. "PDP-7--DECSYS-7," Digital-7-5-S, Digital Equipment Corporation, Maynard, Massachusetts. 1965.
28. Erickson, M. D. The Pacific Northwest Laboratory Hybrid Computer System, BNWL-538. Pacific Northwest Laboratory, Richland, Washington. January 1968.
29. Draper, W. D. A Modified Instruction Set for the FFTF Instrumentation Prototype, BNWL-451. Pacific Northwest Laboratory, Richland, Washington. August 1967.
30. Busness, K. M. Hybrid Computer-Card Reader Interface, BNWL-CC-1671. Pacific Northwest Laboratory, Richland, Washington. June 3, 1968.
31. Busness, K. M. A Magnetic Drum Interface for the PNL Hybrid Computer Facility, BNWL-CC-1651. Pacific Northwest Laboratory, Richland, Washington. May 30, 1968.
32. Digital Logic Handbook, pp. 12-15, Digital Equipment Corporation, Maynard, Massachusetts. 1967.
33. Gerhardstein, L. H. Unpublished Data. Pacific Northwest Laboratory, Richland, Washington. To be published 1968. (Proposed title: SIMPL-1 Systems Technical Manual)
34. Taylor, G. R. Unpublished Data. Pacific Northwest Laboratory, Richland, Washington. (Proposed title: Analog Diagnostic Program)
35. Lenske, W. F. Unpublished Data. Pacific Northwest Laboratory, Richland, Washington. (Proposed title: POT Editor)

APPENDICES

APPENDIX A

SOURCE LANGUAGE SYMBOLS

NAMES

The Table below shows that names (or tags), reference storage locations where constants, variables, instructions or other names are stored.

TYPE OF NAME	PROGRAM LISTING		
	TAG	STORED VALUE	COMMENTS
Constant*	PIE,	3.14	/The constant π is stored (in octal form) in storage location PIE
Variable**	T,	0	/A variable such as temperature is stored in location called T
Instruction	WHERE,	JMS JOE	/The instruction JMS JOE is stored in location WHERE
Name	XY,	TBL1	/Location XY is where the name TBL1 is stored

*Names can also stand for constants, For example:

PIE = 3.14.

Whenever PIE is used in the program the assembler replaces it with the octal equivalent of 3.14

**Storage locations for named variables containing a # or > are automatically assigned by the assembler.

Symbolic names (or address tags) may use up to six letters and digits. Characters following the sixth symbol of a name are ignored (eg. the symbolic name CONVERT is interpreted as CONVER). The first character of a name must be:

1. Letter (A through Z)
2. Period (.)
3. Dollar sign (\$)

The remaining characters can be a letter, period, dollar sign or a number (0 thru 9). The dollar sign and period also have special assembler functions. The period is used as a voltage indicator when preceded by a digit or as a current address indicator when preceded by a space and followed by a space, tab, carriage return, +, or - sign. The dollar sign is normally reserved for user and library subroutine communication. (Pseudo instructions can be used for address tags or variable names.)

Examples:

\$CL1
TEMP
POWER1
SPHEAT
.60

NUMBERS

A number is any grouping of six (6) or less digits excluding voltage (.) or decimal (') indicators. For example:

100' (decimal integer)
1599.99 (voltage)
354617 (octal integer)
0.52 (voltage)
.52 (a name not a number because a digit to the left of decimal point was omitted)

CONTROL

The arithmetic and program control characters are summarized below:

ARITHMETIC*		PROGRAM CONTROL	
SYMBOL	USE	SYMBOL	USE
↑	Exponentiation	↵ (Carriage Return)	Terminate Word
*	Multiply	+ (Tab)	Terminate Word
\ (Cap L)	Divide	, (Comma)	Assign Symbolic Address
␣ (Space)	Add	= (Equal)	Define Parameter
+	Add	/ (Slash)	Comments - Slash Must Follow ✓ or +
-	Subtract		Storage - Slash Must Follow Alpha Numeric Symbols
!	Inclusive OR	(	Initiate Constant
&	Logical AND	)	Terminate Constant
' (Apostrophe)	Decimal Indicator	#	Assign Single Register
.(Decimal Point)	Voltage Indicator	>	Assign Multi Register (Normally Three)
		\$	Designates User or Library Routines or Locations
Example use		.(Decimal Point)	Current Address Indicator
LAC (10' + 2*3		(Form Feed)	End of a Source Program Page (Ignored by Assembler)
is equivalent to			
LAC ('18			
or LAC (22			

*For a detailed explanation of most of the arithmetic and control functions refer to the PDP-7 symbolic assembler programming manual. Differences between the SIMPL1 instructions and DEC's instructions reflect changes to the standard software system.

The example shown as a footnote to this arithmetic section shows how literal constants may be represented. Care must be exercised in using these symbols to insure producing the right numbers. For example:

10.0+3 ≠ 1000.0 volts

here is why

The decimal equivalent of 10.0 volts = $(\frac{2^{13}}{100}) 10'$
= $C*10'$

Therefore

$10.0+3 = (C*10')^3 = (\frac{2^{13}}{100})^3 (10')^3 = (\frac{2^{13}}{100})^2 (1000.)$

However, the result shown in the accumulator would be garbage because of accumulator overflow. The largest number permitted is 1599.99. If 1000.0 (volts) were desired, the following notation could be used.

$1.0 * 10^4 + 3 = (C*1)*10^4 + 3$
= $C \times 1000 = 1000.$

If the voltage 40.0 were desired the following sequence could be used:

$1000.\backslash'25 = (C)(1000)\backslash'25 = (C)(40) = 40.$

If the voltage 43 were desired the following sequence could be used:

$1000.\backslash'25 + 3. = 43.$

because $\frac{(C)(1000')}{25'} + (C)(3') = C(40') + C(3') = 43.$

In order to verify if an arithmetic assembler operation will produce the desired number a numerical unit analysis similar to that given above should be performed.

Assembler arithmetic operations cannot be used for multiplying problem variables. They can be used for multiplying constants. (Variable multiplication is accomplished with SIMPL1 library routines like HMPY2\$.)

APPENDIX BLIST OF SIMPL-1 FUNCTIONS

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
<u>1. ARITHMETIC FUNCTIONS</u>			
ADDITION	ADD	LAC X ADD Y	1. TIME = 3.5 μ sec 2. AC = X + Y 3. See Hybrid Instruction Set
SUBTRACTION	SUB	LAC X SUB Y	1. TIME = 3.5 μ sec 2. AC = X - Y 3. See Hybrid Instruction Set 4. MIST must precede sub-instruction
NEGATION	CMA	CMA	1. See Hybrid Instruction Set
MULTIPLY	HMPY1\$	LAC X JMS HMPY1\$ Y	1. TIME = 33 - 38 μ sec 2. AC = $\frac{X*Y}{100}$ 3. Y < 100.
MULTIPLY	HMPY2\$	LAC X JMS HMPY2\$ LAC Y	1. TIME = 35 - 40 μ sec 2. AC = $\frac{X*Y}{100}$
MULTIPLY	HMPY3\$	LAC X JMS HMPY3\$ LAC Y LAC Z	1. TIME = 59 - 67 μ sec 2. AC = $\frac{X*Y}{Z}$
DIVIDE	HDIV\$	LAC X JMS HDIV\$ LAC Y	1. TIME = 47 μ sec 2. AC = $100 \frac{X}{Y}$
MULTIPLY BY 10	X10\$	LAC X JMS X10\$	1. TIME = 19 - 23 μ sec 2. AC = 10*X
MULTIPLY BY 5	X5\$	LAC X JMS X5\$	1. TIME = 20 - 23 μ sec 2. AC = 5*X
MULTIPLY BY 2	X2\$	LAC X JMS X2\$	1. TIME = 20 μ sec 2. AC = 2*X
MULTIPLY BY 0.5	X.5\$	LAC X JMS X.5\$	1. TIME = 12 μ sec 2. AC = 0.5*X
MULTIPLY BY 0.2	X.2\$	LAC X JMS X.5\$	1. TIME = 9 - 13 μ sec 2. AC = 0.5*X
MULTIPLY BY 0.1	X.1\$	LAC X JMS X.1\$	1. TIME = 9 - 13 μ sec 2. AC = 0.1*X

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
<u>2. TRANSCENDENTALS</u>			
SQUARE	HSQ\$	LAC X JMS HSQ\$	1. TIME = 28 μ sec 2. $AC = \frac{X^2}{100}$, $X < 399.99$ = 1599.99, $X \geq 399.99$
CUBE	HCUBE\$	LAC X JMS HCUBE\$	1. TIME = 45 μ sec 2. $AC = \frac{X^3}{1000}$, $X < 251.97$ = 1599.99, $X \geq 251.97$
SQUARE ROOT	HSQRT\$	LAC X JMS HSQRT\$	1. TIME = 90 μ sec 2. $AC = 10\sqrt{X}$, $X \geq 0$
COMMON LOG	HLOG\$	LAC X JMS HLOG\$	1. TIME = 100 μ sec 2. $AC = 100 \log_e X$, $X \geq 0$
EXPONENT (BASE 10)	HEXP\$	LAC X JMS HEXP\$	1. TIME = $75 - 80 \mu$ sec ($\frac{X}{100}$) 2. $AC = 10^{\frac{X}{100}}$, $X < 320.41$ = 1599.99, $X \geq 320.41$
COSINE	HCOS\$	LAC X JMS HCOS\$	1. TIME = 70 - 90 μ sec 2. $AC = 100 \cos(\frac{\pi}{2} * \frac{X}{100})$ (100. = 90°)
SINE	HSIN\$	LAC X JMS HSIN\$	1. TIME = 77 - 97 μ sec 2. $AC = 100 \sin(\frac{\pi}{2} * \frac{X}{100})$
QUANTIZER	QUAN\$	LAC X JMS QUAN\$ A	1. TIME = 45 μ sec 2. $AC = A * n\{\frac{X}{A}\}$
LIMITER(+ and -)	LIMIT\$	LAC X JMS LIMIT\$ A B	1. TIME = 21 - 32 μ sec 2. $AC = X$ if $B < X < A$ = B if $X \leq B$ = A if $X \geq A$
<u>3. LOGICAL FUNCTIONS</u> (See PDP-7 Instruction Set)			
AND	AND	LAC X AND Y	1. TIME = 3.5 μ sec 2. $AC = A \cap B$
EXCLUSIVE OR	XOR	LAC X XOR Y	1. TIME = 3.5 μ sec 2. $AC = (A \cap B') \cup (A' \cap B)$
COMPARE	CAS	LAC X CAS Y	1. TIME = 3.5 μ sec 2. MIST Instruction Must Preceed CAS 3. if $AC > Y$ no skip AC = Y skip 1 instruction AC < Y skip 2 instructions

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
<u>4. FUNCTION GENERATORS</u>			
FUNCTION GENERATOR (Equal Spaced X's)	FG2\$	LAW TAG JMS FG2\$ LAC X (function table format) TAG, X0 XMULT LRS RX N Y0 Y1 . . . YN	1. TIME = 93 - 104 μ sec 2. AC = F(X) 3. Equal spaced points 4. Linear interpolation between points 5. L = 1 if X is outside of function table 6. X0 = First X coordinate N = No. of segments in function Y0 = First Y coordinate 7. Obtain XMULT(a voltage) and "RX" from table below $XMULT = A \frac{(\text{Table Value})}{\Delta X}$
			Table for calculating values for "MULTIPLIER" and "SHIFT COUNT" for FG2\$ & FG3\$

<u>Range of ΔX</u>	<u>Range of ΔY</u>	<u>A(Voltage)</u>	<u>RX and RY</u>
400.01 TO 800.00		1280000.0	17
200.01 TO 400.00		640000.0	16
100.01 TO 200.00		320000.0	15
50.01 TO 100.00		160000.0	14
25.01 TO 50.00		80000.0	13
12.51 TO 25.00		40000.0	12
6.26 TO 12.50		20000.0	11
3.13 TO 6.25		10000.0	10
1.57 TO 3.12		5000.0	7
0.79 TO 1.56		2500.0	6
0.40 TO 0.78		1250.0	5
0.20 TO 0.39		625.0	4
0.10 TO 0.19		312.5	3

Example for FG2\$:

If ΔX were chose to be 10 volts, the value
of "RX" would be 11 and

$$XMULT = \frac{20000.}{10.} = 2000.$$

Example for FG3\$:

If ΔX were chose to be 30 volts and ΔY 1 volt
then from the table

$$RX = 13$$

$$XMULT = \frac{40000.}{30} = 1333.33$$

$$RY = 6$$

$$YMULT = \frac{2500.}{1.} = 2500.$$

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>																																								
FUNCTION GENERATOR OF TWO VARIABLES	FG3\$	LAW TABLE JMS FG3\$ LAC X LAC Y ... (function table format) TABLE, X0 XMULT LRS RX N Y0 YMULT LRS RY M Z00 Z10 . . . Z00 Z01 Z0M Z1M . . . ZNM	1. TIME = 272 - 304 μsec 2. AC = F(X,Y) 3. L = 1 if X or Y outside of function table 4. First order interpolation between equally spaced points (ΔX and ΔY can be different) 5. See table for determining $RX = \frac{A}{X}$ $RY = \frac{A}{Y}$ 6. N = Number of X segments = 1-number of X points M = Number of Y segments = 1-number of Y points 7. TABLE FORMAT <table><tr><td></td><td>Y₀</td><td>Y₁</td><td>...</td><td>Y_M</td></tr><tr><td>X₀</td><td>Z₀₀</td><td>Z₀₁</td><td>...</td><td>Z_{0M}</td></tr><tr><td>X₁</td><td>Z₁₀</td><td>Z₁₁</td><td>...</td><td>Z_{1M}</td></tr><tr><td>.</td><td>.</td><td>.</td><td>.</td><td>.</td></tr><tr><td>.</td><td>.</td><td>.</td><td>.</td><td>.</td></tr><tr><td>.</td><td>.</td><td>.</td><td>.</td><td>.</td></tr><tr><td>.</td><td>.</td><td>.</td><td>.</td><td>.</td></tr><tr><td>X_N</td><td>Z_{N0}</td><td>Z_{N1}</td><td></td><td>Z_{NM}</td></tr></table>		Y ₀	Y ₁	...	Y _M	X ₀	Z ₀₀	Z ₀₁	...	Z _{0M}	X ₁	Z ₁₀	Z ₁₁	...	Z _{1M}	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	X _N	Z _{N0}	Z _{N1}		Z _{NM}
	Y ₀	Y ₁	...	Y _M																																							
X ₀	Z ₀₀	Z ₀₁	...	Z _{0M}																																							
X ₁	Z ₁₀	Z ₁₁	...	Z _{1M}																																							
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X _N	Z _{N0}	Z _{N1}		Z _{NM}																																							
FUNCTION GENERATOR (Arbitrary Spaced X's)	FG1\$	LAC X JMS FG1\$ TAG (function table format) TAG, N X1 X2 . . . XN Y1 Y2 . . . YN	1. TIME = 151 + 14*N 2. AC = F(X) 3. Spacing of Points is arbitrary (X's must be in ascending order) 4. Linear interpolation between points 5. N = Number of points in function 6. X1 = First X coordinate XN = N th X coordinate Y1 = First Y coordinate YN = N th Y coordinate																																								

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
FUNCTION GENERATOR	FG4\$	LAC X JMS FG4\$ TAG M (function table format) TAG, N X0 XMULT LRS RX Y0 Y1 : : : YN	1. TIME = 250 + 100*M 2. AC = F(X) 3. Equal spaced points 4. Value of M determines order of interpolation. M may have values from 1 to 5 5. X0 = first X coordinate N = No. of segments in function Y0 = First Y coordinate 6. Obtain XMULT and RX from same table used for FG2\$ $XMULT = \frac{A(\text{from table})}{\Delta X}$ 7. Can be used for cross plotting (For straight line interpolation use FG1\$ or FG2\$).

5. TIME DEPENDENT FUNCTIONS

CALCULATE
NUMBER OF
CLOCK PULSES

ASYNCHRONOUS OPERATION
(For problems that do not use a
clock service subroutine)

41/	ISZ \$CL1	1. TIME = 47 - 67 μ sec
50/	ISZ \$CL2	2. Clock and API must be turned on as required in the program
	:	3. Can be used with RINT\$
	JMS CNP\$	4. AC = N _p (number of clock pulses)
	0	5. The location following JMS CNP\$(i.e. 0) holds the last clock value.
	...	

SYNCHRONOUS OPERATION
(For programs requiring periodic updating
through a clock service routine)

41/	ISZ \$CL1	1. TIME = 47 - 67 μ sec
50/	JMS CLSRV	2. Must be used for synchronous programs such as time delays if ICL\$ and RCL\$ are not used
	:	3. Clock and API must be turned on as required in program
	JMS CNP\$	4. AC = N _p (number of clock pulses)
	0	5. The location following JMS CNP\$(i.e. 0) holds the last clock value.
	:	
CLSRV,	LAC NCLOCK	
	ADD \$CL2	
	DAC \$CL2	
	LAC NCLOCK	
	CMA	
	IAC	
	DAC \$CL1	

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
INITIALIZE REAL-TIME CLOCK	ICL\$	JMS ICL\$ TS FC NIC NII TAG1 OR Ø TAG2 OR Ø TAG3 OR Ø TIME, Ø	<ol style="list-style-type: none"> 1. TIME = 135 + TIME IN TAG1, etc. 2. To be used in program initialization to <ol style="list-style-type: none"> a. Set the clock frequency location \$FC b. Set the time scale location \$TS c. Initialize the clock API hardware d. Compute clock counters for compute and IC modes e. Establish user program locations for performing synchronized time dependent operations (time-delay, etc.) f. Establish a location (TIME) in the users program that will contain the time (voltage scaling) since compute mode was entered. (The digital computer mode is entered by storing the number 4 in location MODE\$ or by using JMS AMODE\$ to check if analog computer is in compute.) The time scale (TS) is taken into account in computing this value. g. Save all hardware registers (AC, link, etc.) at interrupt time 3. The number of computing frames is given by: $\frac{\text{Time(voltage scaling)}}{\text{Loop time/(computing fraction)}}$ <p>where the computing fraction is:</p> $\frac{10^6}{(\text{NIC})(\text{TS})} - (135 + \text{TIME in TAG1, etc.} - \frac{(\text{FC})(3.5)}{(\text{NIC})(\text{TS})})$ $\frac{10^6}{(\text{NIC})(\text{TS})}$ 4. The digital computer should calculate at least 10-20 values of each variable per cycle of its highest frequency. 5. NOMENCLATURE <ul style="list-style-type: none"> TS = Time scale (any number > 1) FC = Clock frequency (60' or 50000') NIC = Number of iterations/sec in compute mode NII = Number of iterations/sec in IC mode TAG1 = TAG in user's program requiring interrupt service during compute mode (Ø for no action) TAG2 = TAG in user's program requiring interrupt service during IC mode (Ø for no action) TAG3 = TAG in user's program requiring interrupt service during HOLD mode (Ø for no action) TIME = LOCATION CONTAINING TIME (in sec of voltage scaling) since entering compute modes
RELEASE CLOCK API CHANNEL	RCL\$	TAG1, ... : JMP RCL\$	<ol style="list-style-type: none"> 1. TIME = 2. When using the subroutine ICL\$, the programmer can specify a location where control should be transferred for time dependent operations. (See TAG1, TAG2, or TAG3, in the ICL\$ listing). The last instruction of the time dependent subroutine must be a JMP RCL\$ instruction

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
TIME DELAY	TD1\$	LAW TAG JMS TD1\$ Ø Ø LAC W XX Ø Ø Ø DAC .-2 LAC YIN HLT (table format) TAG, TAU LAC (NI N WMAX TAG+N+4/	1. TIME = $240 + 10.5 * N(I.C.)$ = 160 to 176 (Compute) 2. The program must be synchronized by the real-time clock 3. The storage location \$MODE must contain the computer mode (see note 2 given with AMODE\$). a. The IC mode must be entered at least once to initialize the delay. b. In the HOLD mode the delay is frozen. c. In compute the delay works properly. 4. NOMENCLATURE NI = Number of iterations per sec(problem time) TAU = Minimum time delay (for maximum flow) N = Number of segments in the delay function W = Flow variable WMAX = Maximum flow (corresponds to TAU) YIN = Input variable (temperature) RMAX = Maximum rate of change YIN λ = Approximate time constant if YIN is a decaying function ω = Approximate frequency if YIN is a sinusodial function. τ_{MAX} = Maximum time delay ERROR = Error in function 5. DEFINING EQUATIONS $N = (R_{MAX}) \frac{\tau_{MAX}}{ERROR}$ $N_I = \frac{R_{MAX}}{ERROR} * \frac{W_{MIN}}{WMAX} + 2$ (N_I must be an integer multiple of 1,2,4,5) $R_{MAX} = \frac{YIN_{MAX}}{\lambda}$ (first order decay) = $\omega YIN_{(MAX)}$ (second order) 6. Program will place analog computer in IC MODE and HLT digital computer if the following inequality is violated $1 > \frac{N_I * TAU}{N} < 16$ 7. AC = YIN(t- τ)
RECTANGULAR INTEGRATION	RINT\$	LAW . JMP RINT\$ LAC \$MODE LAC NP LAC YØ LAC X LLSS K or LRSS K ADD Y Ø DAC Y : NOP JMP .+1	1. TIME = $57 + 71 * N$ μ sec where N = Number of integrations nested in calling sequence 2. The mode variable must be provided according to the standards of \$MODE 3. LLSS K or LRSS K produces an integrator gain of $(2^{**}(+K))$ or $(2^{**}(-K))$ respectively 4. For synchronous operation NP = Number of clock pulses since last calculation (see CNP\$ or ICL\$ and RCL\$) 5. YØ = Initial condition X = Input variable $\left(\frac{dY}{dt}\right)$ Y = Output variable 6. AC = $\int X dt + YØ$ 7. Any number of integrations can be nested in single calling sequence

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
6. A/D AND D/A CONVERSION & CONTROL			
ANALOG TO DIGITAL BLOCK TRANSFER	ADC\$	LAC (N JMS ADC\$ M DAC X DAC Y NOP : : DAC Z ...	<ol style="list-style-type: none"> 1. $TIME = 45 + 19.25*A + 17.5*B$ where A = Number of used channels B = Number of unused channels in the selected block overload servicing time used channels = 60 μsec unused channels = 35 μsec 2. If any channels are overloaded and the A/D over- load API channel is on the channels will be automatically serviced. The value is set to <u>+99.99</u>. Upon return to the calling program AC = No. of overload channels 3. N = First channel of block M = Last channel of block 4. A NOP in the calling sequence can be used to skip a channel. In the calling sequence given above channel N+2 is not used
DIGITAL TO ANALOG BLOCK TRANSFER	DAC\$	LAC (N JMS DAC\$ M LAC X LAC Y SKP : : LAC (-25.00 LAC Z	<ol style="list-style-type: none"> 1. $TIME = 44 + 32*A + 19*B$ where A = Number of used channels B = Number of unused channels in the selected block 2. If any channel is given a value greater than 99.99 (17777 OCTAL) an error counter is incre- mented and that D to A channel is set to <u>+99.99</u>. Upon return to the calling program AC = No. of overload channels 3. N = First channel of block M = Last channel of block 4. A SKP in the calling sequence can be used to skip a channel. In the calling sequence given channel N+2 is skipped. Channel M-1 is used to transfer -25 volts to analog computer.
DETERMINE ANALOG COMPUTER MODE	AMODE\$	JMS AMODE\$	<ol style="list-style-type: none"> 1. $TIME = 18 - 28 \mu$sec 2. The AC at exit and the memory location \$MODE are set to one of the following values 0 if POT set 1 if Hold 2 if Standby 3 if I.C. 4 if compute 3. AMODE\$ should be used with all mode sensitive subroutines (integrator, time-delay, etc.) if the digital mode is controlled by the analog mode 4. After JMS AMODE\$ has been used, the program may use LAC \$MODE
SET ANALOG MODE	SMODE\$	LAC X JMS SMODE\$	<ol style="list-style-type: none"> 1. $TIME = 45 \mu$sec 2. X = desired mode of compute(comment 2-AMODE\$) 3. This routine also sets the memory location \$MODE 4. This routine is useful for controlling the analog computer rep-op-rate 5. If X is not 0 through 4 the computer mode is not changed, the link is set and \$MODE is not set to new value

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
<u>7. NUMBER CONVERSION</u>			
<u>INTEGER BCD TO BINARY CONVERSION</u>	IDBC\$	LAC X JMS IDBC\$...	1. TIME = 16 - 20 μ sec 2. Converts four digit unsigned BCD digits (1248) to binary integers 3. Example use: POT settings (sent through the interface) from the analog computer are in integer BCD. If it were desired to make a digital computer calculation on this POT setting, the BCD number must first be converted to binary 4. X = BCD NUMBER 5. AC = Binary equivalent of BCD NUMBER
<u>VOLTAGE BCD TO VOLTAGE BINARY CONVERSION</u>	VDBC\$	LAC X JMS VDBC\$...	1. TIME = 40 - 47 μ sec 2. Converts interface BCD voltage to voltage binary 3. BIT 0 is used for sign (1 = negative) 4. BIT 1 is for decimal point If BIT 1 = 1 the number is xxx.x If BIT 1 = 0 the number is xx.xx 5. Example use: Amplifier voltages read into digital computer from digital voltmeter are in voltage BCD. This routine converts the BCD number to a digital voltage for processing with normal hybrid routines 6. AC = BINARY VOLTAGE
<u>INTEGER BINARY TO BCD(1248) CONVERSION</u>	IBDC\$	LAC X JMS IBDC\$(error)(Okay)	1. TIME = 90 μ sec 2. Input binary number must be positive and less than 1000 ₁₀ 3. If there is an input error the return point follows JMS IBDC\$ on the listing. The binary integer is not converted AC = Binary integer. If there is no input error the return point is the second instruction following JMS IBDC\$ AC = BCD NUMBER 4. Example of use: Once a POT setting is calculated by the digital computer its value must be converted to BCD for transfer through the interface to the analog servo set POT system
<u>BINARY VOLTAGE TO BCD(1248) CONVERSION</u>	VBDC\$	LAC X JMS VBDC\$(error)(Okay)	1. TIME = 90 μ sec 2. Input (binary) voltage must be positive and less than 100.00 volts 3. If there is an input error the return point follows JMS VBDC\$ on the listing. The voltage is not converted AC = BINARY VOLTAGE If there is no input error the return point is the second instruction following JMS VBDC\$ AC = BDC NUMBER

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
<u>8. TELETYPE OUTPUT LIBRARY</u>			
A. INITIALIZATION			
a. API	IATYP\$	LAW TBUF LMQ LAW TBUFE JMS IATYP\$	1. Initialization must be a part of the main hybrid program 2. This subroutine also enables the teletype API channel 3. TBUF = First address of memory buffer TBUFE = Last address of memory buffer 4. The memory buffer must contain at least two words 5. Example for setting 101 word buffer using the tags TBUF and TBUFE TBUF, TBUF+100/ TBUFE, TBUFE+1/
b. NOW INTERRUPT ITYP\$		JMS ITYP\$	1. Should be called in initialization part of main program
B. ACCUMULATOR PRINTING			
a. OCTAL			
1. Signed	TOCTS\$	JMS TOCTS\$	Left adjusted and leading zeros are suppressed
2. Unsigned	TOCT\$	JMS TOCT\$	Left adjusted and leading zeros are suppressed
b. DECIMAL			
1. Signed	TDECS\$	JMS TDECS\$	Left adjusted and leading zeros are suppressed
2. Unsigned	TDEC\$	JMS TDEC\$	Left adjusted and leading zeros are suppressed
c. VOLTAGE	TVOLT\$	JMS TVOLT\$	
d. BINARY CODED DECIMAL (BCD)			
1. BCD Voltage	TBCDV\$	JMS TBCDV\$	1. Input is interface BCD <u>Voltage</u> Format The sign and decimal point are used 2. Output format is XX.XX or XXX.X
2. BCD INTEGER	TBCDP\$	JMS TBCDP\$	1. Input is interface BCD integer 2. All four digits are typed
3. BCD INTEGER	TBCDI\$	JMS TBCDI\$	1. Input is four digits of 1,2,4,8 BCD 2. Left zeros are suppressed
e. ASCII CHARACTERS			
1. API Typing	ATYP\$	JMS ATYP\$	1. ASCII character in the AC is stored in the buffer and is typed when the teleprinter is ready. If the buffer is full, the program will loop until there is an open location
2. Non-Interrupt	TYP\$	JMS TYP\$	1. Has an automatic time out of one second so hardware initialization is not necessary
3. TRIM	T3T\$	JMS T3T\$	1. Words are coded by the hybrid assembler PSEUDO - Instruction "TRIM" 2. Each character has six bits

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
C. SPACING PROGRAMS			
a. Carriage return and line feed	TCR\$	JMS TCR\$	
b. Teletype space	TSP\$	JMS TSP\$	
c. Form feed	TFRM\$	JMS TFRM\$	
d. Horizontal tabulation	TTAB\$	JMS TTAB\$	
D. MESSAGE PRINT	TMSG\$	LAW TAG JMS TMSG\$	1. Every message must have a tag before the PSEUDO instruction TEXT. (See explanation of TEXT given in Appendix IV on pseudo instructions.) 2. Messages can be placed a. At the end of the main program b. At the end of subroutines c. As a separate subroutine
E. DEVICE TRANSFER	TTYP\$	LAW TYP\$ DAC TTYP\$	1. Any of the teletype output programs (TMSG\$, TVOLT\$, etc.) can use other output devices by setting the location of the output subroutine into the location TTYP\$ (i.e.) LAW PUNCH DAC TTYP\$ Would result in a punched paper tape output 2. JMS I TTYP\$ can be used instead of JMS ATYP\$ for printing
9. <u>SPECIAL NAMES & STORAGE LOCATIONS</u>			
CLOCK FREQUENCY	\$FC		1. Used by time dependent programs 2. Normally 50000' or (11610 ₈) but can be changed by user
TIME SCALE	\$TS		1. Used by time dependent programs 2. Normally 1 but can be any number greater than 1 (see comments for ICL\$)
CLOCK	\$CL1		
CLOCK	\$CL2		
MODE STORAGE	\$MODE		1. Stores mode of analog computer if read by AMODE\$ 2. See comments for AMODE\$
DVM CHANNEL SELECTOR	\$MXDVM		1. Contains instruction MX23
<u>(SPECIAL NAMES USING AUTO INDEX REGISTER)</u>			
	FGI\$		1. Name associated with auto index register 17 and is used by function generator programs
	\$INTI		2. Name associated with auto index register 16 and is used by the integration subroutine RINT\$
	\$TDI		1. Name associated with auto index register 15 and is used by the time delay program TDI\$

(Auto index registers 10 thru 14 are available to the user)

(SPECIAL STORAGE LOCATIONS)

Memory locations 40 thru 57 are reserved as return points for API interrupts (see Appendix VI). Some hybrid programs have been clobbered by spurious API pulses when these locations have been used in the regular program. Therefore, its advisable to put HALTS in all unused API channel locations.

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
10. CARD READER			
READ A CARD	CARD\$	CONVCA\$ = 10 CARDB\$ = 11 JMS CARD\$ JMS CNVCD\$ or JMS CONVT\$	1. Must select an auto index register for CARDB\$ (and CNVCA\$ if CNVCD\$ is used for conversion from IBM code to ASCII). 2. The calling sequence given will read a card and convert the IBM characters to ASCII. If IBM characters are desired use: CARDB\$ = 10 JMS CARD\$ 3. The information contained in the card buffer (CBUF\$ thru CBUF\$ + 110) will be lost unless it is transferred out before another card is read. 4. If a CAF is used in the main program, the card reader must be made ready after the program has been started. 5. Subroutine CARD\$ disables the API. It is enabled before returning to the main program. 6. CNVTC\$ converts the contents of the card buffer to ASCII, character for character in the same buffer. If a character cannot be located in the conversion table a backward slash is put in its place. 7. CNVCD\$ performs all operations of CNVTC\$ and converts two or more spaces on a card with a carriage return and line feed. (A blank card is interpreted as a carriage return and a line feed.) 8. <u>SPECIAL KEYPUNCH CHARACTERS:</u> Conflicting characters from one keypunch to another, as well as "invisible" characters, have made several special codes necessary. # 3 over 4 punch ! 1 over 4 punch "FORM" 1 over 2 over 4 punch or "END OF PAGE" The keys on some machines are imprinted with a character other than that which is desired. DESIRED IMPRINT (%) "Box shape" = # + & @ ' or - (not the regular minus)

LIST OF SIMPL-1 FUNCTIONS (contd)

<u>FUNCTION</u>	<u>SYMBOLIC NAME</u>	<u>CALLING SEQUENCE</u>	<u>REMARKS</u>
11. SET POTS AND READ ANALOG COMPONENTS UNDER CONTROL OF USERS PROGRAM			
SET POTS ON THE ANALOG WITHIN USERS PROGRAM	PSET\$	LAW TBL2 JMS PSET\$ LAW TBL2 N ... (table format) TBL1, :P000 :P025 :P002 ... TBL2, 9.99 10.00 6.23	<p>1. TBL1 contains the interface codes for the pot addresses. TBL2 contains the corresponding pot settings. N is the number of pots to be set.</p> <p>2. The program requires the use of one multiplexer line. The line normally selected is MX23 and the SEL hole on the analog must be patched to MX23. If a different MX channel is desired then it must be patched to the SEL hole and the following sequence must precede the use of PSET\$</p> <p style="text-align: right;">LAC (MXN DAC \$MXDVM</p> <p>where N is the number of the selected channel.</p> <p>3. This program requires that the teletype be initialized and uses library routines TMSG\$, TTYP\$, VDBC\$, IDBC\$.</p> <p>4. Pots can also be set by using the POT COEFFICIENT EDITOR described in Appendix VII, but this method must be used external to the users program.</p>
TO READ ANALOG COMPONENTS AND STORE THE READ- INGS IN A TABLE AND PRINT THE READINGS IF DESIRED. (This can be accomplished within the users program)	READ\$	CLL or STL LAW TBL1 JMS READ\$ LAW TBL2 N ... (table format) TBL1, :A005 :M012 :F013 ... TBL2, Ø Ø Ø ...	<p>1. TIME = µsec per component (when printout is not requested.)</p> <p>2. TBL1 contains a list of analog component addresses and TBL2 is a table where the readings are stored. N is the number of components to be read.</p> <p>3. The program will list the components and their readings if the link is set when the program is called or it will simply read and store the values if the link is cleared.</p> <p>4. This program requires the use of a multiplexer line and it must be patched to the SEL hole. The channel normally selected for use is channel 23, but any channel N may be selected if it is patched to the SEL hole and the following sequence precedes the use of READ\$</p> <p style="text-align: right;">LAC (MXN DAC \$MXDVM ...</p> <p>5. This program requires that the teletype be initialized and uses the library routines TTYP\$, TMSG\$, TCR\$, TTAB\$, and TVOLT\$.</p> <p>6. The READ POTS program and POT EDITOR program described in Appendix VII can also be used for reading pots, but these programs must be executed external to the users program.</p>

APPENDIX C HYBRID ASSEMBLER INSTRUCTIONS

MEMORY REFERENCE INSTRUCTIONS			
Symbol	Code	Operation	Cycle
CAL	00	Call subroutine.	2
I	02	Indirect addressing.	1
DAC	04	Deposit accumulator.	2
JMS	10	Jump to subroutine.	2
DZM	14	Deposit zero in memory.	2
LAC	20	Load accumulator.	2
XOR	24	Boolean exclusive OR.	2
ADD	30	Add, 1's complement.	2
TAD	34	Add, 2's complement.	2
* SUB	34	Subtract.	2
XCT	40	Execute.	1
ISZ	44	Increment and skip if zero.	2
AND	50	Boolean AND.	2
SAD	54	Skip if AC different from memory.	2
* CAS	54	If, AC > Y No skip AC = Y Skip 1 inst. AC < Y Skip 2 inst.	2
JMP	60	Jump.	1

*The instruction MIST must precede these statements.

MODIFIED INSTRUCTION SET			
MIST	705302	Modified instruction set.	1
MICL	705202	Modified instruction clear.	1

OPERATE INSTRUCTIONS			
Symbol	Code	Operation	Event Time
OPR	740000	Operate group or no operation.	
or			
NOP	740000		
CMA	740001	Complement accumulator.	3
CML	740002	Complement link.	3
OAS	740004	Inclusive OR AC switches with AC.	3
RAL	740010	Rotate AC and link left.	3
RAR	740020	Rotate AC and link right.	2
HLT	740040	Halt.	-
SMA	740100	Skip if AC<0.	1
SZA	740200	Skip if AC=0.	1
SNL	740400	Skip if link#0.	1
SKP	741000	Skip unconditionally.	1
SPA	741100	Skip if AC positive.	1
SNA	741200	Skip if AC#0.	1
SZL	741400	Skip if link#0.	1
IAC	742000	Increment AC.	3
RTL	742010	Rotate AC and L left two places.	2,3
RTR	742020	Rotate AC and L right two places.	2,3
CLL	744000	Clear link.	2
STL	744002	Set link#1.	2,3
RCL	744010	Clear link, then rotate AC and L left.	2,3
RCR	744020	Clear link, then rotate AC and L right.	2,3
CLA	750000	Clear AC.	2
CLC	750001	Clear and complement AC.	2,3
LAS	750004	Load AC from switches.	2,3
GLK	750010	Get link into AC 17.	2,3
LAW	76XXXX	Load the AC with LAW XXXX.	-
LAM	777777	Load AC minus (ie. LAM -5)	-

EAE INSTRUCTIONS			
Symbol	Code	Operation	Time(sec)
EAE	640000	No operation.	1.75
LRS	640500	Long right shift.	1.6+0.1n
LRSS	660500	Long right shift, signed.	1.6+0.1n
LLS	640600	Long left shift.	1.6+0.1n
LLSS	660600	Long left shift, signed.	1.6+0.1n
ALS	640700	Accumulator left shift.	1.6+0.1n
ALSS	660700	Accumulator left shift, signed.	1.6+0.1n
NORM	640444	Normalize, unsigned.	2.4+0.35n+0.2m
OAMQ	642000	OR MQ+AC, Results in MQ.	1.75
NORMS	660444	Normalize, signed.	1.6+0.1n
MUL	653122	Multiply, unsigned.	1.6+0.1n
MULS	657122	Multiply, signed.	2.4+0.1n+0.25m
DIV	640323	Divide, unsigned.	2.4+0.1n+0.25m
DIVS	644323	Divide, signed.	2.4+0.35n+0.2m
IDIV	653323	Integer divide, unsigned.	2.4+0.35n+0.2m
IDIVS	657323	Integer divide, signed.	2.4+0.35n+0.2m
FRDIV	650323	Fraction divide, unsigned.	2.4+0.35n+0.2m
FRDIVS	654323	Fraction divide, signed.	2.4+0.35n+0.2m
LACQ	641002	Load AC with C(MQ).	1.75
LACS	641001	Load AC with C(SC).	1.75
CLQ	650000	Clear MQ.	1.75
ABS	644000	Take absolute value of AC.	1.75
GSM	664000	Get sign and magnitude.	1.75
OSC	640001	Inclusive OR the SC into the AC.	1.75
OMQ	640002	Inclusive OR the MQ into the AC.	1.75
CMQ	640004	Complement the MQ.	1.75
LMQ	652000	Load MQ with C(AC).	1.75

n = shift count
m = one bits in multiplier

INPUT/OUTPUT TRANSFER INSTRUCTIONS			
Symbol	Code	Operation	Cycles
PROGRAM INTERRUPT			
IOF	700002	Interrupt off. Disable the PIC.	1
ION	700042	Interrupt on. Enable the PIC.	1
PERFORATED TAPE READER			
RSF	700101	Skip if reader flag=1.	1
RCF	700102	Inclusive OR reader buffer into AC and clear flag.	1
RRB	700112	Read reader buffer and clear reader flag.	1
RSA	700104	Reader in alphanumeric.	1
RSB	700144	Reader in binary.	1
PERFORATED TAPE PUNCH			
PSF	700201	Skip if punch flag=1.	1
PCF	700202	Clear punch flag.	1
PSA or PLS	700204	Punch alphanumeric.	1
	700206		
PSB	700244	Punch binary.	1
DECTAPE SYSTEM			
MMRD	707512	Read one word into AC.	1
MMWR	707504	Write one word from AC.	1
MMSE	707644	Select transport from AC 2-5.	1
MMLC	707604	Set DECTape control from AC 12-17.	1
MMRS	707612	Read status bits into AC 0-8.	1
MMDF	707501	Skip on DECTape data flag.	1
MMBF	707601	Skip on DECTape block end flag.	1
MMEF	707541	Skip on DECTape error flag.	1

TELETYPE KEYBOARD			
Symbol	Code	Operation	Cycles
XSF	700301	Skip if keyboard flag=1.	1
KRB	700312	Read the keyboard buffer and clear flag.	1
TELETYPE TELEPRINTER			
TSF	700401	Skip if teleprinter flag=1.	1
TCF	700402	Clear the teleprinter flag.	1
TLS	700406	Load teleprinter buffer, select and print; set flag.	1
MULTIPLEXER			
MXRN	701101	Random select.	1
MXSE	701102	Sequentially select.	1
MXRP	701104	Repetitively select.	1
MXO	701202	Select Ch. 0 and convert.	TI50
MX1	701222	1	1
MX2	701242	2	2
MX3	701262	3	3
MX4	711202	4	4
MX5	711222	5	5
MX6	711242	6	6
MX7	711262	7	7
MX8	721202	8	8
MX9	721222	9	9
MX10	721242	10	TI60
MX11	721262	11	2
MX12	731202	12	3
MX13	731222	13	4
MX14	731242	14	5
MX15	731262	15	6
MX16	704502	16	7
MX17	704522	17	8
MX18	704542	18	9
MX19	704562	19	TI70
MX20	714502	20	1
MX21	714522	21	2
MX22	714542	22	3
MX23	714562	23	4

(REQUIRES ONE CYCLE)

MAGNETIC DRUM MEMORY			
Symbol	Code	Operation	Cycles
DCLR	706006	Load core loc. counter & prepare to read. Loads AC 5-17 into DCL.	
DCLW	706046	Load core loc. counter & prepare to write. Loads AC 5-17 into DCL.	
DRSE	706001	Skip on drum error.	
DRDN	706101	Skip on drum transfer completion.	
DCLC	706002	Clear core loc. counter & drum buffer.	
DFC	706102	Clear drum block add. & field select.	
DF0	706126	Load drum block add. & select field #	
DF1	706146		
DF2	706166		
DF3	716106		
DF4	716126		
DF5	716146		
DF6	716166		
DF7	726106		
DF8	726126		
DF9	726146		
DF10	726166		
DF11	736106		

AUTOMATIC PRIORITY INTERRUPT			
Symbol	Code	Operation	Cycles
CAC	705501	Clear all channels.	
ASC	705502	Enable selected channel(s).	
DSC	705604	Disable selected channel(s).	
EPI	700044	Enable API.	
DPI	700004	Disable API.	
ISC	705504	Initiate break on selected channel.	
DBR	705601	Debreak.	
I/O EQUIPMENT			
IORS	700314	Input/output read status.	
TTS	703301	Skip if KSR 33 is used.	
CAP	703302	Clear all flags.	
SKP7	703341	Skip if processor is a PDP-7.	

DIGITAL VOLT METER			
Symbol	Code	Operation	Cycles
AALD	705002	Load address buffer register.	1
RYSP	701401	Skip if address flag=1.	1
		Skip if POT coef. flag=1.	1
		Skip if DVM RDBK flag=1.	1
PCLD	705102	Load POT coef. buffer register.	1
DVMR	701404	DVM read and load buffer reg.	1
DVML	701402	Load DVM buffer reg. into AC.	1
SET AND SENSE LINES			
SET1	702104	DLS set line 1.	1
SET2	704504	DLS set line 2.	1
SET3	704602	DLS set line 3.	1
SET4	704604	DLS set line 4.	1
SEN1	702101	Skip if sense line 1 is set.	1
SEN2	704501	Skip if sense line 2 is set.	1
SEN3	704601	Skip if sense line 3 is set.	1
SEN4	70XX01	Skip if sense line 4 is set.	1
DIGITAL TO ANALOG CONVERTERS			
DAO	702002	Select CH 0 and convert.	TI75
DA1	702022	1	6
DA2	702042	2	7
DA3	702062	3	8
DA4	712002	4	9
DA5	712022	5	TI80
DA6	712042	6	1
DA7	712062	7	2
DA8	722002	8	3
DA9	722022	9	4
DA10	722042	10	5
DA11	722062	11	6
DA12	732002	12	7
DA13	732022	13	8
DA14	732042	14	9
DA15	732062	15	TI90
DA16	702102	16	1
DA17	702122	17	2
DA18	702142	18	3
DA19	702162	19	4
DA20	712102	20	5
DA21	712122	21	6
DA22	712142	22	7
DA23	712162	23	8
ANALOG TO DIGITAL CONVERTER			
ADOV	701201	Skip if overload.	1
ADSF	701301	Skip if A/D flag set.	1
ADCV	701304	Convert.	1
ADRB	701312	Read A/D output.	1
ANALOG COMPUTER MODE SET AND SENSE			
SBSF	702001	Skip if standby flag is set.	1
SDBY	702004	Select standby mode.	1
ICSF	705001	Skip if IC mode is set.	1
IC	705004	Select IC mode.	1
HDSF	705101	Skip if hold mode is set.	1
HOLD	705104	Select hold mode.	1
CSF	705201	Skip if compute mode is set.	1
COMP	705204	Select compute mode.	1
PTSF	705301	Skip if POT set mode is set.	1
PSET	705304	Select POT set mode.	1
VSF	701501	Skip if servo flag is set.	1
SENV	701504	POT servo operate.	1
CARD READER			
CRSD	706401	Skip if card reader is done.	
CRSF	706501	Skip if card reader is ready.	
CRR	706504	Read cards.	
CBSF	706601	Skip if card reader buffer is loaded.	
CRBS	706602	Shift card reader buffer into AC one shift.	
CRBC	706604	Clear card reader buffer.	
CRDN	706701	Skip if card is done.	
CRCP	706702	Clear card reader flags.	
CRSP	706704	Stop card reader.	

(REQUIRES ONE SLOW CYCLE)
OF 3.36 usec

APPENDIX D

ASSEMBLER PSEUDO-INSTRUCTIONS*

RADIX CONTROL

DECIMAL All numbers not imbedded in symbols can be interpreted as decimal or octal, respectively. The initial mode is octal (see page 7). * A series of digits containing an apostrophe (') will be considered to be a decimal constant without regard to the pseudo-instructions OCTAL or DECIMAL. ('100 = 100₁₀ = 144₈).

VOLTS A series of digits containing a decimal point (.) is interpreted as a voltage as long as the decimal point is preceded by a digit (25.00 = 40008).

RATIO A series of digits containing a decimal point is interpreted as a ratio if the pseudo instruction RATIO is given before the number, under RATIO Control 0.25 = 40008. If the pseudo instruction VOLTS is used the assembler (decimal point) mode is returned to voltage.

:

A series of characters preceded by a colon (:) is converted from a 8,4,2,1 BCD sequence to its octal equivalent. Examples of the two forms are:

1. BCD POT Coefficient (:3805 = 034005₈)
2. BCD Analog Address (:P100 = 0604008₈)

TABLE FORMATION

SHIFT Causes the word preceding SHIFT to be rotated left nine binary positions and masked with 777000, leaving the right half blank. SHIFT is useful in forming double entry tables, tables with one value stored in the leftmost nine bits and another value in the rightmost nine bits.

SYMBOL TABLE CONTROL

EXPUNGE Removes all symbols (except pseudo-instructions) from the Assembler's symbol table.

FIX Resets the symbol table so that all currently defined symbols are part of the permanent symbol table. (This instruction overrides the ACS option to restore at assembly time.)

VARIABLE CONTROL

VARIABLES Places all currently defined variables at addresses beginning with the address indicated by the location counter before processing of the program continues.

BAR N Allows N registers for each variable containing the character > (see page 10).

MULTIPLICATION CONTROL

NORMUL This is the normal multiplication mode. It causes the answer from a "*" multiplication to be taken from the MQ (which contains the 18 least significant bits of the 36 bit product.)

MODMUL This causes the answer from a "*" multiplication to be taken from the AC (which contains the 18 most significant bits of the 36 bit product.)

PUNCH CONTROL

PUNDEF SYMB1, SYMB2, SYMB3 Punches definitions of the listed symbols in Assembler format.

SYMBOLS Punches ensuing symbols in Assembler format.

NOSYMBOLS Stops the punching of Assembler symbols and restores the mode set by ACS concerning DDT symbols.

PUNCH A Punches the value of the expression A in binary at this time.

(See pages 25-26 for a more detailed explanation)

END OF PROGRAM

NOINPUT Suppresses punching of the loader--punches a JMP 17600, the starting address of the FF Loader.

START A Upon loading, causes the program to start at register A.

PAUSE A Upon loading, causes the computer to halt. When CONTINUE is pressed, the program will start at A. (See page 17.)

*Page numbers refer to the PDP-7 Symbolic Assembler Programming Manual (Digital-7-3-S), Digital Equipment Corporation (1965)

LINKAGE CONTROL

INTERNAL This indicates that the symbolic name is a tag internal to the Sub-program example:

INTERNAL CONV
CONV, LACX#

INTERNAL is used to establish address definition for the linking loader.

In a sub-program, a tag containing a dollar sign (\$) may be used to eliminate the INTERNAL pseudo-instruction.

Example: \$CONV, LAC X

EXTERNAL This indicates that the symbolic name or names following are external to the main program or sub-program being assembled. The use of EXTERNAL must occur before the tags in question are mentioned in the symbolic listing.

Example: EXTERNAL X, Y
:
:
LAC X
:
:
JMS Y

The EXTERNAL pseudo-instruction completes the communication linkage necessary for the loader to load user sub-programs and library sub-routines.

Any external tag containing a dollar sign (\$) need not be mentioned in an EXTERNAL pseudo-instruction.

Example: JMP \$CONV

LIBFRM This is used following a sub-program to indicate that the program is to be punched in a special library format. All the library tapes are of this format. The user can create his own library tape by following the instructions for preparing a library tape. The linking loader will selectively load these programs. A LIBFRM pseudo-instruction may have any number of arguments but all the tags must have been referred to by an INTERNAL pseudo-instruction or must contain \$.

Example: LIBRARY FORMAT EXAMPLE

\$CONV, 0
LMQ
LAC (400000
EAE 122
631463
DAC VALUE
JMP I \$CONV
INTERNAL VALUE
VALUE, 0
LIBFRM \$ CONV, VALUE
PAUSE

In this example, a library format entry for \$CONV and VALUE will be punched at the front of the library tape. If either \$CONV or VALUE or both are called for in the main program (EXTERNAL VALUE must have been used), the linking loader would load the entire sub-program in the example into memory.

TEXT HANDLING

The following pseudo-instructions to the Hybrid Assembler can be used to generate character and text codes in a program:

CHAR This instruction causes the ASC II code of the next non-space character to be taken as a numeric value (LAW CHAR 0 = LAW 260)

TRIM This instruction causes the characters following the "space" after TRIM and preceding a termination character (carriage return or tab) to be placed in memory as ASC II trim codes. The ASC II trim codes are:

TRIM CODE	ASC II CODE	CHARACTER
0	---	none
1 to 32	301 to 332	A to Z
33 to 37	333 to 337	[,] , etc.
40 to 77	240 to 277	space, " , " , etc.

Example:

HEART, TRIM HAVE A HEART!
is identical to
HEART, 100126
54001
401005
12224
410000

A subroutine, such as, T3T\$ in the teletype output library can be used to print a ASC II trim coded word.

TEXT The pseudo-instruction "TEXT" causes text trim codes to be placed into memory. The text starts after the space, tab, or carriage return following TEXT and continues until a @ symbol is encountered. Any ASC II character except @ can be used in a TEXT coded message.

Example:

DOG, TEXT MY DOG HAS FLEAS@
will place the text trim codes for "MY DOG HAS FLEAS." into memory starting at symbolic address DOG.

A subroutine, such as, TMSG\$ in the teletype output library should be used print the encoded text.

*Pseudo - instructions are commands affecting the assembly process without appearing in the output. These instructions have no other effect upon assembly and are ignored when forming storage words. Pseudo - instructions may not be used as address tags or variable names.

ASSEMBLER PSEUDO-INSTRUCTIONS (contd)Use of PSEUDO-instruction LIBFRM For Preparing a User LIBRARY Format Tape

The "library format" pseudo-instruction, LIBFRM, is used following a sub-program to indicate that the program is to be punched in a special library format. All the library tapes are of this format. The user can create his own library tape by following the instructions for preparing a library tape. The linking loader will selectively load these programs. A LIBFRM pseudo-instruction may have any number of arguments but all the tags must have been referred to by an INTERNAL pseudo-instruction or must contain \$.

Example:

```
LIBRARY FORMAT EXAMPLE
$CONV,      0
            LMQ
            LAC (4000000
            EAE 122
            631463
            DAC VALUE
            JMP I $CONV
INTERNAL VALUE
VALUE,      0
LIBFRM $CONV, VALUE
PAUSE
```

In this example, a library format entry for \$CONV and VALUE will be punched at the front of the library tape. If either \$CONV or VALUE or both are called for in the main program (EXTERNAL VALUE must have been used), the linking loader would load the entire sub-program in the example into memory.

Preparing a Library Tape

A library format tape should be created as follows:

1. Terminate all the sub-program symbolic listings with a LIBFRM pseudo-instruction.
2. Select the proper ordering of the sub-program symbolic tapes so that sub-routines that are called by other library sub-routines come last.
3. Assemble the programs in reverse order to that desired. (Assembler output tape comes out of punch backwards.)
4. If a readable title is desired, assemble a dummy title maker as the first tape of the last program assembled.
5. The AC switches should be used to perform these functions:

ACS	POSITION	FUNCTION
0	up:	Look at switches 1-4
	down:	Ignore switches 1-4
1	up:	Suppress punching
	down:	Punch
2	up:	Suppress DDT symbols
	down:	Punch DDT symbols
3	up:	Take this title on this tape
	down:	Don't take title on this tape
4	up:	Restore assembler
	down:	Don't restore assembler
13	up:	Suppress readable title on library format tape
	down:	Punch readable title on library format tape.
14	up:	Type spaces for tabs
	down:	Type automatic tab
15	up:	Restore symbol table to permanent symbols (after symbol printouts if requested). Starting the next assembly with CONTINUE has the same effect.
	down:	No action taken
16	up:	Symbol printout, numerical order
	down:	No action taken
17	up:	Symbol printout, alphabetical order
	down:	No action taken

On library tapes, it is desirable to suppress the readable titles of the individual programs so as to shorten the tape. It is also desirable to suppress symbol punching for DDT so as to save space in DDT's symbol table.

NOTE: DDT symbols for "internal tags" are punched regardless of the condition of the AC switches.

APPENDIX E

AUTOMATIC PRIORITY INTERRUPT INSTRUCTIONS AND EXAMPLES

API CHANNEL FLAG ASSIGNMENTS

EXAMPLE 2. PERIODIC A/D CONVERSION OF CHANNEL 14 USING THE API AND 5 kHz CLOCK

API Channel	AC BIT	Speed (max)	Flag	Memory Location	Location	Instruction	Operation
0	2	50 kHz	DRUM (DRDN)	40	41	ISZ 4000	Instruction executed as a result of a break on API Channel 1 which is a 5 kHz clock. Each time the 5 kHz clock pulses, this instruction will be executed.
1	3	5 kHz	CLOCK 1	41			
2	4	VARIABLE	DLS PI2	42			
3	5	5 kHz	DECTAPE (MMDF) (MMBF) OR GATE (MMEF)	43	100	LAC (777755)	
4	6	85 kHz	A/D OVERLOAD (ADOV)	44	101	DAC 4000	Deposit initial value in clock location 4000.
5	7	VARIABLE	DLS PI 1	45	102	CAC	Clear all API Channels.
6	8	300 Hz	PT READER (RSF)	46	103	LAC (040200)	Load AC with API Channels to be enabled.
7	9	63.3 Hz	PT PUNCH (PSF)	47	104	ASC	Enable selected channels.
10	10	5 kHz	CLK OVERFLOW	50	105	EPI	Enable API.
11	11	10 Hz	TTY PRINT (TSF)	51	106	Continue	
12	12	10 Hz	TTY READ (XSF)	52			
13	13	VARIABLE	DRUM - (DRDN)	53			
14	14	VARIABLE	DLS PI 3	54	--		
15	15	2 Hz	CARD READER (CRSF) (CBSF) OR GATE (CRDN)	55	--		
16	16	50 Hz	INTERFACE RELAY (RYSF)	56	301	--	Instruction being executed when clock location 4000 overflows.
17	17	20 CPM	SERVO (SVSF)	57	50	JMS 600	Instruction executed as a result of clock overflow on API channel 10.

EXAMPLE 1

From the table above CLOCK 1 and CLK OVERFLOW (API channels 1 and 10) are initialized by micro programming AC BIT 3 and 10.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0

The corresponding octal number is 040200. The programming sequence required to initialize API channels 1 and 10 is:

```

41/      ISZ CL1
50/      JMP SVC
      .
      .
      LAC (040200)
      ASC
      EPI
      .
      .
SVC,     0
      .
      .
      DBR
      JMPI SVC

```

Every 1/5000 second a data break executes the instruction in location 41. Which in this example is ISZ CL1. (A clock service routine usually reinitializes CL1 to a negative number.) Every 1/5000 second the value of CL1 is incremented until its value passes thru 777777 to 0. At this point API channel 10 transfers control to location 50 (which is usually a JMS to a service routine). If a service routine is used it should first store the contents of AC, MQ, PC, and link before proceeding with interrupt calculations (such as, integration or time delay). After interrupt calculations are performed the value of CL1 should be reinitialized to a negative number and the values of the AC, MQ, PC and link restored.

The SIMPL1 subroutines ICL\$ and RCL\$ can be used to automatically perform the above operations. (However, ICL\$ and RCL\$ require more machine time than generally required with assembly language.

Example 2 illustrates in detail how a API could be used for periodic conversion of A/D channel 14.

```

600      0      The link and the PC are stored in location 600.
601      DAC 4050      Save AC in location 4050.
602      LACQ      Load AC with contents of MQ.
603      DAC 4051      Save MQ in location 4051.
604      MX14      Convert MX channel 14 from analog voltage to
                    digital word.
605      ADSF      Skip if A/D converter flag is set.
606      JMP .-1      Jump back.
607      ADRB      Read A/D converter output register into the AC.
610      DAC 6600      Deposit AC in memory location 6600.
611      LAC (777762) Reinitialize clock counter.
612      DAC 4000      Deposit initial value in clock location 4000.
613      LAC 600      Load AC with Link and PC.
614      RAL      Restore Link.
615      LAC 4051      Load AC with contents of MQ before interrupt
                    occurred.
616      LMQ      Restore MQ
617      LAC 4050      Restore AC with value it had before interrupt
                    occurred.
620      DBR      Debreak
621      JMP I 600      Return to main program sequence.
302      --      Next instruction in main program executed.

```

APPENDIX F
SIMPL-1 SYSTEM PROGRAM INDEX

<u>BLOCK</u>	<u>TITLE</u>	<u>APPLICATION</u>		
<u>DECTAPE INPUT/OUTPUT</u>				
1	D.T. (HIGH) READER	READ A PROGRAM INTO MEMORY		
2	D.T. (RIM, FF) WRITER	TRANSFER RIM & FF TO MAG TAPE		
4	D.T. (CORE) WRITER	TRANSFER FROM CORE TO MAG TAPE		
5	D.T. (DT COPY) FAST COPIER	COPY MAG TAPES		
6	D.T. SELECTIVE COPIER	COPY SELECTED BLOCKS TO NEW MAG TAPE		
7	D.T. OCTAL PRINT	PRINT CONTENT OF MAG TAPE IN OCTAL		
10	DECSYS BOOTSTRAP	USED TO LOAD DECSYS-7 FORTRAN II PROBLEMS		
20	ZERO BLOCK FINDER	LISTS ALL BLOCKS OF LOCATIONS CONTAINING ZERO		
100	DECTOG	DECTAPE FORMAT GENERATOR		
<u>PAPER TAPE INPUT/OUTPUT</u>				
12	LOW R.I. PUNCH	PUNCH READ IN MODE PROGRAMS FROM CORE		
13	HIGH R.I. PUNCH			
14	LOW RIM PUNCH	PUNCH RIM MODE PROGRAM FROM CORE		
15	HIGH RIM PUNCH			
16	TAPE (PAPER) REPRODUCER	REPRODUCE PAPER TAPE		
17	F.F. OCTAL PRINT	USED FOR DEBUGGING FUNNY FORMAT SYSTEM PROGRAMS (i.e., THE ASSEMBLER)		
24	LIBDUB	DUPLICATE HYBRID RELOCATABLE LIBRARY FORMAT TAPE		
42	SYMBOLIC TAPE LISTER	LIST SYMBOLIC TAPE WITH PAGE NO.		
<u>CARD INPUT/OUTPUT</u>				
115	LIST DECK	TYPE CONTENTS OF DECK OF CARDS		
120	PUNCH DECK	PUNCH PAPER TAPE OF CONTENTS ON CARDS		
<u>EDITOR</u>				
26	SYMBOLIC TAPE EDITOR	LIST SYMBOLIC AND INSERT PAGE NO.		
<u>ASSEMBLERS</u>				
227	ABSOLUTE HYBRID			
247	RELOCATABLE HYBRID ASSEMBLER			
207	EXTENDED ASSEMBLER (DEC)			
<u>DEBUGGING PROGRAMS</u>				
44	HYBRID DDT			
750	BASIC DDT (OPERATING INSTRUCTIONS IN DIGITAL 7-4-S)			
<u>MEMORY DUMPS</u>				
21	OCTAL MEMORY DUMP (PRINTER)			
22	ABSOLUTE MEMORY DUMP (PRINTER)			
<u>ANALOG SETUP AND CHECKOUT</u>				
60	READ POTS	LIST POTS FROM ANALOG COMPUTER		
125	PUNCH STEADY STATE CHECK TAPE	PUNCHES OUTPUT PAPER TAPE OF ANALOG COMPUTING ELEMENTS		
126	STEADY STATE CHECK	READS PREVIOUSLY PUNCHED PAPER TAPE AND COMPARES WITH PRESENT VALUES		
300	POT COEFFICIENT EDITOR			
<u>OPEN BLOCKS</u>				
56-57	110-114	226	312-677	742-747
62-77	142-206	245	715-717	757-1100

APPENDIX G

SIMPL-1 SYSTEMS PROGRAM OPERATING INSTRUCTIONSDECTAPE INPUT/OUTPUTBLOCK 1 - TO READ A PROGRAM INTO MEMORY

1. Select DECTape Unit
Set AC-2 thru AC-5 to octal address of Unit
2. Select Program Block Number
Set AC-6 thru AC-17 with (Block No.)

Selected program should be read into core memory

If not, set address switches to 7640 and depress START - the HIGH DSD reader should be read from DECTape by the LOW DSD reader - some programs will destroy both readers, if this happens, use the read-in format paper tape* - this should not happen often

PROGRAM WILL ENTER MEMORY AND MAY BE EXECUTED

*Load read-in format tape into reader, address 17600, and press READ-IN.

BLOCK 2 - DSD DECTAPE WRITER (RIM,FF)(TRANSFER (RIM,FF) TO MAG TAPE)

1. Call writer into memory thru the DECTape reader
2. Select DECTape Unit
Set AC-2 thru AC-5 to octal address of Unit
3. Designate Block Number (where you wish your program to start)
4. Load RIM or FUNNY FORMAT tape in reader
Set transport write-lock SW to write
5. Set AC-0 to indicate format of paper tape
Set to one to indicate RIM or ZERO to indicate FUNNY FORMAT
6. If AC-0 is one you may demand a PAUSE after read-in by setting AC-1 to ONE
7. Depress CONTINUE
Program will be loaded and computer will HALT with the next open block number in the accumulator

BLOCK 4 - DSD DECTAPE "CORE" WRITER (TRANSFER FROM CORE TO MAG TAPE)

1. Load program into memory (any method of loading)
2. Load writer (any method of loading)
3. Select DECTape Unit
Set AC-2 thru AC-5 to octal address of Unit
4. Designate Block Number (where you wish your program to start)
5. Depress CONTINUE
6. Select program starting address
Set AC-5 thru AC-17
7. Demand PAUSE on loading if desired
Set AC-0 to ONE
8. Depress CONTINUE
9. Set first core location this block
10. Depress CONTINUE
11. Set last core location this block
12. If this is last block set ACO to ONE
13. Depress CONTINUE
14. If ACO was ZERO program will halt with ZERO in the accumulator CONTINUE from Step 9
If ACO was ONE program will halt with the next open block in the accumulator
LOAD COMPLETE

BLOCK 5 - "DTCOPY" (DSD DECTAPE) (COPY MAG TAPES)

1. Select DECTape Unit (AC Switches 2-5)
2. Select Block Number (AC Switches 6-17)
3. Select HIGH or LOW CSE DECTape Reader (Address Switches)
4. Depress START
5. Load tape to be copied on Unit 1 (write-lock)
6. Load blank tape on Unit 2 (write)
7. Depress CONTINUE

BLOCK 6 - DECTAPE SELECTIVE COPY (COPIES SELECTED BLOCKS TO NEW MAG TAPE)

This is a simple minded procedure which copies information from a DECTape on Unit One to a DECTape on Unit Two. Information is transferred through memory one block at a time with no comparison or sum-checking. The check-sum read from Unit One is written (right or wrong on Unit Two

USE:

1. Read selective copy routine into memory
2. Put tape to be copied on Unit One (write-lock)
3. Put blank tape on Unit Two (write)
4. Select first block to be copied (AC Switches 6-17)
5. Depress CONTINUE
6. Select last block to be copied (AC Switches 6-17)
7. Depress CONTINUE
8. Program halts at location 22 with the last block duplicated in the accumulator
9. To copy another series of blocks return to step 4

BLOCK 7 - DECTAPE OCTAL PRINT

A debugging routine which prints the octal contents of a DECTape

USE:

1. Read DECTape octal print routine into memory
2. Select DECTape Unit
Set AC Switches 2-5 to desired Unit
3. Select starting block
Set AC Switches 6-17 to first block to be printed
4. Depress CONTINUE
5. Routine will print contents of successive blocks until the end of the tape is reached or halted by the operator
6. Routine may be caused to halt at the end of the block being printed by setting ACO to ONE
7. The routine may be restarted at Step 2 by setting the Address switches to 23 and depressing START or if it was halted by setting ACO it may be RESTARTED at Step 2 by depressing CONTINUE

BLOCK 20 - ZERO BLOCK FINDER

This routine maps the location of all ZEROS from location 100 to the end of memory

The program starts automatically when loaded. No operator intervention is necessary

BLOCK 100 - DECTOG

(See DECUS furnished program 2-A (white notebooks) for information)

SIMPL-1 SYSTEMS PROGRAM OPERATING INSTRUCTIONS (contd)PAPER TAPE INPUT/OUTPUTBLOCK 10 - DECSYS BOOTSTRAP

1. Read program from mag tape
2. See DECSYS-7 Operating Manual (Digital-7-5-S)

BLOCK 12 - LOW READ IN PUNCH

1. Read in program from mag tape
2. Set lower address in address switches
3. Press CONTINUE
4. Set high address in address switches
5. Press CONTINUE
6. See DECUS furnished program 1-R (white notebook) for further information on program

BLOCK 13 - HIGH READ IN PUNCH

1. Same operating instructions as for Low Read In Punch (Block 12)
2. See DECUS furnished program 1-R (white notebook) for further information about program

BLOCK 14 - LOW RIM PUNCH

1. Same operating instructions as for Low Read In Punch (Block 12)
2. See DECUS furnished program 1-0 (white notebook) for further information about program

BLOCK 15 - HIGH RIM PUNCH

1. Same operating instructions as for Low Read In Punch (Block 12)
2. See DECUS furnished program 1-0 (white notebook) for further information about program

BLOCK - 16 - TAPE REPRODUCER

1. Read in program from mag tape
2. Put paper tape in reader
3. Press CONTINUE

BLOCK 17 - FF OCTAL PRINT

1. Read in program from mag tape
2. Place paper tape in reader
3. Press CONTINUE

BLOCK 24 - LIBDUB

1. Read in program from mag tape
2. Put original library tape in reader
3. Press CONTINUE (this duplicates readable title)
4. Press CONTINUE (this reads first program into memory and types name(s) of library program on Teletype)
5. (a) Press CONTINUE to punch what was read in during step 4. When computer halts go to step 4 to read in next program
(b) If deleting a program set address switches to 100 and press START. This reads next program into memory and types program name(s) on Teletype. After computer halts go to step 5a.
(c) If changing program take old tape out of reader (be sure to mark position of tape), place new assembled tape in reader, set address switches to 100, and press START. This reads new program into memory and types program name(s) on Teletype. After computer HALTS go to step 5a.

BLOCK 42 - SYMBOLIC TAPE LISTER

1. Read in program from mag tape
2. Put paper tape in reader
3. Set AC switches to 0. (If AC switches were 5, page numbers would be printed as 5-1, 5-2, etc.)
4. Press CONTINUE

CARD INPUT/OUTPUT

BLOCK 115 - LIST DECK uses the KSR 35 Teletype to list the information, one card per line.

Two or more spaces on the card are converted to a tab before output. The last block of spaces on the card is ignored. A carriage return and a line feed are typed or punched after each card. If a character cannot be found in the conversion tables, a backward slash is put in its place.

Load the deck in the card reader hopper with row 9 nearest slot, face down. Press START on the reader after the program is in core and running. When all cards have been read, another deck may be loaded. Press START on the reader to begin output.

Program may be restarted at location 100.

BLOCK 120 - PUNCH DECK uses the paper tape punch to provide the user with an ASCII tape.

Two or more spaces on the card are converted to a tab before output. The last block of spaces on the card is ignored. A carriage return and a line feed are typed or punched after each card. If a character cannot be found in the conversion tables, a backward slash is put in its place.

Load the deck in the card reader hopper with row 9 nearest slot, face down. Press start on the reader after the program is in core and running. When all cards have been read, another deck may be loaded. Press start on the reader to begin output.

Program may be restarted at location 100.

MEMORY DUMPSBLOCK 21 - OCTAL MEMORY DUMP PRINTER

1. Call printer into memory thru the DECTape reader
2. The memory block used by the printer program will be typed out on the Teletype
3. To use: Enter first location to be printed on ACS
4. Press CONTINUE
5. Enter LAST location on ACS
6. Press CONTINUE
7. To REPEAT go to step 3
8. Printing may be suppressed at any time by putting AC-0 up

TO PRINT ANOTHER BLOCK GO TO STEP 3

BLOCK 22 - ABSOLUTE MEMORY DUMP PRINTER

1. Read in program from mag tape through DECTape reader
2. Set low address in AC switches
3. Press CONTINUE
4. Set high address in AC switches
5. Press CONTINUE

ANALOG SETUP AND CHECK OUTBLOCK 60 - READ POTS

1. Read in program through DECTAPE READER. Pots are listed automatically without further operator intervention. Poted on Block 300 could also be used for this function.

BLOCK 125 - PUNCH STEADY STATE CHECK TAPE

When a steady state has been reached by the problem either in IC or COMP modes, the Punch Steady State Check Tape program is called from block 125 of the DSD Master. It automatically places the 2133 in HOLD mode, scans A, F, L, M and R points and punches the tape. Notation should be made on the tape to indicate which mode the 2133 was in when the program started.

BLOCK 126 - STEADY STATE CHECK

1. The Steady State Check program is called from block 126 of the DSD Master. The program will halt in location 16001. If a voltage deviation limit other than 0.5 volts is desired, the negative BCD value should be entered in the location whose address is in the accumulator at the time of the halt.
2. Load the paper tape in the reader.
3. When the 2133 has reached steady state IN THE SAME MODE AS WHEN THE TAPE WAS MADE, press continue, or, if the user elected to change the deviation limits, "start" at location 16002. The program will indicate "TEST COMPLETED" when finished.

SIMPL-1 SYSTEMS PROGRAM OPERATING INSTRUCTIONS (contd)

EDITOR OPERATING INSTRUCTIONS*

INPUT - TAPE OPERATIONS

R	Read one page of text
nR	Read <u>n</u> lines of tape
Z	Skip one page of text
nZ	Skip <u>n</u> pages of text

LIST

B	Back up and print
nG	Get next location tag after line <u>n</u>
nL	Print line <u>n</u>
n,mL	Print lines <u>n</u> through <u>m</u>
Q	Print uncommented the entire buffer
nQ	Print line <u>n</u> uncommented
n,mQ	Print lines <u>n</u> through <u>m</u> uncommented
W	Write the entire buffer
nW	Write <u>n</u> pages. Equivalent to K, n(R,W,K).
"Rubout"	Rubout typed immediately after carriage return will cause listing of the next line. Otherwise, "rubout" will erase last character typed.
"Line Feed"	Print next line (if first character typed in command mode.) Otherwise, delete all typed input on this line when in append mode.

PROGRAM MODIFICATIONS IN TEXT MODE

A	Append
nC	Change line <u>n</u>
n,mC	Change lines <u>n</u> through <u>m</u>
nI	Insert text before line <u>n</u>
"Rubout"	Erase last character. (When rubout is first character after a carriage return, the editor mode is changed from text to command mode.)

PROGRAM MODIFICATIONS IN COMMAND MODE

nD	Delete line <u>n</u>
n,mD	Delete lines <u>n</u> through <u>m</u>
K	Kill the text buffer
n,mX	External insert. Insert <u>n</u> lines of text from paper tape after line <u>m</u>
nY	Individual character correction on line <u>n</u> . (First "rubout" stops printing. Remaining rubouts erases characters one at a time.)
"Line Feed"	Print first line (if first character typed). Otherwise delete all typed input on this line.

OUTPUT - TAPE OPERATIONS

nF	Punch <u>n</u> lines of tape feed
N	Punch and next page. Equivalent to P,S,K,R
mN	Punch, duplicate, and read. Equivalent to P,S,m-1(T),R
O	Punch and kill. Equivalent to P,S,K
P	Punch the contents of the buffer
nP	Punch line <u>n</u>
n,mP	Punch lines <u>n</u> through <u>m</u>
S	Punch form feed (FIODEC:stop code)
nT	Duplicate <u>n</u> pages of tape. Equivalent to K,n(R,P,S,K)

SPECIAL FUNCTIONS

"Carriage Return"	Complete specified action
:/	Total line indicator
.	Current address indicator
AC Switch 0	Down - produces normal operation
	Up - stops printing or punching

*If the D.T.(HIGH) READER is in core the editor is called from mag tape by:

1. Setting tape unit number in AC Sw. 0-5
2. Setting block number (26) in AC Sw. 5-17
3. Setting address switches to 17640 or 7640
4. Pressing START
5. To restart editor without destroying contents of buffer address 22 and press START

POT COEFFICIENT EDITOR*

LOAD POT SETTINGS

ALL COMMANDS EXCEPT / AND RUBOUT MUST BE FOLLOWED BY
A CARRIAGE RETURN.

SIMPL-1 SYSTEMS PROGRAM OPERATING INSTRUCTIONS (contd)

SIMPL-1 SYSTEMS PROGRAM OPERATING INSTRUCTIONS (contd)

SIMPL-1 SYSTEMS PROGRAM OPERATING INSTRUCTIONS (contd)ASSEMBLER ERROR MESSAGES*SYMBOL AND FORMAT ERRORS

The appearance of the diagnostic is:

ERROR	OCTAL ADDRESS	SYMBOLIC ADDRESS
-------	---------------	------------------

The error legend is:

Error	Meaning
IFC	Illegal format in symbolic address tag. The tag is ignored. (See page 17.)**
IFI	An expression using CHAR or FLEX was formed improperly. (See page 38.)
IFL	Illegal format in a PUNDEF list. (See page 26.)
IFP	Illegal format in a parameter assignment. The assignment is ignored. (See page 8.)
IFS	START or PAUSE used incorrectly. Assembly continues as if START or PAUSE had been used with no expression following. (See page 17.)
ILF	Illegal format in a pseudo-instruction such as BAR. The pseudo-instruction is ignored.
INS	An illegal format in a PUNDEF list--two commas appeared in a row or a digit appeared.
LIT	An illegal character was found in a PUNDEF list. The character is taken as a terminator.
MDT	The value of the complex symbolic address assignment (tag) and the location counter disagree. The symbolic address tag is redefined if possible. (See page 17.)
SCE	Storage capacity of the symbol table was exceeded. No recovery is possible.
TUA	Too many undefined symbols appeared in a symbolic address assignment (tag). Location counter remains unchanged. (See page 17.)
UBR	An undefined symbol appeared in a BAR pseudo-instruction. The setting of BAR remains unchanged.

SYMBOL DEFINATION ERRORS

The appearance of the diagnostic is:

ERROR	PREVIOUS VALUE	SYMBOL	NEW VALUE
-------	----------------	--------	-----------

The error legend is:

Error	Meaning
MDT	A previously defined symbol was redefined with a comma. (See page 17.)
RDA	An attempt was made to redefine a permanent symbol with a comma. The symbol was not redefined.
RPS	A permanent symbol was redefined. (See page 8.)

CHARACTER AND SYMBOL ERRORS

The appearance of the diagnostic is:

ERROR	OCTAL ADDRESS	SYMBOLIC ADDRESS	CAUSE
-------	---------------	------------------	-------

The error legend is:

Error	Meaning
ICH	A character not part of the Assembler's source language was used. The character is ignored. (See page 7.)
ILP	A character read from tape did not have an odd number of holes across the line. Place the correct character (if possible) in bits 12-17 of the ACS and press CONTINUE.
UAA	An undefined symbol appeared in an absolute address assignment (/). The current address indicator remains unchanged.
UPA	An undefined symbol appeared in a parameter assignment. The assignment is ignored. (See page 8.)
UPN	An undefined symbol appeared in a PUNCH pseudo-instruction. The symbol is ignored.
UST	An undefined symbol appeared in a START or PAUSE instruction. The symbol is ignored and the START or PAUSE taken alone. (See page 17.)

*With the exception of SCE (Storage capacity exceeded) and ILP (illegal parity), assembly continues automatically after error message has been printed.

**Page references refer to the PDP-7 Symbolic Assembler Programming Manual (DIGITAL-7-3-S)

SIMPL-1 SYSTEMS PROGRAM OPERATING INSTRUCTIONS (contd)ABSOLUTE VERSUS RELOCATABLE ASSEMBLY

The advantages for using a relocatable assembler are:

1. Subroutines (both user and library) need only be assembled once.
2. Main programs may be modified and changed without destroying the linkage between the main program and previously written subprograms.
3. Core memory is more effectively utilized because only the ones needed are loaded into memory.
4. Unused portions of core can be eliminated by program packing.

A relocatable assembly is specified if the first non-comment program entry is not an absolute address assignment. An absolute assembly is specified if the first non-comment program entry contains an absolute address assignment (i.e. 642/). For example in the listing

```

PILOT EJECTION STUDY
/PROGRAM CONSTANTS
41/  ISZ $CLI
50/  JMS SRVC
60/
BGN,  CAC
.
.
.
PAUSE

```

would be assembled absolute because the first non-comment entry (41/ ISZ \$CLI) contains an absolute address assignment (41/). The starting address BGN is stored in location 60. [The locations between 40 and 57 are reserved at API channels and are not generally used for other purposes (see item 10 of Appendix B).]

The following listing would be assembled relocatable:

```

PILOT EJECTION STUDY
/PROGRAM CONSTANTS
M,   70
.
.
.
PAUSE

```

As indicated in the program operating instruction of Appendix D-8, the program would be loaded at memory location 100 if AC switch 0 is down, or the starting location is taken from AC switches 5-17 if AC switch 0 is up.

The following technique is recommended for referencing absolute addresses when using the relocatable assembler:

```

PILOT EJECTION STUDY
/PROGRAM CONSTANTS
BGN,
41/  ISZ $CLI
50/  JMS SRVC
BGN/
.
.
.
PAUSE

```

Absolute memory locations can also be placed between the end of a main program and prior to beginning an API clock service routine. For example,

```

PILOT EJECTION STUDY
/PROGRAM CONSTANTS
M,   70
.
.
.
/MAIN PROGRAM
LOOP, JMS AMODE$
.
.
.
JMP LOOP
/API CLOCK SERVICE ROUTINE
SRVC,
41/  ISZ $CLI
50/  JMS SRVC
SRVC/ 0
.
.
.
DBR
JMP I SRVC
PAUSE

```

Programming errors relating to absolute or relocatable assembly can be avoided by noting that programs starting relocatable must end relocatable. Conversely, programs beginning absolute must end absolute.

SIMPL-1 SYSTEMS PROGRAM OPERATING INSTRUCTIONS (contd)

DDT OPERATING INSTRUCTIONS

Character	Action	Character	Action
CLEAR MEMORY		SPECIAL REGISTERS	
KILLS	Resets the symbol table to the initial list. Modified definitions are retained only if altered on line. Definitions added from a user's symbol table tape are restored to their original values.	A\$	Accumulator storage (at breakpoints).
ZERO\$	Clears memory available to the user.	L\$	Link storage (at breakpoints).
LOADING THE PROGRAM		MQ\$	Multiplier quotient storage (at breakpoints).
LOAD\$	Load a FF format tape (storage words only).	SC\$	Step counter storage (at breakpoints).
TABLE\$	Load only the symbols from a FF format tape.	MODE\$	Normal (MICK) or Modified (MIST) PDP-7 mode storage (at breakpoints).
DEBUG\$	Load both storage words and symbols.	M\$	Mask used in search; M\$+1 and M\$+2 contain first and last address of the area to be searched.
OUTPUT FORMAT		F\$	Contains the lower limit of DDT as the address part of an XOR instruction.
a. <u>Address of Location Being Examined</u>		B\$	Contains the current breakpoint location.
RELAT\$	Sets the mode in which DDT types out locations to <u>relative</u> (symbolic).	TAB\$	Contains 0 for KSR-35 (auto-tab) Contains 1 for KSR-33 Normally 0
OCTAL\$	Sets the mode in which DDT types out locations to octal.	SYMBOL DEFINITION	
b. <u>Contents of Location Being Examined</u>		k,	Define the symbol <u>k</u> as the tag of the currently open register.
SYMB0\$	Sets the mode in which DDT types out words to <u>symbolic</u> .	(...)	Define the enclosed symbol as the value preceding the (.
CONST\$	Sets the mode in which DDT types out words to octal <u>constants</u> .	SEARCHING	
VOLT\$	Causes DDT to print the contents of locations as an unsigned decimal number.	N WORD\$	Search for all occurrences masked with M\$ of the expression N.
DECIM\$	Causes DDT to print the contents of locations as an unsigned decimal number.	N NOT\$	Search for all words not equal to the expression N after masking with M\$.
c. <u>Controls Both Address and Contents</u>		N ADDRE\$	Search for all words masked with M\$ with the same effective address as N.
ABSOL\$	Sets the mode in which DDT types out words to <u>absolute</u> . That is, the instruction code is typed as symbolic while the address is typed in octal.	MISCELLANEOUS OPERATIONS	
PROGRAM EXAMINATION AND MODIFICATION		k#	Execute the expression <u>k</u> as an instruction.
space	Separation character meaning arithmetic plus.	Q\$	Last <u>quantity</u> typed out by DDT.
-	Separation character meaning arithmetic minus.	BAUD0\$	Causes DDT to read the symbols on a funny format paper tape (assembler output, DDT output, or linking loader output) as 6 bit baudot trim codes. This instruction should be used for all programs assembled prior to February 1, 1968 or for any other programs not assembled on the SIMPL1 Hybrid Assembler.
/	Register examination character: When following the address of a register, it causes the register to be opened and its contents printed. Immediately following a register printout, slash will cause the register addressed therein to be opened.	ASCII\$	Causes DDT to read the symbols on a funny format paper tape (assembler output, DDT output, or linking loader output) as 6 bit ASCII trim codes. This will be the normal operating mode of DDT and should only be necessary after a tape of the type described in BAUD0\$ has been loaded. The ASCII symbol mode applies to all tapes assembled on the BNW - SAS PDP-7 Hybrid Assembler on or after February 1, 1968, Hybrid DDT output tapes, and linking loader symbol punch tapes.
carriage return	Make modifications, if any, and close register.	PUNCHING OPERATIONS	
line feed	Make modifications, if any, close register, and open next sequential register.	INPUT\$	Punch the input block.
)	Make modification and open addressed register. (The sequence is not changed.)	N PUNCH\$	Punch the contents of N.
&(ampersand)	Make modifications, if any, and open addressed register. (Establishes a new sequence.)	N; M PUNCH\$	Punch N to M, inclusive.
:(colon)	Type last quantity as an octal integer.	PUNSY\$	Causes DDT to punch on paper tape the entire non-permanent symbol table.
=	Type last quantity as a voltage.	START\$	Punch a start block.
+	Type last quantity as a decimal integer.	SPECIAL CHARACTERS	
*	The digit sequence being typed is to be taken as a decimal number. (Example: Typing of 1000* 1000 10*00 etc. will be taken by DDT to mean 1750 octal.)	"RUBOUT"	Deletes last typing sequence. For example, suppose the instruction in location JOE is JMS HMPY2\$ and it's desired to modify the instruction to JMP STRT. However, in the process of making the modification an error was made (i.e., an S was typed for a P.) The Teletype output would appear as shown below (underlined expressions are typed by user and expressions not underlined are type by DDT.)
.	When a point occurs in a sequence of digits being sent to DDT from the keyboard and the point follows the first digit of the sequence, the entry is taken by DDT to be an expression of voltage. (100.00 corresponds to 20000 octal.)		
.(period)	Current location.		
RUNNING THE PROGRAM BREAKPOINTS AND TRAPS			
k" (double quote)	Insert a breakpoint at the location specified by <u>k</u> . If no address is specified, remove any breakpoint.		
k' (single quote)	Transfer control to the location specified by <u>k</u> , or to the address in the start block on tape if no address is specified.		
! (exclamation)	Proceed from a breakpoint.		
TRAP\$	Place a trap location at 21 for CAL.		

*If the D.T.(HIGH) READER is in core, DDT is called from mag tape by:

1. Setting tape unit number in AC SW 0-5
2. Setting block number (44) in AC SW 5-17
3. Setting address switches to 17640 or 7640
4. Pressing start
5. To restart DDT address 16000 and press start

JOE/ JMS HMPY2\$ JMS ?JMP STRT
 -/ JMS STRT +
 "RUBOUT"

APPENDIX H

TYPICAL PROGRAMMING AND OPERATING ERRORSPROGRAMMING ERRORS

1. Are dollar signs (\$) used on all library functions?
2. Are all tags correctly spelled? (i.e., have you said TMP when it should be TEMP?)
3. Make sure spaces are not substituted for tabs. If bugs in program cannot be found check to see if spaces were substituted for a tab by re-listing the source paper tape program.
4. Do JMP instructions contain +.N rather than .+N or . N?
5. Have you used the correct calling sequence for library subroutines?
6. Have you confused decimal, octal, and voltage numbering systems?
7. Have you used literals properly? i.e., LAC 36 means load the accumulator with contents of location 36. In contrast LAC (36 means load the accumulator with the octal number 36.
8. Have you used slashes for comments?
9. Have you confused absolute and relocatable assembler addresses identification?
10. When making DDT decimal integer patches use * rather than ' as the decimal indicator. (In DDT the use of (') starts the program running.)
11. Have pseudo-instruction names been used as tags?

OPERATING ERRORS

1. ADC Channels show overload and limit. DAC Channels do not show overload. Be sure to check ranges of variables trunked to analog to insure that most significant bits are not lost.
2. Is the write lock switch on the DECTapes in the center position?
3. Are tape unit switches addressed to the right units?
4. Have assembled tapes been loaded in the proper manner? (Remember assembler output tapes are loaded upside down and backwards.)
5. Have you used memory locations 40-57? If so examine API indicator lights to see if spurious API pulses have clobbered your program.

APPENDIX I

	<u>Octal</u>		<u>Decimal</u>
*For Example:	JMP -17	is equivalent to	JMP -15'
	DAC +24	is equivalent to	DAC +20'
	LLS 12	is equivalent to	LLS 10'

Every PDP-7 digital computer operation is performed in the binary numbering system. Other numbering systems (such as BCD) are needed for equipment compatibility. For example, information to and from the analog computer's address selector system must be coded in alpha-decimal to BCD. However, all operations performed by the digital computer utilizes the binary numbering system.

$$\begin{aligned} 1101_2 &= 1 \times (2)^4 + 1 \times (2)^3 + 0 \times (2)^2 + 0 \times (2)^1 + 1 \times (2)^0 \\ &= 16 + 8 + 0 + 0 + 1 \\ &= 25_{10} \end{aligned}$$

BIT POSITION	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VALUE	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1

The procedure of converting from decimal to binary is:

		<u>REMAINDER</u>	
2)25		1	
2)12		0	
2)6		0	
2)3		1	+
2)1		1	Read Answer
0			

Even though the digital computer performs all operations in binary arithmetic, it is sometimes more convenient to convert a binary number through an octal number to obtain the decimal equivalent. The conversion from binary to octal can be done by segmenting the binary number in groups of three before making the visual conversion. Three binary places can be used to represent any number between 0 and 7 as shown below:

	<u>OCTAL</u>	<u>DECIMAL</u>
000	0	0
001	1	1
010	2	2
011	3	3
100	4	4
101	5	5
110	6	6
111	7	7

The binary number 11001 can be grouped as:

```
011 001 = Binary Number
3 1 = Octal Number
```

or $011001_2 = 31_8$

The procedure for converting from octal to decimal is:

$$\begin{aligned} 31_8 &= 3 \times (8)^1 + 1 \times (8)^0 \\ &= 24 + 1 \\ &= 25_{10} \end{aligned}$$

To convert from decimal to octal the following procedure is used:

$$\begin{array}{r} \text{REMAINDER} \\ 8 \overline{)25} \\ 8 \overline{)3} \\ \underline{0} \end{array} \quad \begin{array}{r} 1 \\ 3 \end{array} \quad +$$

Read Answer

or $25_{10} = 31_8$

The decimal numbering system is understood by almost everyone. (For example: $25_{10} = 2 \times (10)^1 + 5 \times (10)^0$) However, extreme care must be exercised in using SIMPLI software to avoid confusion caused by the integer decimal system.

Decimal integers should not be used to represent problem variables such as temperature, pressure, specific heat, concentration, etc. The hybrid subroutines have been conditioned to recognize problem variables as "digital voltages."

Decimal integers may be used for those applications specified in the RECOMMENDED NUMBERING SYSTEM APPLICATIONS.

The term binary voltage (or just voltage) is used to denote the special numbering system used by SIMPL1 arithmetic routines. The equation relating the decimal equivalent (N) to a "binary voltage" (V) is:

$$N = \frac{V \cdot 8192}{100}$$

In essence, the eighteen bit digital word is conditioned to recognize algebraic sign and seventeen bits of numerical information. The smallest representable voltage is ± 0.012 and the largest is ± 1599.99 . In other words, the resolution is 0.012 volts.

The reason for adopting a new numbering system is the necessity for relating analog voltages to digital integers. The largest decimal number representable on an analog computer is 100.0 volts, and the accuracy of most analog computing elements is .01 volts. On the other hand, the largest seventeen bit decimal integer is $2^{18}-1$ or 262,143. The smallest integer is 1 (decimal fractions are not allowed in the integer digital system.) To make the numbering systems of both machines compatible, the integer representation of the digital's seventeen bit word was rescaled to cover the range of ± 5199.99 to ± 0.12 . However, numerical transfer to and from each computer must be less than ± 49.99 .

The analog computer address select system is coded for a special alpha-decimal to BCD equivalence as shown in Table I.

BCD

<u>ALPHA</u>	<u>DECIMAL</u>	<u>BCD</u> <u>8421</u>
A	0	0000
F	1	0001
G	2	0010
K	3	0011
L	4	0100
M	5	0101
P	6	0110
R	7	0111
T	8	1000
U	9	1001

The format and an example for addressing POT 126 is shown in Table II.

ACC 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

 8 4 2 1 2 1 8 4 2 1 8 4 2 1

XX 0110	XX	01	0010	0110	BCD ADDRESS
P		1	2	6	ALPHA-DECIMAL

The integer binary coded decimal numbering system must be used for reading POT coefficients from the analog computer or setting POTs from the digital computer.

The BCD integer format is shown in Table III.

ACC	0	1		2	3	4	5		6	7	8	9		10	11	12	13		14	15	16	17
				8	4	2	1		8	4	2	1		8	4	2	1		8	4	2	1
	SPARE		THOUSANDS				HUNDREDS				TENS				UNITS							

The integer BCD to binary conversion subroutine (IDBC\$) and integer binary to BCD subroutine (BDC\$) are included in the hybrid software to perform the necessary POT coefficient conversions.

The digital output of the analog computers digital voltmeter is coded according to the format shown in Table IV.

ACC 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

8 4 2 1 8 4 2 1 8 4 2 1 8 4 2 1

TENS TENS TENS HUNDRETHS

OR HUNDREDS TENS UNITS HUNDRETHS

DECIMAL = (XXX.X WHEN ONE
XX.XX WHEN ZERO)

SIGN (MINUS = ONE
PLUS = ZERO)

The digital voltmeter can be used to interrogate any analog voltage without using a separate ADC channel. When this is done the analog BCD voltage presented to the digital computer's accumulator must be converted to a digital "binary voltage" before it can be used for a computation. This conversion is performed by the voltage BCD to voltage binary (VBDCS) conversion subroutine.

APPENDIX J

INDICATORS AND CONTROLS FOR DIGITAL COMPUTER AND INTERFACE

Manual control of the PDP-7 is exercised by means of keys and switches on the operator console. Visual indications of the machine status and the content of major registers and control flip-flops is also given on both the operator console and on the indicator panel. Indicator lamps light to denote the presence of a binary 1 in specific register bits and in control flip-flops. Lighted control indicators denote activation of the associated control functions.

INDICATORS AND CONTROLS FOR DIGITAL COMPUTER AND INTERFACE (contd)

INDICATORS AND CONTROLS FOR DIGITAL COMPUTER AND INTERFACE (contd)

INDICATORS AND CONTROLS FOR DIGITAL COMPUTER AND INTERFACE (contd)

APPENDIX K

EXAMPLE MULTIPLY AND DIVIDE PROGRAMS WITHOUT USING SIMPL-1 FUNCTIONS

MULTIPLY WITH MUL or MULS

To use the multiply (both signed and unsigned) instructions, the basic calling sequence is to load the accumulator with one number before the instruction and to have the other number in the location following the multiply instruction. An example follows:

```
LAC X      /"X" into AC
MUL (MULS) /Multiplication instruction
Y          /"Y" in AC-MQ as 36 bit number
```

In both the signed and the unsigned multiplication "Y" (see example above) must be the absolute value of the number to be multiplied. The sign of "Y" should be in the link; therefore, if "Y" is a constant the link can be set or cleared preceding the multiplication to indicate the proper sign of "Y". With this type of multiplication "Y" can be of

```
CLL (STL)  /CLL if "Y" is positive; STL if "Y" is
            /negative
LAC X      /Absolute value of "Y"
MUL (MULS) /"XY" in AC-MQ as 36 bit number
Y          /"XY" in AC-MQ as 36 bit number
```

any magnitude up to 777777₈ and still be considered positive.

If "Y" is a variable it can be loaded into the location following the multiply instruction and its sign can be placed into the link with the following instructions:

```
LAC Y      /Positive or negative variable
GSM        /Sign link; Abs(Y) AC
DAC .+3
LAC X
MUL (MULS)
Ø
. . . .   /XY in AC-MQ as 36 bit number
```

The instruction GSM places the sign bit of the variable into the link and takes the absolute value of the number. Once again the link could be set or cleared in place of the GSM instruction and "Y" would be considered as an 18 bit number.

When using the MUL instruction the variable "X" in the examples above will be considered as an 18 bit positive number. If the instruction MULS is used, "X" will be a 17 bit number with bit Ø as its sign. The multiplication will take this sign and the value of the link into consideration to produce the correct sign on the product.

All of the examples above are valid where "X" and "Y" are both octal integers or where one of them is an octal integer and the other a scaled number such as a voltage. When multiplying two scaled numbers together it is necessary to take the scaling into account because the multiplication effectively squares the scale factor. Because of this, it is necessary to divide the product by the scale factor to provide proper scaling. When voltages are being used this scale factor is $2^{13}/100$.

Most generally, when one is multiplying two voltages, it is convenient to perform the multiplication in an analog fashion where the product would be divided by 100. Therefore, the analog type multiplication of two voltages is easily performed by dividing the product by 100 ($2^{13}/100$) which is merely 2^{13} . Since the product is normally found in the AC-MQ as a 36 bit number it is necessary to divide by 2^{13} and then multiply by 2^{18} to get the answer into the AC. This can be accomplished by merely multiplying by 2^5 . An example of this follows:

```
LAC Y
GSM
DAC .+3
LAC X
MULS
Ø
LLS 5      /Shift left 5 bits - (multiply by 25)
. . . .   /XY/100 in AC
```

The answer, XY/100, can not be larger than 1599.99 volts for this type of multiplication.

If increased speed is desired in a multiplication and it is known that the variable "X" is less than an 18 bit number, the multiply instruction can be modified slightly. Instead of using MULS once can use MULS-C where C is the number of bits difference between 18 and those contained in the number "X". To multiply by a fifteen bit number once could use MULS-Ø3 since 18-15=3. The reason this is possible is that multiplication is performed through a shift-add sequence; if a bit is zero no addition is necessary. It must be recognized, therefore, that the result in this type of a multiplication is actually the product times 2^C in the AC-MQ. An example follows:

```
LAC Y
GSM
DAC .+3
LAC X      /15 bit number
MULS-3
Ø
. . . .   /
```

Advantage can be taken of this property of multiplication in multiplying two voltages. In a previous example, the result in the AC-MQ was shifted five places right to give the properly scaled answer in the AC; the instructions could be changed as follows:

```
LAC Y      /Voltage variable
GSM
DAC .+3
LAC X      /Voltage variable
MULS-1
LLS 4
. . . .   /XY/100 in AC
```

The MULS instruction always places bit Ø of the accumulator into the EAE sign bit register and then takes the absolute value of the number which always makes bit Ø a zero. Hence, as shown in the above example, it is possible to ignore this bit in the multiplication and then reduce the shift count in the next instruction. This saves approximately 0.2 micro-seconds for each multiplication.

The HMPY1\$ and HMPY2\$ subroutines for the multiplication of two voltages use the type of sequence shown in the above example. For a general multiplication this is the fastest sequence presently available. More speed could be obtained, however, by limiting the size of the numbers. Also, these multiplication subroutines do take time for checking for overflow in the result of the multiplication and locking the result at either + or - 1599.99 volts. If it is felt in a particular case that maximum speed must be obtained and it is unnecessary to check for overflow then a fast multiplication subroutine follows:

/Calling Sequence

```
/LAC X      /X input
/JMS MPY
/LAC Y      /Y input
/. . . .   /RTN PT . AC = XY/100

MPY, Ø
GSM
DAC .+4
XCT I MPY
ISZ MPY
MULS-1
Ø
LLS 4
JMP I MPY
```

The HMPY2\$ subroutine averages 35-40 micro-seconds. By sacrificing checking for overflow within the subroutine this average time is changed to 27.5 - 33.75 micro-seconds, or a savings of 6.25 - 7.5 micro-seconds. In cases where overflow is a concern it could be checked at the return point of the calling sequence.

EXAMPLE MULTIPLY AND DIVIDE PROGRAMS WITHOUT USING SIMPL-1 FUNCTIONS (contd)

DIVIDE WITH DIV or DIVS

The divide instructions cause the 36 bit number in the AC-MQ to be divided by the 18 bit number following the instruction. The quotient is in the MQ and the remainder is in the AC. An example follows:

```

. . . . /36 bit number in AC-MQ
DIV (DIVS) /Divide unsigned or signed
Y /18 bit number
. . . . /Quotient in MQ; remainder in AC

```

(In many special cases it is useful to have a 36 bit number for the numerator, but for the examples shown here, this number will be limited to 18 bits.)

With either the signed or unsigned division the value "Y" in the above example must be the absolute value of the variable or constant. The sign of "Y" should be in the link. If "Y" is a constant the link can be set or cleared before the divide instruction to indicate the proper sign of "Y".

```

CLL (STL) /CLL for positive "Y"; STL for negative "Y"
LAC X /Numerator
LRSS 18' /Load in MQ
DIV (DIVS)
Y /Absolute value
. . . . /Quotient in MQ; remainder in AC

```

If "Y" is a variable its absolute value can be loaded in the register following the divide instruction and its sign can be stored in the link.

```

LAC Y /Signed variable
GSM /Sign + link; Abs(Y) + AC
DAC .+4
LAC X
LRSS + 18'
DIV (DIVS)
Ø
. . . . /Quotient in MQ; remainder in AC

```

Of course, the link could be set or cleared in place of the GSM instruction and "Y" would be considered as an 18 bit number with its sign specified in the link.

When using the unsigned divide instruction (DIV) the numerator "X" will be considered as an 18 bit positive number. If the instruction DIVS is used "X" will be a 17 bit number with bit Ø as its sign. The division will take this sign and the value of the link into consideration to produce the correct sign on the quotient.

All of the above examples are valid where "X" is either an octal integer or a scaled number, such as a voltage, as long as the denominator is only an octal integer. When dividing two scaled numbers it is necessary to take the scaling into account because the division effectively cancels the scale factor. The answer must be multiplied by the scale factor which in the case of voltages is $2^{13}/100$.

Most generally, when one is dividing two voltages it is convenient to perform the division in an analog fashion where the answer is $100 X/Y$. Therefore, the analog type division of two voltages is easily performed by multiplying the quotient by 100 ($2^{13}/100$) which is merely 2^{13} . Instead of multiplying the quotient by 2^{13} the same result can be accomplished by multiplying the numerator by 2^{13} . An example of this follows:

```

LAC Y
GSM
DAC .+5
LAC X
LRSS + 18' /Load in MQ
LLSS + 13' /Multiply by  $2^{13}$ 
DIV (DIVS)
Ø
. . . . /100 X/Y → MQ

```

Obviously, one could say that instead of dividing by 2^{18} and multiplying by 2^{13} it would be better to divide by 2^5 , thereby accomplishing the same thing with one instruction. This is valid except that it is necessary to take into account the final 13 bits in the MQ, making certain that they are all zeros in the case of a positive "X" and all ones in the case of a negative "X". This is accomplished with the shift instructions in the above example because the sign bit is carried into the lower bits of the MQ. However, in an unsigned division the same thing could just as well be accomplished with the following:

```

LAC Y
GSM
DAC .+5
LAC X
CLQ /Ø → MQ
LRSS + 5 /Divide by  $2^5$ 
DIV
Ø
. . . . /100 X/Y → MQ

```

This has an advantage in that the instructions CLQ and LRSS + 5 can be combined into one instruction through micro programming.

```

LAC Y
GSM
DAC .+5
LAC X
CLQ!LRSS + 5
DIV
Ø
. . . . /100 X/Y → MQ

```

Obviously, the quotient (100 X/Y) can not exceed 1599.99 volts. If it does the link is set as an indication of overflow.

It has been found that if instead of DIVS one uses DIVS-1, the answer is still correct except that it is divided by two. It is possible to take advantage of this when dividing two voltages. In a previous example the properly scaled quotient was located in the MQ by dividing the numerator by 2^5 before the division. Using the DIVS-1 instruction instead of the DIVS instruction a voltage division can be performed as follows:

```

LAC Y
GSM
DAC .+5
LAC X
LRSS + 18' /Load in MQ
LLSS + 14' /Multiply Y by  $2^{14}$ 
DIVS-1
Ø
. . . . /100 X/Y → MQ

```

One might notice that in the fifth instruction in this example, the numerator is shifted one place further than in the previous example showing division of two voltages. This actually adds about 0.1 micro-seconds to the program, but the DIVS-1 instruction actually makes a savings of about 0.35 micro-seconds over DIVS. This provides a total savings of about 0.25 micro-seconds in the use of this program.

If one were concerned about time required to perform divisions the following subroutine could be used in place of HDIV\$. The calling sequence is altered in that the denominator is loaded into the accumulator first and no attempt is made to detect overflow. This makes the average time about 42 micro-seconds instead of the 47 micro-seconds for the HDIV\$ subroutine.

```

/CALLING SEQUENCE
/LAC Y /Denominator
/JMS DIVID
/LAC X /Numerator
/. . . . /Rtn. Pt. 100 X/Y in AC

DIVID,
Ø
GSM
DAC .+6
XCT I DIVID
ISZ DIVID
LRSS 18'
LLSS 14'
DIVS-1
Ø
LACQ
JMP I DIVID

```


K-3

NOTES

APPENDIX L

DDT DEBUGGING EXAMPLE

This example demonstrates the use of DDT debugging methods and the use of SET lines for controlling analog IDACAS integrators for solving double integral problems. (This technique can also be expanded to solve partial differential equations. However, this is only one hybrid technique for solving that class of problems.)

THE PROBLEM

Find the volume enclosed by the paraboloid:

$$X^2 + Y^2 = A^2 Z^2$$

where

$$A^2 = 0.1$$

Z ranges from 0 to 1

PROBLEM ANALYSIS

This is not a practical example because an analytical solution exists.

$$\text{i.e. } V = \frac{\pi A^2 Z^3}{3} = \frac{\pi A^2}{3} = 0.10472 \quad (\text{for } Z = 1)$$

However, the problem may be solved by an iterative hybrid technique as shown in Figure 1.

Figure 1

Figure 2

The paraboloid is segmented into a number (i.e., 100) of slabs. (The constant NOITER in the program listing is set to 100.) The volume of each slab is evaluated by multiplying the area by the incremental height.

$$V = \sum_{DELTZ=1}^{NOITER} (DELTZ) (AREA)$$

$$= DELTZ \sum_{1}^{NOITER} (AREA)$$

$$Z = 1 = (NOITER) (DELTZ)$$

The slab area shown in Figure 2 is evaluated by solving the equation

$$A_k = \int_0^{AZ} y dx$$

(NOTE: The limit of integration is variable for each slab)

Multiplication of A_k by 4 gives the total area. The volume is then found by

$$V = 4(DELTZ) \sum_{1}^{NOITER} \int_0^{AZ} \sqrt{A^2 Z^2 - x^2} dx$$

AMPLITUDE SCALING

Scaling factors of 100 for A^2 , 100 for Z^2 , and 1000 for DELTZ seem reasonable because

$$100A^2 = 10$$

$$100Z^2 \rightarrow \text{ranges from 0 to 100}$$

$$1000 \text{ DELTZ} = 10$$

SIMULATION DIAGRAMS

Figures 3 and 4 show analog and digital logic diagrams for solving the problem. Figure 5 contains the listing (mistakes are circled), assembler error messages, and the DDT input/output required to debug the problem. Underlined expressions in the DDT output are those typed by the user. The symbols $\uparrow$ and $\downarrow$ are Teletype line feed and carriage return characters also typed by the user. Column 3 explains the debugging procedure. Figure 6 shows strip chart recordings for each of the 11 debugging steps.

ACCURACY

Since accuracy considerations of analog and hybrid computers are "shadowed" by false impressions, it is worthwhile explaining the 3% answer obtained in this problem. The theoretical answer is 0.10472 and the computer answer is 0.10778. (According to the distorted accuracy opinions 3% accuracy is all one can expect with an analog computer.)

The solution of this problem by iterative techniques required 100 open ended integrations. To achieve the overall accuracy of 3% each integration must be accurate to 0.03%. (This is acceptable on 99% of scientific and engineering problems.)

Figure 4

Figure 5

LOGIC FOR CONTROL OF IDACAS INTEGRATORS

PROGRAM TO FIND THE VOLUME OF A PARABOLOID
/OF THE FORM $X^2 + Y^2 - A^2 Z^2 = 0$
/PROGRAM CONSTANTS

```

INTERG, 0
NOITER, -100+1
TDELTZ, 10.00

/PROGRAM INITIALIZATION
BGN,
  DAC TTYP$
  CLA
  DA0
  MXRN /INITIALIZE THE MULTIPLEXER
  SDBY /PUT THE COMPUTER INTO STANDBY
  JMS WAIT
  M1
  AOSF
  JMP -1
  ADRB
  ADOV
  SKP
  JMP . 6
  ABS
  CAS (0.10
  NOP
  JMP . 2
  JMP . 5
  SETI
  JMS WAIT
  JMS WAIT
  JMP -15
  LAS
  SPA /READY TO CALCULATE
  JMP -2 /NO
  MX0 /YES, CONVERT THE VALUE OF A+2
  AOSF
  JMP -1
  ADRB
  DAC HUNA2#
  LAC TDELTZ
  DAC Z0 /LOAD 1000 DELTA Z
  DAC Z0 /INITIALIZE THE FIRST VALUE OF 1000Z TO
  /1000 DELTA Z
  JMS X.15
  JMS HSQ$ /FORM 100+Z+2
  DA0 /INITIALIZE THE ANALOG FOR THE FIRST VALUE OF
  /100Z+2
  DAC Z2

```

```

/START COMPUTATION LOOP
SETI
MX1 /CONVERT THE VALUE OF 100X+2
LAC HUNA2 /FORM 100A+2Z+2 (I.E. THE END POINT OF
JMS HMPY2$ /INTEGRATION FOR THE PRESENT ITERATION)
LAC Z2
DAC END /SAVE THE LIMIT ON INTERGRATION
AOSF /HAS MX1 BEEN CONVERTED
JMP -1 /NO
ADRB /YES
MX1 /START THE CONVERSION AGAIN
CAS END /HAVE WE REACHED THE END POINT OF INTEGRATION
NOP /YES
JMP SSAV /YES
JMP CON /NO, WAIT
NOP /NO, WAIT
MX2 /CONVERT THE VALUE OF THE INTEGRAL FOR THE
/PRESENT ITERATION (1/4*100*DZ*INTEGRAL)
AOSF
JMP -1
ADRB
ADD INTERG /ADD IT ON TO THE PRESENT VALUE OF THE INTEGRAL
ISZ NOITER /HAVE WE ITERATED OVER ALL OF Z
/I.E. FROM Z=0 TO Z=1
JMP RESET /NO, CONTINUE WITH NEXT ITERATION
JMP PRINT /YES, PRINT OUT THE ANSWER
SETI
LAC TDELTZ
ADD Z0 /FORM THE NEW VALUE OF 1000Z FOR THIS ITERATION
JMS X.15
JMS HSQ$
DA0 /INITIALIZE THE ANALOG FOR THE NEW VALUE OF
/100Z+2
DAC Z2
JMS WAIT /WAIT FOR THE IDACAS TO SETTLE INTO IC
SETI
JMP GO /ITERATE
PRINT,
SETI
LAW MS1
JMS TMSG$
LAC HUNA2
JMS TVOLT$
JMP TTAB$ /MULTIPLY BY 4
LAC INTERG
LLSS 2
JMS TVOLT$
JMP BGN

```

```

MS1, TEXT
VALUE OF VALUE OF THE
100A+2 INTEGRAL
TIMES 10000
0
/USER SUBROUTINE
WAIT, 0
LAS /THE AC SW'S ARE CHANGED ACCORDING TO THE
/SETTLING RATE OF THE IDACAS INTEGRATORS
DAC CNT#
ISZ CNT
JMP -2
JMP I WAIT
PAUSE

```

Initialization for modified instructions (MIST) INTERG, and NOITER are missing

Wrong name

INTERG must be updated (DAC INTERG)

Z is not updated (DAC Z)

You must JMS to a subroutine (JMS TTAB\$)

Infinite Loop (JMP -1)

ASSEMBLER ERROR MESSAGES

PROGRAM TO FIND THE VOLUME OF A PARABOLOID

```

END 167*
TDELTZ 170*
Z2 171*

```

DDT INPUT/OUTPUT

Underlined expressions are those typed by the user.
Expressions not underlined are typed by the DDT.

```

1 TDELTZ/ 0 10.00
BGN/
260 DAC CNT +
WAIT 3/ ISZ CNT +
WAIT 4/ JMP WAIT 2+
WAIT 5/ JMP I WAIT 2
-1/ JMP WAIT 2 JMP -12
2 BGN/
RESET 2/ ADD Z JMP 5718
TTYP$ 5/ JMP I TTAB$ 1
TTYP$ 6/ JMS TTYP$ 54
TTYP$ 7/ DAC TTYP$ 60
RESET 3/ JMS X.15
3 BGN/
NOITER/ LAW MS 2467 7777802
4 BGN/
NOITER/ LAW MS 2467 7777802
RESET-3/ ISZ NOITER HLT
5 BGN/
GO-2/ SETI HLT
6 BGN/
BGN/ LAW TTYP$ JMP TTYP4
TTYP$ 10/ JMS TTYP$ 54
TTYP$ 11/ DAC TTYP$ 60
TTYP$ 12/ JMS TTYP$ 34
BGN 1/ DAC TTYP$ 100
GO-2/ HLT
7 BGN/
VALUE OF VALUE OF THE
100A+2 INTEGRAL
TIMES 10000
10.07
20/ TTAB$ 12
TTAB$/ 0
PRINT 5/ JMP TTAB$ JMS TTAB$
8 BGN/
BGN/ JMP TTYP$ 10
TTYP$ 10/ MIST
TTYP$ 11/ LAW TTYP$
TTYP$ 12/ JMP BGN 1
TTYP$ 13/ JMP TTYP$ 5
TTYP$ 14/ JMS TTYP$ 100
BGN 1/ DAC TTYP$ 2
9 BGN/
VALUE OF VALUE OF THE
100A+2 INTEGRAL
TIMES 10000
10.08
0.04
RESET-4/ ADD INTERG JMP 7008
TTYP$ 11/ LACQ
TTYP$ 115/ DAC TTYP$ 113
TTYP$ 116/ LAC TTYP$ 120
SSAV 11/ ISZ NOITER
10 BGN/
VALUE OF VALUE OF THE
100A+2 INTEGRAL
TIMES 10000
10.08
1074.40
VALUE OF VALUE OF THE
100A+2 INTEGRAL
TIMES 10000
5.09
-1583.02
BGN/ JMP TTYP$ 10
TTYP$ 10/ MIST
TTYP$ 11/ LAW MS 2423
TTYP$ 12/ DAC NOITER
TTYP$ 13/ LAW TTYP$
TTYP$ 14/ JMP BGN 1
TTYP$ 15/ DAC TTYP$ 60
11 BGN/
VALUE OF VALUE OF THE
100A+2 INTEGRAL
TIMES 10000
5.08
541.17
VALUE OF VALUE OF THE
100A+2 INTEGRAL
TIMES 10000
10.10
1076.12
INPUTS
NOITER PUNCH$
TDELTZ PUNCH$
WAIT 4 PUNCH$
RESET 2 PUNCH$
TTYP$ 5: TTYP$ 7 PUNCH$
PRINT 5 PUNCH$
RESET-4 PUNCH$
TTYP$ 114: TTYP$ 116 PUNCH$
BGN PUNCH$
TTYP$ 10: TTYP$ 15 PUNCH$
STARTS
KILLS
ZEROS
DEBUG$
LOAD$ 6 13467
703 13467
12 BGN/
VALUE OF VALUE OF THE
100A+2 INTEGRAL
TIMES 10000
10.08
1075.38

```

From assembly output it can be seen that TDELTZ was not defined so it was defined before debugging started.

From the output after BGN' #1 it can be seen that the iteration loop is not being reached. From the glow of the current address and PC lights it was obvious that the program was in a loop. By alternately hitting stop and continue and observing the address lights it was determined that the loop was at location 260 and thereafter. By examining the content of location 260 and the following locations it was observed that the WAIT subroutine has a mistake JMP -2 should have been JMP -1. The program was repaired and then restarted.

From the output after BGN' #2 it can be seen that Z is not being incremented. By looking at the listing at the place where Z is being incremented it can be seen that Z is being incremented but not updated. This can be repaired with the patch shown after BGN' #2.

From the output after BGN' #3 it was thought that maybe the iteration counter was not being incremented so the program was stopped and the iteration counter examined. It was found to be set at -100+1 indicating that it had not been incremented. To verify it, the program was restarted.

The program was stopped and NOITER was re-examined. Since it still contained -100+1 it was assumed that the program was never reaching the instruction ISZ NOITER so a HLT was put in this location and the program restarted.

From the output after BGN' #5, it was noted that there was no change in the output and the program did not HLT, thus indicating that the RESET part of the program was not being entered. The integrators, however, were still being iterated. There are only two places other than in the RESET portion of the program, where the SETI instruction occurs (SETI causes the integrators to change modes). A HLT was placed in one of these and the program restarted.

From the output after BGN' #6 it can be seen there was no change in the output and the program did not HLT indicating that the SETI instruction following the CAS (D.10 instruction must be in a loop, but this could only happen if the Modified Instruction Mode had not been selected. An examination of the listing indicated that it had been neglected so a patch was added in the free part of core between 571 and 13467. The HLT which were added were also removed.

From the output after BGN' #7 it seemed as if the program was working but it CAL'ed out. By examining location 20 the address +1 from which the CAL occurred is obtained. Since it CAL'ed out from the first location in a subroutine, it was thought that maybe in calling a subroutine a JMP was used rather than JMS. An examination of the listing indicated that this was the case and so it was repaired and the program restarted.

From the output after BGN' #8 it was obvious that the program was not going to stop iterating after 100 iterations as it had previously, thus, indicating that NO ITER (The iteration counter) was not being re-initialized. An examination of the listing verified that and so the program was patched as indicated and restarted.

From the output after BGN' #9 and the value of 0.00 for the intergal it was thought that maybe INTERG was not being updated. An examination of the listing verified this and the program was patched and restarted.

Program Response (a) for $100 A^2 = 10.04$ was correct so $100 A^2$ was changed to 5.03 but the answer (b) was wrong. This indicates that INTERG must not be initialized between runs. An examination of the listing verified this and the program was patched as indicated and restarted.

From the output after BGN #11 it can be seen that the program has been debugged. A DDT tape of the patches was then punched (see the sequence from INPUTS through STARTS). All of the locations that were changed in the debugging process were punched. A further check was then made to see if all the patches had been punched. The symbol table was killed and the memory was zeroed. The program tape and the tape of patches were reloaded and the program was rerun (BGN #12). From the response it can be seen that all of the patches were punched. The program can now be rerun at any time by simply loading the main program tape and then the tape of DDT patches.

DDT DEBUGGING EXAMPLE (contd)

Recorder output for each step during the DDT debugging process

DDT DEBUGGING EXAMPLE (contd)

PROGRAM TO FIND THE VOLUME OF A PARABOLOID
/OF THE FORM $X^2 + Y^2 - A^2Z^2 = 0$
/PROGRAM CONSTANTS

INTERG, 0
NOITER, -100.1
TDELZ, 10.0

/PROGRAM INITIALIZATION
BGN,

LAW TYP\$
DAC TTP\$
CLA
DA0
DZM INTERG
DZM Z
MIST
MXRM /INITIALIZE THE MULTIPLEXER
LAM -100.1
DAC NOITER
SDBY /PUT THE COMPUTER INTO STANDBY
JMS WAIT
MX1
ADSF
JMP .-1
ADRB
ADOV
SKP
JMP . 6
ABS
CAS (0.10
NOP
JMP . 2
JMP . 5
SETI
JMS WAIT
JMS WAIT
JMP .-15
LAS
SPA /READY TO CALCULATE
JMP .-2 /NO
MX0 /YES, CONVERT THE VALUE OF A+2
ADSF
JMP .-1
ADRB
DAC HUNA2#
LAC TDELZ /LOAD 1000 DELTA Z
DAC Z# /INITIALIZE THE FIRST VALUE OF 1000 Z TO
/1000 DELTA Z
JMS X.1\$
JMS HSQ\$ /FORM $100+Z^2$
DA0 /INITIALIZE THE ANALOG FOR THE FIRST VALUE OF
/100 Z+2

/START COMPUTATION LOOP

GO, SETI /PUT INTO COMPUTE
LAC HUNA2 /CONVERT THE VALUE OF $100X^2$
JMS HMPY2\$ /FORM $100A+2Z^2$ (I.E. THE END POINT OF
LAC Z2 /INTEGRATION FOR THE PRESENT ITERATION)
CON, DAC END /SAVE THE LIMIT ON INTERGRATION
ADSF /HAS MX1 BEEN CONVERTED
JMP .-1 /NO
ADRB /YES
MX1 /START THE CONVERSION AGAIN
CAS END /HAVE WE REACHED THE END POINT OF INTEGRATION
NOP /YES
JMP SSAV /YES
SSAV, JMP CON /NO, WAIT
NOP /CONVERT THE VALUE OF THE INTEGRAL FOR THE
/PRESENT ITERATION ($1/4*100*DZ*INTEGRAL$)

NOP
NOP
NOP
MX2
ADSF
JMP .-1
ADRB
ADD INTERG /ADD IT ON TO THE PRESENT VALUE OF THE INTEGRAL
DAC INTERG
ISZ NOITER /HAVE WE ITERATED OVER ALL OF Z
/I.E. FROM Z=0 TO Z=1
JMP RESET /NO, CONTINUE WITH NEXT ITERATION
RESET, JMP PRINOT /YES, PRINT OUT THE ANSWER
SETI

LAC TDELZ
ADD Z# /FORM THE NEW VALUE OF 1000Z FOR THIS ITERATION
DAC Z
JMS X.1\$
JMS HSQ\$
DA0 /INITIALIZE THE ANALOG FOR THE NEW VALUE OF
/100Z+2

DAC Z2
JMS WAIT /WAIT FOR THE IDACS TO SETTLE INTO IC
SETI /PUT INTEGRATORS INTO COMP
PRINOT, JMP GO /ITERATE
SETI

LAW MS1
JMS TMSG\$
LAC HUNA2
JMS IVOLT\$
JMS TTAG\$
LAC INTERG
LLSS 2 /MULTIPLY BY 4
JMS IVOLT\$
JMP BGN
MS1, TEXT

VALUE OF VALUE OF THE
100A+2 INTEGRAL
@ TIMES 10000

/USER SUBROUTINE

WAIT, 0
LAS /THE AC SW'S ARE CHANGED ACCORDING TO THE
/SETTLING RATE OF THE IDACS INTEGRATORS

DAC CNT#
ISZ CNT
JMP .-1
JMP I WAIT

/USER SUBROUTINE

WAIT, 0
LAS /THE AC SW'S ARE CHANGED ACCORDING TO THE
/SETTLING RATE OF THE IDACS INTEGRATORS

DAC CNT#
ISZ CNT
JMP .-1
JMP I WAIT
PAUSE

PROGRAM TO FIND THE VOLUME OF A PARABOLOID

END 175*
Z2 177*

TABLE\$ 577 13472

INPUT\$
1: 576 PUNCH\$
START\$
BGN'

VALUE OF VALUE OF THE
100A+2 INTEGRAL
10.10 TIMES 10000
1073.44

L-4

BWML-878

BWML-878

PILOT EJECTION STUDY

The statement for this problem is taken from SEG-TDR-64-1. "MIDAS Programming Guide".

The purpose of this investigation is to determine the trajectory of a pilot ejected from a fighter aircraft in order to ascertain whether he will strike the vertical stabilizer of the aircraft. Several combinations of aircraft speed and altitude will be investigated since the drag on the pilot, causing his relative horizontal motion with respect to the aircraft, is a function of air density and velocity (squared). The ejection system is so devised that it causes the pilot and his seat to travel along rails at a specified exit velocity V_E , at an angle θ_E backward from vertical. The seat becomes disengaged from the rails at $Y = Y_1$. This first phase of the ejection is illustrated in Phase I.

Once the pilot and seat combination leaves the rails, it follows a ballistic trajectory which can be determined; however, since it is the relative motion of the pilot with respect to the aircraft (which is assumed to fly level at constant speed) that is important, we can formulate our equations so as to obtain this directly. This phase of the ejection is shown as Phase II.

The governing equations are:

$$\dot{X} = V \cos \theta - V_A$$
$$\dot{Y} = V \sin \theta$$
$$\dot{V} = 0$$
$$= -\frac{D}{m} - g \sin \theta$$
$$\dot{\theta} = 0$$
$$= -(g \cos \theta)/V$$
$$D = \frac{1}{2} C_d S V^2$$

Constants

$m = 7$ slugs

$g = 32.2$ ft/sec²

$C_d = 1$

$S = 10$ ft²

$Y_1 = 4$ ft

$V_E = 40$ ft/sec

$\theta_E = 15^\circ (=15/57.3$ radians)

$V_A = 900$ ft/sec

$\rho = 2.3769 \times 10^{-3}$ slugs/ft³

The initial values of V and θ (pilot's initial velocity vector at moment of leaving cockpit rails) are given by:

$$V(0) = \sqrt{(V_A - V_E \sin \theta_E)^2 + (V_E \cos \theta_E)^2}$$
$$\theta(0) = \tan^{-1} \frac{V_E \cos \theta_E}{V_A - V_E \sin \theta_E}$$
$$X(0) = Y(0) = 0$$

A run is to be terminated when any one of these conditions occurs:

- $X \leq -60$ feet (pilot beyond vertical stabilizer)
- $Y \geq 30$ feet (pilot well above 12 ft. high tail)
- $t \geq 4.0$ secs.

Plot $\dot{V}$, V , θ , X , and Y vs. time

Plot X vs. Y

APPENDIX M

SIMPL-1 HYBRID SOLUTION FOR THE PILOT EJECTION STUDY

PRINTOUT FOR REAL TIME SOLUTION
 (A TOTAL OF 331 COMPUTING FRAMES WERE USED)

VA	RHO				
900.00	237.70				
TIME (X100 SEC)	VDOT	V	THETA	X	Y
0	0.00	890.38	43.52	0.00	0.00
1	0.00	890.38	43.52	-0.09	0.35
2	0.00	890.38	43.52	-0.18	0.71
3	0.00	890.38	43.52	-0.29	1.11
4	0.00	890.38	43.52	-0.40	1.51
5	0.00	890.38	43.52	-0.50	1.87
6	0.00	890.38	43.52	-0.61	2.28
7	0.00	890.38	43.52	-0.71	2.64
8	0.20	890.38	43.52	-0.82	3.04
9	0.00	890.38	43.52	-0.93	3.44
10	0.00	890.38	43.52	-1.01	3.80
11	-1331.77	883.42	43.33	-1.15	4.20
12	-1290.31	871.36	42.94	-1.36	4.55
13	-1255.27	857.87	42.60	-1.72	4.94
14	-1216.92	846.25	42.20	-2.23	5.29
15	-1185.19	833.52	41.85	-2.31	5.65
16	-1150.57	822.78	41.43	-3.58	5.97
17	-1120.71	810.52	41.06	-4.37	6.34
18	-1088.57	800.35	40.64	-5.39	6.68
19	-1061.21	788.97	40.27	-6.36	6.97
20	-1031.55	777.88	39.83	-7.59	7.30
21	-1003.36	763.32	39.44	-8.79	7.59
22	-979.71	757.31	38.99	-10.24	7.91
23	-953.33	748.92	38.60	-11.58	8.18
24	-930.77	738.93	38.15	-13.24	8.48
25	-906.52	730.30	37.73	-14.80	8.74
26	-886.19	720.80	37.27	-16.64	9.02
27	-863.37	712.74	36.79	-18.32	9.26
28	-844.29	703.70	36.36	-20.36	9.55
29	-823.13	695.86	35.88	-22.49	9.78
30	-805.51	687.23	35.45	-24.45	10.04
31	-785.60	679.91	34.95	-26.76	10.29
32	-769.20	671.67	34.51	-28.82	10.51
33	-750.54	664.53	33.98	-31.34	10.76
34	-734.96	656.65	33.55	-33.53	10.96
35	-717.75	648.96	33.02	-36.16	11.19
36	-703.23	642.30	32.55	-38.55	11.39
37	-687.46	634.94	32.02	-41.32	11.61
38	-671.91	628.69	31.54	-43.79	11.79
39	-658.62	621.63	31.00	-46.71	12.00
40	-644.09	615.52	30.52	-49.34	12.17
41	-631.85	608.75	29.96	-52.39	12.37
42	-617.95	603.00	29.41	-55.46	12.54
43	-606.52	596.51	28.90	-58.29	12.72
44	-593.56	590.99	28.32	-61.54	12.89

SIMPL-1 ALL DIGITAL SOLUTION FOR THE PILOT EJECTION STUDY (contd)DISCUSSION OF SIMPL-1 (ALL DIGITAL) PILOT EJECTION STUDY

The problem definition, flow charts, computer program and output are contained on the preceding pages.

This example is significant because it demonstrates:

1. Amplitude scaling
2. Use of function generator programs
3. The format and method of printing header messages on Teletype
4. Method of storage allocation for numeric printout
5. User subprograms and computer initialization
6. The ICL\$ (initialize real-time clock) and the corresponding programs serviced by the automatic priority interrupt
7. Pre-calculation of initial conditions
8. Auto index registers for answer storage and retrieval
9. The main computing loop and subroutine RINT\$
10. The use of the teletype library for printing out answers.

SCALING

Since this is an all digital simulation, all values should be scaled between ± 10 (or 50) and ± 1599.99 . On a large complex problem scaling information could be obtained by first writing an APACHE (5) or MIDAS (6) program. Since this is a relatively simple problem, amplitude scaling can be accomplished by inspection. From equations and constants given in the problem definition, it is obvious that θ , M , C_d , S , V^2 , ρ and the squared terms in the $V(0)$ equation require amplitude scaling. (A scale factor for the switching variable $Y1$ is not needed.) For convenience the following relationships (showing scaling factors) are chosen.

$$\begin{aligned}
 1000 \theta &\approx 400 \\
 10 M &= 70 \\
 100 C_d &= 100 \\
 10 S &= 100 \\
 10^{-4} V^2 &= 81 \\
 10^5 \rho &= 273.69 \\
 100 \cos \theta &\approx 100 \\
 100 \sin \theta &\approx 4.0 \\
 \{0.1 V_A - 0.1 V_E \sin \theta\} &\approx 81 \\
 0.1 V_E \cos \theta &\approx 4
 \end{aligned}$$

(scaling for this term is required for compatibility with other terms in $V(0)$ calculation)

SIMPL-1 HYBRID SOLUTION FOR THE PILOT EJECTION STUDY (contd)

```

PILOT EJECTION STUDY
/PROGRAM CONSTANTS
M,      70.0      /10*M
G,      32.2
CD,     100.      /100*CD
S,      100.      /10*S
YI,     4.0
VE,     40.0
VA,     900.
RHO,    237.69    /10*5*RHO
THETA E, 15.0*100'\90'
/INITIALIZE COMPUTER
BGN,    MXRN
MIST
/MAIN PROGRAM LOOP
LOOP,   JMS AMODES
        SUP 4
        SNA
        JMP MAIN
/Calculate INITIAL CONDITIONS
INITIAL,
        LAC THETA E
        JMS HSIN$
        CMA
        JMS HMPY2$
        LAC VE
        ADD VA
        JMS X.1$
        DAC TEMP1
        LAC THETA E
        JMS HCOS$
        JMS HMPY2$
        LAC VE
        DAC TEMP2
        JMS HDIV$
        LAC TEMP1
        DAC THAIC
        LAC TEMP1
        JMS HSQ$
        DAC TEMP1
        LAC TEMP2
        JMS X.1$
        JMS HSQ$
        ADD TEMP1
        JMS HSQRT$
        DAC VIC
        /IC FOR V
/SET IC VALUES
D5
LAC THAIC
D44
/MAIN PROGRAM LOOP
MAIN,   JMS ADC$
        J
        DAC THETA
        DAC X
        DAC Y
        DAC VI
        LAC VI
        JMS XI0$
        CMA
        DAC V
        LAC THETA
        CMA
        JMS HMPY1$
        6.36
        DAC ANGLE
        JMS HCOS$
        DAC COS1
        JMS HMPY3$
        LAC G
        LAC VI
        DAC DTHETA /DTHETA*DT
        LAC COS1
        JMS HMPY2$
        LAC V
        SUB VA
        JMS X.1$
        DAC DX
        LAC ANGLE
        JMS HSIN$
        DAC SIN1
        JMS HMPY2$
        LAC V
        DAC DY
        LAC SIN1
        JMS HMPY2$
        LAC G
        CMA
        DAC SAVE1
        LAC VI
        JMS HSQ$
        JMS XI0$
        DAC SAVE2
        LAC CD
        JMS HMPY3$
        LAC RHO
        LAC (200.
        JMS HMPY3$
        LAC S
        LAC M

```

/DIGITAL TO ANALOG BLOCK TRANSFER

/CHECK TO SEE IF DONE COMPUTING

PAUSE

DISCUSSION OF THE SIMPL-1 (hybrid) PILOT EJECTION SIMULATION

Notice on the illustrations to the left that every program must have:

1. A title
2. A tabulation of program constants
3. A computer initialization section
4. A main program loop for
 - (a) mode checking
 - (b) pre-calculation of initial conditions (optional)
 - (c) analog to digital transfer
 - (d) digital calculations
 - (e) digital to analog transfer
 - (f) computing termination test (optional)
5. A PAUSE statement

TITLE

The title for the listing is "Pilot Ejection Study."

TABULATION OF PROGRAM CONSTANTS

The slash (/) in the line "/Program Constants" is an assembler comments character. If a carriage return (↵) or tab (⇥) precedes the slash (/), the assembler ignores all information following the slash until the next carriage return.

Notice the utility of the slash in comments for M, CD, S, and RHO. The /10*M informs the reader that the number 70.0 is ten times the value of M (which is 7). Numerical values of all program constants and variables must contain a decimal point to signify voltage scaling (see Appendix C).

The listing for THETA E demonstrates a useful feature of the SIMPL-1 assembler for preforming mathematical operations. The sequence of operations (15*100'\90') are used to convert THETA E from degrees to the voltage units required by the HSIN\$ and HCOS\$ subroutines. The functions of the symbols (*, ', and \) are explained in Appendix A, Source Language Symbols.

COMPUTER INITIALIZATION

In this example the modified instructions and random select multiplexer modes are specified.

MAIN PROGRAM LOOP*

The first function performed by the main computing loop is to check the analog computers mode. The initial condition calculations are entered for every analog computer mode except COMPUTE. The I.C. values are transferred to the analog computer through use of assembly language digital to analog conversion instructions.

The derivative calculation loop begins with the analog to digital block transfer calling sequence. The derivative calculations are then accomplished by interconnecting mathematical building blocks as required by scale factors and the mathematical model. The test to determine if $d\theta/dt$ and dV/dt are set to zero is made prior to digital to analog block transfer of derivatives. The last function of the program is to determine if X and Y have exceeded end of run limits. If not, the derivative calculations are repeated.

PAUSE

The last statement of any SIMPL-1 program should be the pseudo-instruction PAUSE.

GENERAL REMARKS ABOUT THE PROGRAM

The program as written required 760 memory locations (or 9.3% of the computers 8192 memory locations) and adequately simulated the problem ten times faster than real-time.

The derivative calculation frame time is about 1100 to 1200 μ sec. This could be reduced to about 800 μ sec by replacing analog to digital and digital to analog block transfers with assembly language listings. Further special improvements could be made by performing the calculation for $10^5 SC_d P / (2M)$ only once in the initialization section.

* Scaling data for interconnecting the main program loop computing elements is contained on the logical flow diagram. [A discussion of the scaling technique is also contained in the explanation of the SIMPL-1 (all digital) simulation of this problem.]

PILOT EJECTION STUDY

The statement for this problem is taken from SEG-TDR-64-1. "MIDAS Programming Guide".

The purpose of this investigation is to determine the trajectory of a pilot ejected from a fighter aircraft in order to ascertain whether he will strike the vertical stabilizer of the aircraft. Several combinations of aircraft speed and altitude will be investigated since the drag on the pilot, causing his relative horizontal motion with respect to the aircraft, is a function of air density and velocity (squared). The ejection system is so devised that it causes the pilot and his seat to travel along rails at a specified exit velocity V_E , at an angle θ_E backward from vertical. The seat becomes disengaged from the rails at $Y = Y_1$. This first phase of the ejection is illustrated in Phase I.

PHASE I

PHASE II

Once the pilot and seat combination leaves the rails, it follows a ballistic trajectory which can be determined; however, since it is the relative motion of the pilot with respect to the aircraft (which is assumed to fly level at constant speed) that is important, we can formulate our equations so as to obtain this directly. This phase of the ejection is shown as Phase II.

The governing equations are:

$$\dot{X} = V \cos \theta - V_A$$

$$\dot{Y} = V \sin \theta$$

$$\ddot{Y} = 0$$

$$= -\frac{D}{m} - g \sin \theta$$

$$\dot{\theta} = 0$$

$$= -(g \cos \theta)/V$$

$$D = \frac{1}{2} C_d \rho V^2$$

Constants

$$m = 7 \text{ slugs}$$

$$g = 32.2 \text{ ft/sec}^2$$

$$C_d = 1$$

$$S = 10 \text{ ft}^2$$

$$Y_1 = 4 \text{ ft}$$

$$V_E = 40 \text{ ft/sec}$$

$$\theta_E = 15^\circ (=15/57.3 \text{ radians})$$

$$V_A = 900 \text{ ft/sec}$$

$$\rho = 2.3769 \times 10^{-3} \text{ slugs/ft}^3$$

The initial values of V and θ (pilot's initial velocity vector at moment of leaving cockpit rails) are given by:

$$V(0) = \sqrt{(V_A - V_E \sin \theta_E)^2 + (V_E \cos \theta_E)^2}$$

$$\theta(0) = \tan^{-1} \frac{V_E \cos \theta_E}{V_A - V_E \sin \theta_E}$$

$$X(0) = Y(0) = 0$$

A run is to be terminated when any one of these conditions occurs:

$$X \leq -60 \text{ feet} \quad (\text{pilot beyond vertical stabilizer})$$

$$Y \geq 30 \text{ feet} \quad (\text{pilot well above 12 ft. high tail})$$

$$t \geq 4.0 \text{ secs.}$$

Plot $\dot{V}$, V , θ , X , and Y vs. time

Plot X vs. Y

APPENDIX N

SIMPL-1 ALL DIGITAL SOLUTION FOR THE PILOT EJECTION STUDY

```

PILOT EJECTION STUDY
/PROGRAM CONSTANTS
100/
M, 100.0 /10M
G, 32.2
CD, 100.0
S, 100.0 /10S
Y1, 4.0
VE, 40.0
VA, 900.0
RHO, 2.3769 /10**3(RHO) /CONVERT DEGREES TO VOLTS
THETA_E, 15.0*100**90
/FUNCTION GENERATOR STORAGE
INTAN, 0.0
2292.26
LRS 12
10.0
0.0
17.45
34.90
52.35
69.80
87.25
104.7
122.15
139.80
157.05
174.5
/HEADER MESSAGE
MS1, TEXT
VA, RHO
0
NS2, TEXT
TIME, VDOT
(X100 SEC)
0
/ANSWER STORAGE
TBL,
TBL+601//
/INITIALIZE COMPUTER
BGN1, JMS DELAY
LAC VIC
JMS X.15
DA3
LAC THEIC
DA0
CLA
DA1
DA2
DA4
JMS DELAY
LAC (3
DAC $MODE
CAF
JMS ITYPS
MIST
DZM LCLO
DZM COUNT1#
LAC (TBL-1
DAC 10
JMS ICL$
I
FC, 5000.
NI, 100.
NIC, 100.
SERVC
0
TIMEV, 0
DZM FLAG#
/CALCULATE INITIAL CONDITIONS
LAC THETA_E
JMS HSIN$
CMA
JMS HMPY2$
LAC VE
ADD VA
JMS X.15
DAC TEMPI#
LAC THETA_E
JMS HCOS$
JMS HMPY2$
LAC VE
DAC TEMPI#
JMS HDIV$
LAC TEMPI
DAC SAVE1#
LAW INTAN
JMS FGS$
LAC SAVE1
DAC THEIC /I.C. FOR THETA
LAC TEMPI
JMS HSG$
DAC TEMPI
JMS X.15
JMS HSG$
ADD TEMPI
JMS HSGRT$
JMS X10$
DAC VIC /I.C. FOR VELOCITY
/STORE I.C. VALUES IN OUTPUT TABLE
DZM 1 10
DZM 1 10
LAC VIC
DAC 1 10
LAC THEIC
DAC 1 10
DZM 1 10
DZM 1 10

/MAIN PROGRAM LOOP
LOOP, JMS MODE
LCLO, JMS CNP$
0
DAC NP /BGN INTEGRATIONS
LAW RINTS
JMP $MODE
LAC NP
LAC THEIC
LAC DTHETA
LLSS
ADD THETA
0
DAC THETA /1000 THETA
LAC (0.0
LAC DX
LLSS
ADD X
0
DAC X /X OUTPUT
LAC (0.0
LAC DY
LLSS
ADD Y
0
DAC Y /Y OUTPUT
LAC VIC
LAC VDOT
LLSS
ADD V
0
DAC V /VELOCITY OUTPUT
NOP
JMP .+1
/DERIVATIVES
LAC THETA
JMS HMPY1$
6.35
DAC ANGLE#
JMS HCOS$
DAC COS1
LAC G
JMS X10$
JMS HMPY2$
LAC COS1
JMS HDIV$
LAC V
CMA
DAC DTHETA /D(THETA)/DT
LAC COS1
JMS HMPY2$
LAC V
SUB VA
DAC DX /DX/DT
LAC ANGLE#
JMS HSTH$
DAC SIN1
JMS HMPY2$
LAC V
DAC DY /DY/DT
LAC SIN1
JMS HMPY2$
LAC G
CMA
DAC SAVE1
LAC V
JMS X.15
JMS HSG$
JMS X10$
DAC SAVE2
DAC CD
JMS HMPY3$
LAC RHO
LAC (200.
JMS HMPY3$
LAC S
LAC M
CMA
JMS HMPY2$
LAC SAVE2
ADD SAVE1
DAC VDOT
LAC Y
SUB Y1
SPA
JMP .3
DZM VDOT
DZM DTHETA
LAC THETA
DA0
LAC X
DA1
LAC Y
DA2
LAC V
JMS X.15
DA3
LAC VDOT
JMS X.15
LRS 1
DA4
LAC (1
DAC FLAG
JMP LOOP

```

```

graph TD
    A[PILOT EJECTION STUDY] --> B[PROGRAM CONSTANTS]
    B --> C[FUNCTION GENERATOR STORAGE]
    C --> D[HEADER MESSAGE]
    D --> E[ANSWER STORAGE]

```

[illegible]

Main Program Loop

- ```

graph TD
 Start([Start]) --> Read[Read]
 Read --> Loop{First Loop ?}
 Loop -- No --> Read
 Loop -- Yes --> Print[Print]
 Print --> End([End])

```

Set I.C. Mode

### Calculate Derivatives

## STORE ANSWERS

No.          Print         

|                                          |
|------------------------------------------|
| Use RCL\$ to Restore<br>AC, MQ, SC, LINK |
|------------------------------------------|

|                            |
|----------------------------|
| Return to Program Sequence |
|----------------------------|

PAUSE

SIMPL-1 ALL DIGITAL SOLUTION FOR THE PILOT EJECTION STUDY (contd)DISCUSSION OF SIMPL-1 (ALL DIGITAL) PILOT EJECTION STUDY

The problem definition, flow charts, computer program and output are contained on the preceding pages.

This example is significant because it demonstrates:

1. Amplitude scaling
2. Use of function generator programs
3. The format and method of printing header messages on Teletype
4. Method of storage allocation for numeric printout
5. User subprograms and computer initialization
6. The ICL\$ (initialize real-time clock) and the corresponding programs serviced by the automatic priority interrupt
7. Pre-calculation of initial conditions
8. Auto index registers for answer storage and retrieval
9. The main computing loop and subroutine RINT\$
10. The use of the teletype library for printing out answers.

SCALING

Since this is an all digital simulation, all values should be scaled between  $\pm 10$  (or 50) and  $\pm 1599.99$ . On a large complex problem scaling information could be obtained by first writing an APACHE (5) or MIDAS (6) program. Since this is a relatively simple problem, amplitude scaling can be accomplished by inspection. From equations and constants given in the problem definition, it is obvious that  $\theta$ ,  $M$ ,  $C_d$ ,  $S$ ,  $V^2$ ,  $\rho$  and the squared terms in the  $V(0)$  equation require amplitude scaling. (A scale factor for the switching variable  $Y_1$  is not needed.) For convenience the following relationships (showing scaling factors) are chosen.

$$\begin{aligned}
 1000 \theta &\approx 400 \\
 10 M &= 70 \\
 100 C_d &= 100 \\
 10 S &= 100 \\
 10^{-4} V^2 &= 81 \\
 10^5 \rho &= 273.69 \\
 100 \cos \theta &\approx 100 \\
 100 \sin \theta &\approx 4.0 \\
 \{0.1 V_A - 0.1 V_E \sin \theta\} &\approx 81 \\
 0.1 V_E \cos \theta &\approx 4
 \end{aligned}$$

(scaling for this term is required for compatibility with other terms in  $V(0)$  calculation)

The applicability of the above scale factor can be tested as follows:  
 Since a unity scale factor for  $V$  is acceptable the scale factors selected for  $\rho$ ,  $C_d$ ,  $S$ , and  $V^2$  should produce unity...but will they?

$$\frac{D}{M} = \frac{\rho C_d S V^2}{2M}$$

$$[1] \quad \frac{D}{M} \neq \frac{1}{2} \frac{10^5 \rho [100 C_d] [10 S] [10^{-4} V^2]}{[10 M]}$$

to make the equation compatible the right side must be divided by 1000.

$$[1] \quad \frac{D}{M} = \frac{1}{2} \frac{10^5 \rho [100 C_d] [10 S] [10^{-4} V^2]}{[1000] [10 M]}$$

The value of  $D/M$  is calculated in four steps. (See the main computing loops block diagram.) First the ratio  $(100 C_d)(10^5 \rho)/200$  is evaluated with a HMPY3\$ routine. The second operation involves multiplying this ratio by  $10 S/10 M$  with another HMPY3\$ routine to produce a scale factor of  $10^5$ . The third operation involves squaring  $0.1V$  with a HSQ\$. The resulting scale factor is  $10^{-4} V^2$  because the hybrid squaring routine automatically multiplies the result by  $10^{-2}$ . A scale factor of  $10^{-3}$  for  $V^2$  is obtained by multiplying by 10. The final ratio for  $D/M$  is obtained by multiplying  $-10^5 [C_d \rho S]/[2M]$  by  $10^{-3} V^2$  with a HMPY2\$ routine. The resulting scale factor for  $D/M$  is 1 because the HMPY2\$ automatically divides by an additional factor of 100.

The proper scale factor of 1000 for  $\theta$  is obtained in the main computing loop by multiplying  $G$  by 10 and taking advantage of the 100 multiplying scale factor associated with the hybrid divide routine. Note the necessity of converting  $1000 \theta$  (in radians) to volts by multiplying by  $0.1(\frac{200}{\pi})$  before evaluating the sin and cos functions. In the initial conditions calculation the scale factor of 1000 for  $\theta(0)$  is also obtained by taking advantage of the HDIV\$ and problem variable scale factors. The mechanism for this is left as a reader exercise.

There are two reasons for using a function generator to evaluate the initial condition for  $1000 \theta$  (or THEIC). The first is because the SIMPL-1 language does not contain an inverse tangent function, although for this example the angle is small enough to assume  $\theta = \tan \theta = \sin \theta$ . The second reason is to illustrate the use of a function generator.

#### FUNCTION GENERATOR

The tabular values for the function generator are stored beginning with the tag INTAN. The regular calling sequence occurs as needed in calculating the initial condition for  $1000 \theta$  (or THEIC).

The eleven function generators tabular values in INTAN were obtained at 1° intervals by converting from degrees to radians and multiplying by 1000. The value of 2292.26 for XMULT and RX were obtained as shown in the remarks section of the FG2\$ description:

$$\text{XMULT} = \frac{40000}{17.45} = 2292.26$$

$$\text{RX} = 12$$

The statement following LRS 12 in the listing is 10'. The apostrophe in 10' indicates there are 10 (decimal) segments in 11 tabular values.

#### HEADER MESSAGE

The method for defining the printed output follows the function generator storage information on the listing. The tag (or storage location) MS1 contains the pseudo-instructions TEXT which causes Teletype printing to occur until the symbol @ is encountered when the sequence

```
LAW MS1
JMS TMSG$
```

is called by the PRINT subroutine. Notice that subrouting PRINT causes the voltage values of VA and RHO to be printed beneath the message printed by MS1.

The second header message starting at location MS2 is printed in a similar manner when the sequence

```
LAW MS2
JMS TMSG$
```

is encountered in subroutine PRINT.

ANSWER STORAGE

The tag sequence

```
TBL,
TBL + 601',
```

saves 600 storage locations for answers, since less than 50 increments of the six variables were printed out only 300 locations needed to be saved. The auto index register 10 (discussed later) is used to store and retrieve the answers.

USER SUBPROGRAMS AND COMPUTER INITIALIZATION

Since it was desired to solve the problem in repetitive operation, a delay between compute and I.C. followed by a delay between I.C. and compute was incorporated to dress up the output when plotted on the strip chart recorder. The subroutine DELAY also serves as an example of incorporating a user subroutine within a main program. The subroutine is called by the instruction:

JMS DELAY

subroutine DELAY is composed of the following sequence

```

DELAY, Ø
 LAW
 DAC CNT#
 ISZ CNT
 JMP . 2
 JMP I DELAY
 NOP
 JMP . -4

```

The first location in the subroutines calling instruction sequence is used to store the contents of the program counter when entering the subroutine. For this reason it is customarily coded with a zero (Ø).

The function of the DELAY is to count from 760000₈ up to 777777 (and then zero) and then return to the main program. The instruction JMP I DELAY provides the mechanism for returning to the main program sequence.

The indirect bit (I) of the JMP I DELAY instruction is used for retrieving the address stored by the program counter in location DELAY when originally entering the subroutine. In other words, the JMP I DELAY instructions looks in storage location DELAY for the address of the next executable statement.

The coding sequence between BGN1 and BGN provides the delay, conversion of I.C. problem variables, and software transfer of the computer to I.C. The coding sequence between the tag BGN and the instruction JMS ICL\$ is used for normal computer initialization which include clearing all flags, initializing the Teletype typing subroutine, selecting the modified instruction set, setting important counters to zero and initializing auto index register 10 for answer storage.

The use of the ICL\$ subroutine calling sequence starting with ICL\$ to (but not including) DZM flag# is used for initializing the real-time clock, selecting the time scale, determining frequency of interrupts, and specifying the subroutines to be serviced during priority interrupts. For this example the time scale is unity and subroutine SERVC is entered every 0.01 sec for answer storage. (Note that since subroutine SERVC is called by the automatic

interrupt system that the subroutines first storage location does not contain a zero (Ø) as do subroutines normally called by a main program. Also, note that the last instruction of the subroutine is a JMP RCL\$.)

PRE-CALCULATION OF INITIAL CONDITIONS

Since the computer's mode has been previously set to I.C., the initial conditions are calculated by following the rules of amplitude scaling and building block interconnection as determined by the governing equations. The reader should note that scaling factors for input problem variables properly combine with arithmetic subprogram scale factors to produce the proper output variable scale factor. This is especially true in calculating 1000 θ (or THEIC). However, an addition scale factor of 10 is required in evaluating VIC.

AUTO INDEX REGISTERS FOR ANSWER STORAGE

The use of auto index registers was mentioned in the sections on Message Printing and Computer Initialization.

Storage locations 10 through 14 are reserved as auto index registers. These locations contain special hardware that increments the contents of the location before executing an instruction. This is why auto index register 10 was initialized with the address of TBL-1.

The first need for using auto index register 10 occurs in storing initial conditions for later retrieval during printout. The instruction sequence

DZM I 10	(Stores a zero for TIME in loca TBL)
DZM I 10	(Stores a zero for VDOT in loc TBL+1)
LAC VIC	
DAC I 10	(Stores VIC in loc TBL+2)
LAC THEIC	
DAC I 10	(Stores THEIC in loc TBL+3)
DZM I 10	(Stores a zero for X in loc TBL+4)
DZM I 10	(Stores a zero for Y in loc TBL+5)

The auto index register is not used again until subroutine SERVC is serviced by the automatic priority interrupt system (operating under software control of the ICL\$ subroutine). Further utilization of the auto index register is similar to that given above. However, the reader should note that a counter (COUNT1) is used to determine the number of times the PRINT subroutine was entered.

A test to see if computing should terminate immediately preceeds the last instruction of the PRINT subroutine. It is especially important to note that the last instruction of an ICL\$ called service subroutine must be a JMP RCL\$.

THE MAIN COMPUTING LOOP AND SUBROUTINE RINT\$

The first item of business in the main computing loop is to check the computer mode by calling subroutine MODE. (After the first loop the mode is changed from I.C. to compute.) The second item is to store the last clock value in location NP with the sequence

```

 JMS CNP$
LCCO, Ø
 DAC NP

```

This is followed by the calling sequence for subroutine RINT\$. (Note that before evaluating derivatives RINT\$ is called to provide numerical definition of integrator initial conditions.) The derivatives are evaluated by applying amplitude scaling rules and interconnecting mathematical building blocks as shown on the flow diagram.

The integration routine RINT\$ can either operate synchronous or asynchronous with time. Since the CNP\$ routine is indirectly serviced by ICL\$, the integration in this example is asynchronous with time. Or in other words, fixed time steps are not used. As many time steps (or computing frames) are taken as time permits. By placing a counter in the main loop, 331 steps were evaluated during real-time and only 29 for x10 real-time operation. (These numbers compare favorably with those evaluated by the equations given in comment 3 of the ICL\$ description in Appendix B.)

The test to determine if $Y \geq Y1$ is done once and is followed by digital-to-analog conversion instructions (a strip chart recorder, oscilloscope, or X-Y plotter is used to display the results). The value of VDOT is divided by 20 before D/A conversion by the sequence

```

LAC VDOT
JMS X.1
LRSS 1
DA4

```

The two instructions preceding JMP LOOP set a software flag for transferring the computer mode to compute (see subroutine MODE).

TELETYPE PRINTING OF ANSWERS

The Teletype provides a temporary means of printing out numerical answers (until a line printer is available). However, even with a line printer available, numerical printout is not as desirable as graphical plots already available with the strip chart recorder, oscilloscope, or X-Y plotter.

The first instruction (DPI) of subroutine PRINT disables the priority interrupt. Then if any or all AC switches are set a numerical printout will

be obtained when either $x = -60.$ or $y = 30.$ The heading as explained in the Header Message Section is the first item printed. The numerical information stored starting in location TBL is retrieved by first re-initializing auto index register 10 to TBL-1 with the sequence

LAC (TBL-1
DAC 10

The output is then retrieved by means of an inner and outer nested computing loop. The outer loop initializes COUNT1 to determine when printing is done. The inner loop initializes a second counter for -5 before printing TIME, VDOT, V, THETA, X, and Y. Each time a line is printed, the Teletype is given a carriage return before determining if printing is done. If printing has been completed, the Teletype is given a form-feed (to output last page of paper), and control is transferred to DDT for parameter modification or new programming instructions. Note the last instruction of the program is the pseudo instruction PAUSE.

GENERAL REMARKS ABOUT THE PROGRAM

The program as written required 1840 memory locations (or 23.5% of the 8192 memory locations) and adequately simulated the problem in real time.* The main loop frame time was approximately 1200 μ sec (excluding printing). Approximately 200 μ sec could have been saved by performing the calculation $10^5 SC_{dp}/2M$ only once in the initialization section and by using an assembly language program for the functions performed by the ICL\$ program.

Memory requirements could have been reduced 7.6% by using all analog readout methods (such as, X-Y plotter, strip chart recorder, or oscilloscope).

A memory requirements comparison between the SIMPL-1 (all digital) and FORTRAN problem solving method is difficult because of our inability to discriminate between systems programs and FORTRAN. However, the FORTRAN assembled listing requires approximately 3.3 times that required by SIMPL-1 (all digital) and 6 times that required by SIMPL-1 (hybrid).

---

* The program processed the main loop 331 times during real time operation and 29 times during times ten operation. (Accuracy for times ten operation was not acceptable. The program could theoretically be speeded up by a factor of $\frac{331}{44}$ (or 7.5) and still preserve acceptable accuracy.)

FORTRAN AND ASSEMBLED LISTINGS FOR PILOT ELECTION STUDY

[illegible]

PROCESS CONTROL EXAMPLE ILLUSTRATING ASSEMBLY LANGUAGE PROGRAMMING
OF API CLOCK SERVICE ROUTINE

THE PROBLEM

The time required for the control system and valve to react to a change in level is usually insignificant. However, for the purpose of this example, suppose that there is a one minute time delay present in the control system. (A one minute time delay for a control system is somewhat unrealistic, but for this example it allows the opportunity of using a time delay.)

The block diagram illustrates a feedback control system for a stirred tank reactor. The system components and their parameters are as follows:

- Setpoint:** $-h_{set}$
- Summing Junction:** Combines the setpoint and the negative feedback signal $+h$.
- Controller:** $Z_0 = K_p(e^{+K_1 s} e^{-T_d s}) + 5$
- Time Delay:** $Z_0 = Z_1 (1 - 1)$
- Step Change:** $Q_0 = 1.0$, $Q_{o0} = 1.25$
- Valve:** $Z_0 = Z_1 \times \frac{1}{2}$, $Z_{o1} = 0.2 Z_0$
- Process:** $\frac{dh}{dt} = \frac{1}{A} [q_1 - q_0]$
- Output:** $+h$

$$= h - 5.0$$

K_T = reset rate, repeats per min.

(a) Amplitude scale factors

$$10 \text{ h} = 50$$

10 Q   ≈ 10 to 12.5

$$10 Z_0 = 50$$

(b) Time scale factors

(c) Overall simulation diagrams

(d) Digital time delay

The value of N is estimated as explained in Appendix II

$$N = (R_{MAX}) \left(\frac{T_{MAX}}{ERROR} \right)$$

$$\approx \frac{1}{A} (10Q_1 - 10Q_0) \left(\frac{1}{0.25} \right)$$

$$\approx 1 - (2.5) \left(\frac{1}{0.25} \right)$$

≈ 10

$$N_{-} = \left(\frac{R_{MAX}}{R_{MIN}} \right) \left(\frac{W_{MIN}}{W_{MAX}} \right) + 2$$

$$= (10) \left(\frac{80}{100} \right) + 2$$

When the 5000 cycle/sec clock is used

$$N_{\text{CLOCK}} = \frac{5000 \frac{\text{PULSES}}{\text{SEC}}}{\text{ITERATIONS}}$$

1
5000

$$= 500 \frac{\text{PULSES}}{\text{ITERATION}} \text{ (Real-Time)}$$

05

= 50 for ten times real-time

(e) Digital program & coding

PROCESS CONTROL EXAMPLE ILLUSTRATING ASSEMBLY LANGUAGE PROGRAMMING
OF API CLOCK SERVICE ROUTINES (contd)

```

EXAMPLE WITH A TIME DELAY
/PROGRAM CONSTANTS
WCLOCK, 500.
NI, 10.
/TIME DELAY STORAGE TABLE
TAGI, 1.0
 LAC(NI
 10'
 99.99
TAGI+10'+4/
/COMPUTER INITIALIZATION
BCN,
 MXCN
 CAF
 CAC
 MIST
 LAC WCLOCK
 CMA
 IAC
 DAC $CLI
 LAC (040200
 ASC
 EPI
/MAIN PROGRAM
LOOP,
 JMS AMODES
 MX2
 ADSE
 JMP .-1
 ARDS
 DAC ZI
 MXI
 ADSE
 JMP .-1
 ADRB
 DAC W
 JMP LOOP
SRVC,
41/ ISZ $CLI
52/ JMS SRVC
/CLOCK SERVICE ROUTINE
SRVC/
 0
 DAC ACSV# /SAVING AC CONTENT
 LACQ
 DAC MQSV#
 LACS
 CMA
 ADD (EAE 500
 DAC SCSV# /SAVE STEP COUNTER
 LAC WCLOCK
 CMA
 IAC
 DAC $CLI /THE CLOCK IS RESET
 LAM TAGI /START CALLING SEQ FOR TIME DELAY
 JMS TD16
 0
 0
 LAC W
 XX
 0
 0
 DAC .-2
 LAC ZI
 HLT
 DAS
 LAC SRVC /RESTORE LINK
 RAL
 LAC MQSV /RESTORE MQ
 LMR
 LAC (377777 /RESETTING STEP COUNTER
 XX
SCSV,
 LAC ACSV /RESTORE AC
 DBR /TELLING API WE'RE THROUGH WITH SVRC INTERRUPT
 JMP I SRVC
PAUSE

```

PROCESS CONTROL EXAMPLE ILLUSTRATING ASSEMBLY LANGUAGE PROGRAMMING
OF API CLOCK SERVICE ROUTINES (contd)

The program listing illustration

The program listing illustrates:

1. Program initialization to include:
  - a. The method of specifying a relocatable assembly and then referring to an absolute address between the main program and clock service routine
  - b. API channels
  - c. The method for setting API clock counter
2. The main program which includes:
  - a. Checking the analog mode
  - b. Assembly language programming of analog to digital conversions (instead of using ADC\$)
3. The API clock service routine which includes:
  - a. The methods for storing the contents of the LINK, AC, MQ, and step counter after an API interrupt
  - b. The time delay calling sequence
  - c. The methods for restoring the contents of the LINK, AC, MQ, and step counter
  - d. The method of returning to the main program after an interrupt

PROGRAM INITIALIZATION

The first program entry in the listing (other than the title or program comments) specifies a relocatable assembly if it is not an absolute address assignment such as 100/ 5192/ etc. For example,

```
866/
NCLOCK, 500
```

would have specified an absolute assembly starting in location 866 (i.e. NCLOCK = 866).

Absolute addresses for the API clock and clock overflow channels were used between the main program and subroutine SRVC. The instruction sequence

```
SRVC,
41/ ISZ $CL1
50/ VMS SRVS
SRVC/ 0
```

is used to allow subroutine SRVC to be assembled relocatable. If the tag [SRVC,] were eliminated previous to 41/ then the starting location of the subroutine SRVC would be location 51. This would create three problems. First, if subroutine SRVC required more space than available between location

51 and the programs first relocatable address (NCLOCK), the assembler would mask the overlapping portion of the program. The second problem would occur because the linking loader would not load the program unless a large enough relocation constant was specified. Finally, if the program were loaded, the locations between 40 and 57 are reserved as API channel locations. Spurious API signals could cause interrupts which in turn would cause instructions in those locations to be interrupted and their corresponding instructions executed. This in essence would clobber the program and necessitate reloading.

The method for initializing the clock counter is given by the sequence:

```
LAC NCLOCK
CMA
IAC
DAC $CL1
```

The IAC instruction is required since the incrementing instruction (ISZ \$CL1) stored in location 41 is a two's complement instruction. As mentioned in Example 1 of Appendix F, control is transferred to the clock overflow channel (loc 51) when the clock overflows from 777777_8 to $\emptyset$. Since the ISZ instruction stored in location 41 operates in two's complement arithmetic, the number stored in \$CL1 must therefore be the negative two's complement of the synchronizing counter NCLOCK. The IAC instruction following the CMA instructions provides conversion between one's and two's complement arithmetic. (It should be noted that the same clock initializing sequence is contained in the API clock service routine.)

The multiplexer and API are initialized by the sequence

```
MXRN
CAF
CAC
```

MAIN PROGRAM

Since the time delay subroutine needs the analog computer mode, mode checking is done in the main program with a JMS AMODE\$. The computing frame time for this problem is reduced by A/D converting with assembly language rather than with subroutine ADC\$. The remaining MAIN PROGRAM instructions through the instruction JMP LOOP demonstrate assembly language conversion and storage for the delayed quantity ZI and the variable delay quantity W. (Note that the multiplexer was initialized with an MXRN in the program initialization section.)

API CLOCK SERVICE ROUTINE

As previously mentioned, the program calls for a relocatable assembly. However, the fixed API channel locations 41 and 50 must be referenced. This is done immediately after the main program and before the clock service routine with the sequence

```

SRVC,
41/ ISZ $CL1
50/ JMS SRVC

```

The first order of business for the clock service routine is to save the contents of the LINK, AC, MQ, and the EAE step counter. These registers must be saved since the computer may be in the middle of a "main loop" computation when the clock overflow occurs. The API does not allow the "main loop" program to finish computations before a control is transferred to the service routine. All registers must be restored before control is returned to the main loop. The instruction in location 50 (JMS SRVC) provides the mechanism for saving the contents of the LINK in bit 0 and program counter in bits 5-17 of memory location SRVC/. The instructions for saving the contents of the AC and MQ are straight forward. However, the instruction sequence for saving and recalling the contents of the EAE step counter involves special microprogramming technique for generating a dummy MORM instruction which restores the SC register. The instruction LACS loads the accumulator with the contents of the step counter. To restore the step counter, a dummy normalization instruction must be created through microprogramming and then executed following the instruction LAC (377777. The following example will illustrate the technique:

If the step counter contained a shift count of 44 it would appear in negative two's compliment arithmetic as

```
011 100
```

The contents of the accumulator after the instructions

```

LACS
CMA

```

are

```
111 111 111 111 100 011
```


The contents of the AC after the instruction*

ADD (EAE 500

is the instruction NORM but with the step count modified to equal the original content of the SC. This modified NORM is stored in location SCSV. (The last two octal numbers in the NORM instruction are the step count.)

The sequence for resetting the \$CL1 and the time delay calling sequence follows the instructions for saving the important registers. Immediately following the time delay calling sequence are the instructions for digital to analog conversion and restoring the LINK, MQ, step counter, and AC.

The LINK is restored by merely rotating the contents of location SRVC one position to the right. The instructions for restoring the MQ is equally straight forward. To understand how the step counter is restored one must recall that the NORM (or a modified NORM) instruction shifts the contents of the AC and MQ until AC bit 0 is different than bit 1 or the step count is exceeded. The instruction

LAC (377777

is used to load AC bits 0 and 1 with different numbers so that when the modified normalization instruction is executed no shifting occurs. The step count from the NORM instruction is then incremented, complimented, and deposited in the step counter by computer hardware.

Control is returned to the main program by first disabling the automatic priority interrupt with the instruction DBR and then resetting the program counters address with the JMP I SRVC instruction.

---

* The 5 in the instruction EAE 500 is the micro code for a long right shift. The computer performs the operation ADD (EAE 500 as follows:

	111	111	111	111	100	011	(Contents of AC
+	110	100	000	101	000	000	(Binary code for EAE 500
①	110	100	000	100	100	011	
	end around carry →						1
	110	100	000	100	100	100	

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J. M. Batch	J. W. Helm
T. Bauman	R. J. Hennig
T. M. Beetle	G. M. Hesson
R. D. Benham (5)	P. L. Hofmann
C. A. Bennett	R. L. Hooper
R. A. Bennett	G. Jansen, Jr.
A. G. Blasewitz	R. T. Jaske
J. R. Boldt	B. M. Johnson
C. L. Boyd	H. G. Johnson
D. C. Boyd	E. M. Johnston
C. L. Brown	J. N. Judy
W. L. Bunch	J. H. Kinginger
R. A. Burnett	C. N. Knudson
K. M. Busness	J. R. Kosorok
C. P. Cabell	D. D. Lanning
A. C. Callen	H. D. Lenkersdorfer
C. M. Cantrell	W. F. Lenzke (5)
J. R. Carrell	R. C. Liikala
N. E. Carter	C. W. Lindenmeier
W. E. Cawley	H. E. Little
W. L. Chase	W. W. Little
E. J. Cheyney	J. D. Lodge
T. T. Claudson	R. E. Mahan
E. D. Clayton	W. B. McDonald
P. D. Cohn	W. R. Markillie
C. R. Cole	M. H. Meuser
D. L. Condotta	R. A. Moen
R. R. Cone	C. A. Munro
J. H. Cox	C. R. Nash
V. L. Crow	D. M. Nero
G. M. Dalen	W. L. Nicholson
J. M. Davidson	C. Oster
F. G. Dawson	H. M. Parker
M. H. Deardorff	R. S. Paul
D. R. de Halas	M. G. Patrick
J. L. Deichman	J. A. Perry
V. A. DeLiso	R. E. Peterson
D. E. Deonigi	A. M. Platt
P. J. Dionne	W. A. Reardon
G. E. Driver (2)	R. L. Reynolds
R. V. Dulin	R. L. Richardson
J. A. Eaglin	W. D. Richmond
J. F. Erben	W. E. Roake
M. D. Erickson	D. L. Rohde
E. A. Eschbach	R. B. Rothrock
L. M. Finch	J. T. Russell
C. D. Flowers	W. Sale

Battelle-Northwest (contd)

G. A. Sawyer
J. D. Schaffer
L. C. Schmidt
F. H. Shadel
D. W. Shannon
D. E. Simpson
M. O. Slater
C. R. F. Smith
N. B. Smith
W. G. Spear
R. J. Squires
D. D. Stepnewski
G. H. Strong
C. D. Swanson
G. R. Taylor
C. R. Tipton, Jr.
G. G. Thieme
J. C. Tobin
K. G. Toyoda
F. W. Van Wormer
B. B. Vinson
M. A. Vogel
G. L. Waldkoetter
R. A. Walker
P. C. Walkup
D. M. Walley
J. H. Westsik
L. A. Whinery
R. D. Widrig
T. W. Withers
N. G. Wittenbrock
M. R. Wood
F. W. Woodfield
D. C. Worlton
G. A. Worth
FFTF File (2)
Technical Information Files (5)
Technical Publications (2)
Extra (100)