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INTERACTIVE COMPUTER GRAPHICS APPLIED TO CONTINUOUS SYSTEMS SIMULATION

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ABSTRACT

Interactive computer graphics is beginning to achieve wide acceptance as a valuable tool in assisting the everyday engineer in his engineering activities. This paper describes one of the uses of interactive computer graphics in assisting the engineer - the modeling of continuous systems using CSMP. Continuous systems modeling using interactive computer graphics is being used extensively at The Boeing Company, Huntsville, Alabama. As a result of this utilization many additional requirements have been placed on CSMP. These requirements will be presented in this paper.

INTRODUCTION

Computer-aided-design, computer graphics, man-computer, cathode ray tubes, and interactive graphics are some of the "Computerese" which are beginning to find their way into the vocabulary of engineers and managers. These "Computerese" can be grouped to define the new technology of interactive computer graphics. This technology of interactive computer graphics denotes the give-and-take, or interactive, use of a computer by a user at an input-output graphic display console (i.e., a cathode ray tube).

Since its beginning in the late 1950's, interactive computer graphics is finding more and more acceptance in many technological areas. For example, interactive graphics is being used to analyze airplane structures, design automobiles, monitor hospital patients, condition space flight data, layout circuit boards, perform statistical analyses, and simulate rocket trajectories. Some of these applications are described in the references. This paper is concerned with only one of these applications - the area of continuous systems modeling. One of the continuous systems modeling languages which has been programmed to operate in an interactive environment is Continuous Systems Modeling

Program (CSMP) on the IBM 1130 digital computer (References 1 and 2).

Since the introduction of 1130 CSMP/Graphics at The Boeing Company in Huntsville in March, 1969 the utilization of CSMP has increased to 100 hours per month. As a result of this use by various engineering organizations many new requirements have been placed on CSMP. This paper will discuss the more significant expansions of CSMP, a description of CSMP and the procedures which have been established for using CSMP are presented. A sample problem utilizing CSMP is also presented.

DESCRIPTION OF CSMP

1130 CSMP/Graphics is an IBM Type III Software program and is commonly referred to as a digital analog simulator. It is a block oriented language where the CSMP blocks are analogous to the elements of an analog computer. The menu of blocks include a standard set of twenty-five blocks and five special blocks. Table 1 outlines some of the blocks and the mathematical operations performed by the blocks. For example, to integrate a constant the following blocks are used,



The output would be a ramp with slope "a".

The mathematical operations of the five special blocks are not defined by CSMP. Instead, these blocks are available to define specific simulation requirements. These simulation requirements are defined in the form of a FORTRAN subroutine. The subroutine is stored on the CSMP system disk. The linkage of the subroutine with CSMP is provided by CSMP system software.



















BLOCK	SYMBOL	BLOCK	SYMBOL	BLOCK	SYMBOL
DEAD SPACE		CONSTANT		MULTIPLIER	
FUNCTION GENERATOR		LIMITER		ZERO ORDER HOLD	
GAIN		MAGNITUDE		SUMMER	
HALF POWER		RELAY		DIVIDER	
INTEGRATOR		UNIT DELAY		SIGN INVERTER	
JITTER		WEIGHTED SUMMER		SPECIAL	

TABLE 1
MENU OF BLOCK TYPES

The hardware at The Boeing Company which is being used to run the CSMP/Graphics is an IBM 1130 digital computing system consisting of an 1131 central processing unit, 2501 card reader, 1442 card punch, 1403 printer, and 2250-4 display console equipped with keyboard, function keys, and light pen.

INTERACTIVE USE OF CSMP

The steps which have been defined for using CSMP in an interactive environment are:

1. Write the equations representing the physical system.
2. Construct a CSMP block diagram of the system.
3. Input the block diagram via the 2250-4 display console.
4. Execute the model and revise if necessary.
5. Output the model and/or model results.

Step 1 is an initial step in solving most engineering problems. In step 2 the menu of CSMP blocks described in Table 1 is used to construct a CSMP block diagram of the physical system. Special layout forms have

been designed to facilitate model layout. One of the forms is similar to the image which appears on the display console and is used for laying out the block diagram. The other form is for defining parameter settings and output curves. At the completion of step 2 the model is ready for input via the display console. The general procedure for inputting the model is outlined in Figure 1. A set of start cards are required to initialize the computer and to display the first image on the display. The user light pens STAND ALONE signifying that the computer is to be used in a stand alone environment.

After the next image appears, the user enters via the display keyboard the name of the CSMP program which in this instance is GCSM1. The CSMP program is now transferred from auxiliary storage to core storage. At the completion of the transfer, the user light pens the desired option. If his model is on cards from a previous session he light pens READ CARDS. If this is his first session he light pens PROCEED.

The next image allows the user to construct his model on the screen. After the model has been constructed, the user light pens RUN PROBLEM. The next image allows the user to define his plotting parameters.

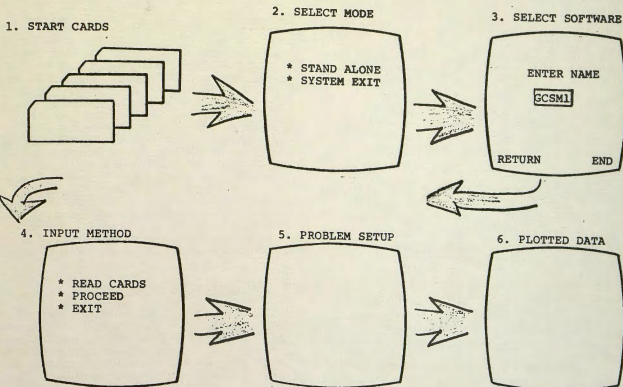


FIGURE 1
CSMP PROBLEM SETUP

The user is now ready to execute his model and review the results on the display console. If the results are not what are expected, the user can interrupt the execution and make the necessary revisions and re-execute. Standard outputs of CSMP are a visual presentation of the results on the display console and a punched deck of the problem.

EXPANSION OF BASIC CSMP

Since the initiation of CSMP at Boeing in March 1969 a number of additional requirements have been placed on CSMP. Some of the major categories of new requirements are:

1. Additional block types
2. Increased problem input parameters
3. Additional output options.

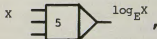
The modifications which have been made to satisfy the above requirements are discussed in the following paragraphs.

ADDITIONAL BLOCK TYPES

The additional block types was a very simple problem once an understanding was

had of the use of the five special blocks (Reference Table 1). Without changing any of the CSMP system software, a very simple technique was devised to expand the number of special blocks to an unlimited number. It was found that by placing a code number in one of the parameters of a special block, many subroutines could be contained within one special block. Then, whenever the subroutine is desired, the proper code number is assigned to one of the parameters (in our instance parameter 2) to signify the desired FORTRAN branching in the subroutine. Some of the present utilization of these special blocks are presented in the following paragraphs.

Special block 5 has been reserved for user created general purpose block types. The mathematical operations stored in block 5 are presented in Table 2. For example, to find the natural log of X, special block 5 is connected as



where parameter 2 of block 5 is set to 5.



PAR 2	OPERATION	PAR 2	OPERATION
1	E^X	20	$X \cdot \sin(X) \cdot \cos(Y)$
2	$\sin(X)$	21	$X \cdot \sin(X) \cdot \sin(Y)$
3	$\cos(X)$	22	$(X+Y)-Z$
4	$\tan(X)$	23	$(X+Y)+Z$
5	$\log_e X$	24	$X \cdot (Y-Z)$
6	$\log_{10} X$	25	$X \cdot (Y+Z)$
7	$X \cdot Y + Z$	26	$X / (Y+Z)$
8	$X \cdot Y / Z$	27	$(X+Y) / Z$
9	$X^Y (Y+Z)$	28	$(X-Y) / Z$
10	X^Y	35	$\sinh(X)$
11	$\sin^{-1}(X)$	36	$\tan^{-1}(X/Y)$
12	$\cos^{-1}(X)$	37	$\cosh(X)$
13	$\tan^{-1}(X)$	38	$\tanh(X)$
14	$\sqrt{X^2 + Y^2 + Z^2}$		
15	$X^2 + Y^2 + Z^2$		
16	DEGRESS \rightarrow RADIANS		
17	RADIANS \rightarrow DEGRESS		
18	$X \cdot \cos(Y)$		
19	$X \cdot \sin(Y)$		

TABLE 2

SPECIAL BLOCK 5 MATHEMATICAL OPERATIONS

The constraints of CSMP permit only three functions to be used in a model with each function described by only eleven evenly spaced points. To have more than three functions per model and also more than eleven points per function, a special FORTRAN subroutine was written and stored in special block 3 which allowed the input of an additional twenty functions. Each function could be defined by more than eleven unevenly spaced points. A very similar procedure as used in special block 5 was established for selecting the desired function from the subroutine. The desired function can be retrieved by setting a code number in parameter two of the special block. Special code numbers were assigned to each user of the special function. Therefore, all users could store their functions within one special block.

The remaining three special blocks have been used for storing mathematical operations peculiar to a specific application. Special block 1 has been used to store the static and time dependent equations for computing a set of orbital elements. Special block 2 has been used to store approximately fifty operations and logical conditions which were used in the simulation of the deployment of a lunar vehicle from a lunar module. Special block 4 has been used to store a simple frequency response program. The block can solve up to fifteen second order uncoupled linear differential equations.

MODEL INPUTS

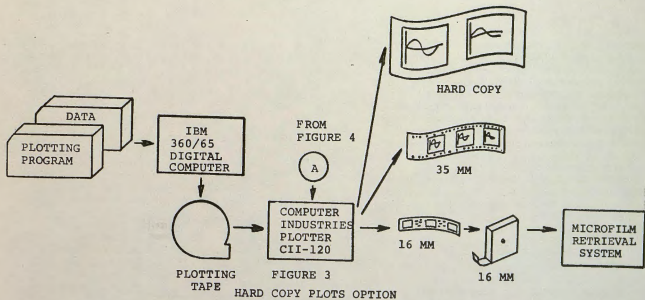
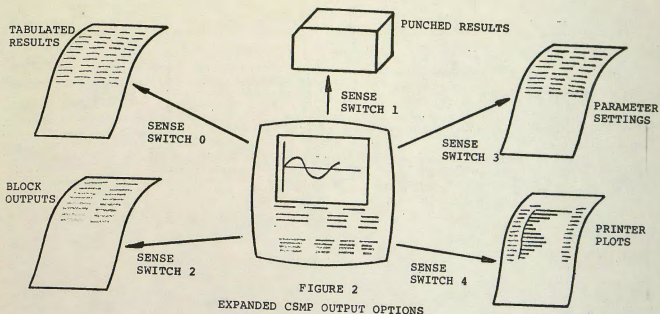
A constraint is imposed on the user in inputting data into CSMP. For setting initial conditions and parameters on CSMP blocks, the maximum number which can be inputted is 9999.9999 for positive numbers and -999.9999 for negative numbers. Many users required the inputting of larger and smaller numbers. Of course, users with smaller models could use the CSMP block type CONSTANT. However, many of the users had models which required the use of all seventy-five blocks. Therefore, to accommodate these users, modifications were made to CSMP system software. These minor modifications required changing the FORTRAN formats. Similarly the integration step size was modified to allow a minimum integration interval of 0.00001.

ADDITIONAL OUTPUT OPTIONS

The standard output provided by CSMP is the visual display on the 2250 of three dependent variables as a function of one independent variable. From requirements established by users the additional output options in Figure 2 have been added to CSMP. These options are controlled by the sense switches on the 1131 CPU. The use of these output options will be discussed in an example in the following section.

Console sense switch 1 is set for obtaining a punched deck of the coordinates of each curve. Since a maximum of three curves can be displayed on the 2250, a maximum of three coordinates are punched as a function of the independent variable for each time interval. The punched deck fulfills two requirements. The first is for obtaining document quality plots of the curves. Figure 3 outlines the flow for obtaining hard copy plots. The punched deck is combined with a FORTRAN plotting program and executed on an IBM 360/65. The output of the program is a plotting tape which is inputted to a Computer Industries 120 plotter. In addition to the hard copy plots which measure 7" x 7", 35 mm and 16 mm film can also be generated. Retrieval codes can be assigned to the 16 mm film images for retrieval through a microfilm retrieval system.

The punched deck of the CSMP results can also be used as input to the Boeing Unified Flight Analysis System (UFAS). UFAS is a set of computer programs developed to ensure efficient and rapid processing of Saturn flight test data. UFAS consists of tape inspection, data conditioning, and data analysis programs which are used for removing errors from data prior to engineering analysis. The data conditioning and



data analysis options have been used on CSMP output to filter unwanted frequencies and to conduct spectral analysis.

Figure 4 outlines the flow for interfacing with the UFAS system. The punched deck is combined with a FORTRAN program which creates a data tape in UFAS format. An IBM 2250-3 display console is used to interact with the UFAS system.

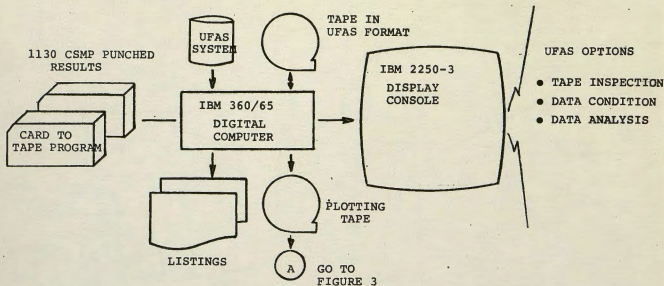


FIGURE 4
UFAS SYSTEM INTERFACE

SAMPLE PROBLEM

A sample problem will be solved to more fully explain the use of CSMP. The example is the mechanical system in Figure 5, consisting of a mass, a spring, and a damper, which are suspended from a fixed position. The problem is to study the time responses for various damping coefficients. Following the steps outlined in a previous section, the equation of motion can be written as

$$M\ddot{x}(t) + B\dot{x}(t) + Kx(t) = f(t).$$

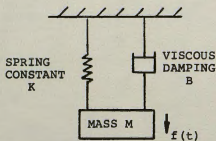


FIGURE 5
MECHANICAL SYSTEM

Note that this equation is a second order linear differential equation which can be used to describe many real world systems. An analogous electrical system is illustrated in Figure 6.

The equation describing this system is

$$L\ddot{q}(t) + R\dot{q}(t) + \frac{q(t)}{c} = f(t).$$

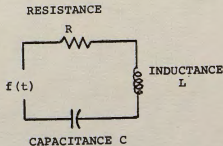


FIGURE 6
ELECTRICAL ANALOGY

From the menu in Table 1 a CSMP block diagram consisting of a summer, two integrators and a constant which represents a unit step function as the excitation force can be constructed of the system.

The two CSMP displays are presented in Figures 7 and 8. Typical outputs of the model for various damping coefficients are presented in Figure 9.

Figure 9 was created by using the hard copy plotting procedures outlined in Figure 3. By using the remaining output options the outputs in Figures 10 and 11 were generated. A point of interest is that the time at the display console to set up and execute the model was less than ten minutes.

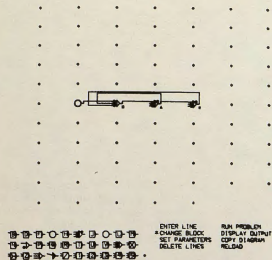


FIGURE 7 CSMP PANEL 1

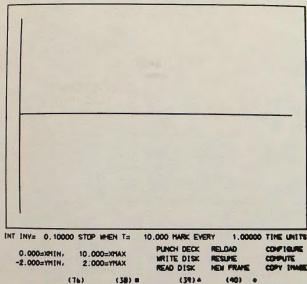
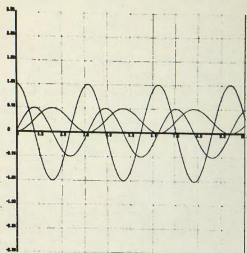
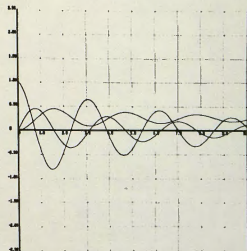


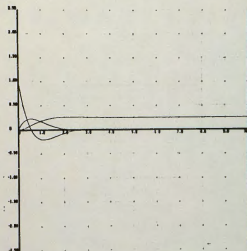
FIGURE 8 CSMP PANEL 2



NO DAMPING



SMALL DAMPING



CRITICALLY DAMPED

FIGURE 9


```

      BLCK=76          BLCK=38          BLCK=39          BLCK=40
0.000000 C0 0.100000E 01 0.000000E 00 0.000000E 00
0.100000E C0 -0.428942E 00 0.452773E 00 0.357235E 00
0.200000E C1 -0.636021E 00 -0.388427E 00 0.407005E 00
0.300000E C1 0.976294E 00 -0.121360E 00 0.592627E-02
0.400000E C1 -0.198900E 00 0.494900E 00 0.290745E 00
0.500000E C1 -0.809503E 00 -0.302032E 00 0.452375E 00
0.600000E C1 0.894238E 00 -0.236966E 00 0.264402E-01
0.700000E C1 0.455908E-01 0.506532E 00 0.233602E 00
0.800000E C1 -0.936932E 00 -0.196630E 00 0.484233E 00
0.900000E C1 0.758007E 00 -0.339174E 00 0.654980E-01
1.000000E C2 0.290401E 00 0.488992E 00 0.177399E 00

```

```

THE OUTPUT OF BLCK 31 = 0.000000E 00
THE OUTPUT OF BLCK 33 = 0.000000E 00
THE OUTPUT OF BLCK 35 = 0.000000E 00
THE OUTPUT OF BLCK 37 = 0.100000E 01
THE OUTPUT OF BLCK 41 = 0.000000E 00
THE OUTPUT OF BLOCK 32 = 0.000000E 00
THE OUTPUT OF BLOCK 34 = 0.000000E 00
THE OUTPUT OF BLOCK 36 = 0.000000E 00
THE OUTPUT OF BLOCK 38 = 0.290401E 00
THE OUTPUT OF BLOCK 40 = 0.177399E 00
THE OUTPUT OF BLOCK 42 = 0.000000E 00

```

```

BLCK=37  PAR1= 1.000000  PAR2= 0.000000  PAR3= 0.000000
BLCK=38  PAR1= 1.000000  PAR2= 0.000000  PAR3= -4.000000
INITIAL CONDITIONS FOR PRECEDING RUN

```

FIGURE 10
SAMPLE PROBLEM OUTPUT OPTIONS

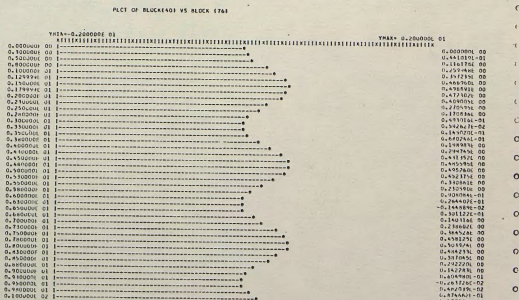


FIGURE 11
SAMPLE PROBLEM PLOTTING OPTION

CONCLUSIONS

In conclusion, some of the features of interactive computer graphics which are inherent in CSMP/Graphics are:

1. The individual with the problem is placed in the loop with the computer.
2. Ease of problem input via a cathode ray tube.
3. Continuous visual review during problem setup and execution.
4. Graphic presentation of pertinent problem parameters.
5. Problem interrupt during execution and re-initialization of input parameters.
6. Parametric analysis ("what if" situations) during one graphic session.

Some major problem areas which must still be overcome are:

1. The relative high cost of interactive graphics hardware.
2. The non-existence of a standard graphics programming language (such as FORTRAN for scientific work).
3. The long lead time before a graphic program is operational.

It is hopeful that this paper has stimulated the reader's thought process as to the vast potential future of interactive computer graphics. We are at the threshold of placing the computer in correct perspective - that of interacting directly with the individual whether he be an engineer or second grade student. In the near future interactive graphics should find its way into many different areas of utilization. As interactive computer graphics is used in more different technological areas, its acceptance will become more wide spread.

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