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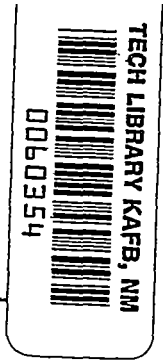
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DATA DISPLAY PROGRAMMING

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DATA DISPLAY PROGRAMMING

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ABSTRACT

The research studies and experimental investigations reported are addressed to the problem of developing more efficient means by which the physical scientist might intimately control the complex data processing operations involved in the analysis and meaningful interpretation of large volumes of sensor data from scientific satellites. Areas of computer graphics technology in which pioneering efforts might prove fruitful are defined and approaches conceived. The results of pilot tests to evaluate proposed techniques from a human factors viewpoint are given. Specific techniques include information transfer via uncommon display media (full color; flicker; animation) and approaches to facilitate the use of a single input device as the means of processing control.

Specifications are developed for an advanced hardware-software system for manipulating and displaying large volumes of data. A man-computer communication station design is recommended which permits finger pointing as a means of input and peripheral equipment to service the display and input devices. Computer software to support man-computer communication is specified using a hierarchical approach. Trade-off guidelines for computer equipment are developed, based on cost and other factors. These guidelines result in a case for the use of individual satellite processors for servicing man-computer communication stations.

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1. INTRODUCTION

Man-computer symbiosis, as defined and prophesied in 1960 by J. C. R. Licklider[1], is a close coupled partnership of man and computer in which the respective abilities of each are used for solving problems that cannot be thought through completely in advance. Since 1960, progress in computer time sharing and information retrieval techniques along with lowered equipment costs have made this man-computer symbiosis economically feasible. Developments in display and control techniques have made possible the close coupled interaction between the partners which is essential for successful symbiosis. Noteworthy accomplishments in this field include the computer-aided design work of Ivan Sutherland[2] and General Motors[3]; the work of Culler and Fried[4] in computer-aided analysis; and work at Project MAC[5] in a variety of applications.

At Goddard Space Flight Center, large volumes of space data are gathered so that experimenters might reach meaningful conclusions about the phenomena being measured by their instrument sensors. The capability for gathering those data is increasing at more than a steady rate. If the experimenters are to keep abreast of the volume of available data, advances must be made in the ability to rapidly process and interpret those data.[6]

The investigative effort reported here is aimed at advancement of the ability to rapidly process and interpret space data through the application of symbiotic display and control techniques. In the course of this work a literature search and several site visits were conducted in order to determine the state of the man-computer art. In several unexplored areas, hypotheses were developed and where practical to do so, were tested: this phase of the work is reported in the appendices. The results of the investigation as presented in the main body of the report are intended to serve as specification criteria and guidelines for an advanced software-hardware system capable of manipulating and displaying large volumes of space data in a form conceptually meaningful to experimenters.

2. PROBLEM MODEL AND APPROACH

In this section the application is defined and the assumptions and constraints which serve to guide the work are specified.

2.1 TELEMETRY DATA PROCESSING

Telemetry may be defined as the science or process by which a measurement made in an inaccessible, inconvenient, or remote location is transferred to another location for use. The primary function of a scientific spacecraft telemetry system is to provide one or more scientists on Earth with measurements of phenomena observed in or from space. These measurements are normally transmitted via radio link, a process with which several problems are typically associated:

a) the weight and cost of telemetry equipment,

b) the necessity of transmitting a large amount of information at a high rate with high reliability,

c) the necessity for establishing standards to allow the use of off-the-shelf equipment and to prevent interference between telemetry systems and between subsystems of a single telemetry system.

Signal conditioning, multiplexing, encoding, and the use of standard fixed-capacity information channels are usually involved in the solution of these problems. As a general consequence of these operations, data is received on the ground in a form which is neither immediately recognizable nor useful to most scientific experimenters.

In order to reduce the complexity, weight, and cost of telemetry equipment on board a spacecraft, the measurement information from a sensor is usually "conditioned" as the first (or second) step in the telemetry process. Most measurements are converted to voltages with fixed lower and upper limits, frequently 0 to 5 volts DC.

When measurements from several sensors are to be transmitted over a single radio link, these measurements must be

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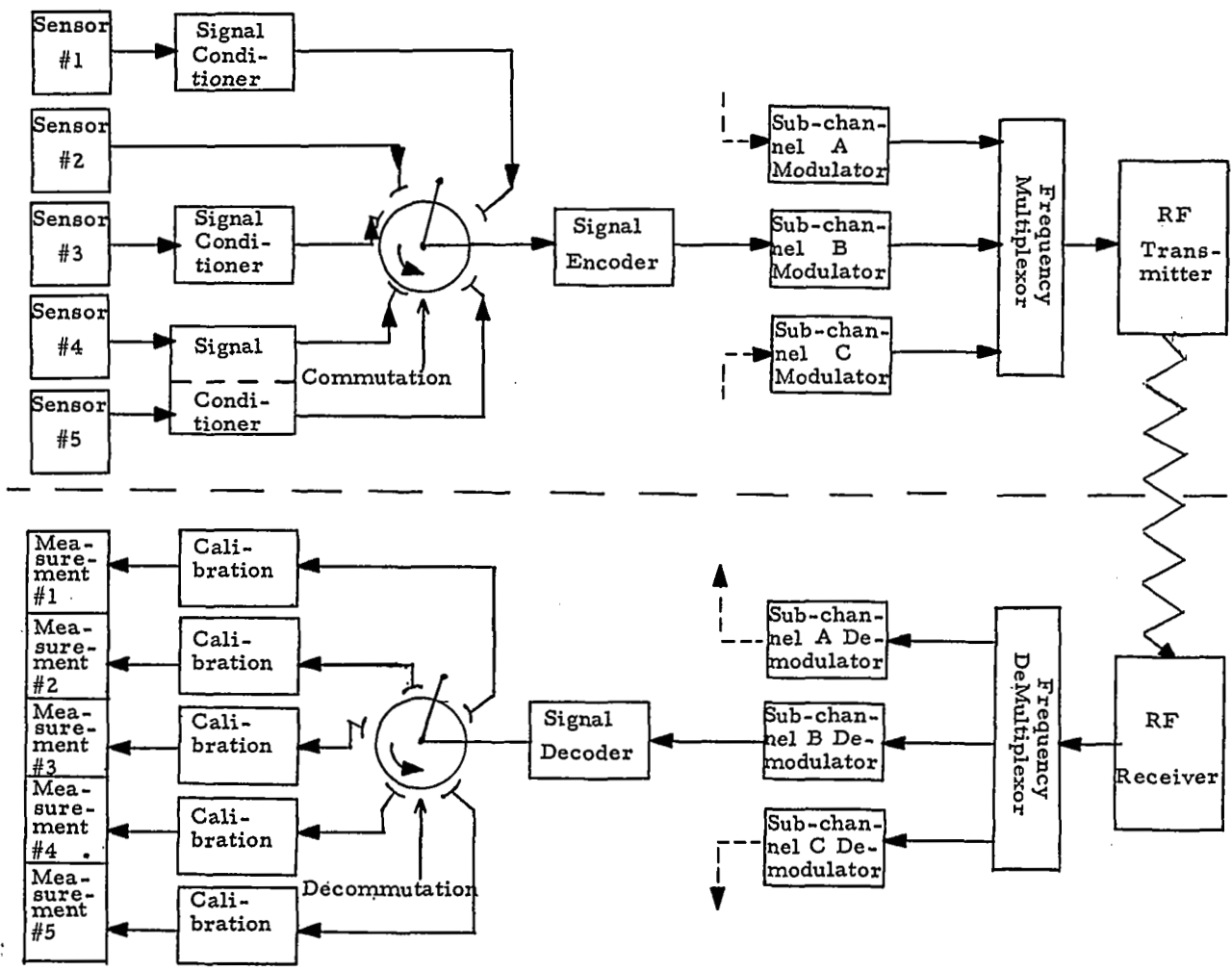
FIGURE 1   BLOCK DIAGRAM OF A TELEMETRY SYSTEM

multiplexed. Either the available radio-frequency bandwidth or the available transmission time (or both) must be divided among the measurements. Frequency multiplexing, and later de-multiplexing during or after reception, is a relatively straightforward engineering problem. In time-division multiplexing, measurements are sampled in cyclic sequence -- "commutated" -- and transmitted in that sequence.

In order to be transmitted, the conditioned, sampled measurement must modulate the radio carrier (or subcarried if frequency multiplexing is also used). The simplest method is direct modulation by the sampled voltage; usually frequency or phase modulation. However, other methods offer advantages in accuracy, reliability, and ease of later decommutation (separation of individual measurements). The two methods which seem to offer the greatest advantages are pulse-code modulation (PCM) and pulse-frequency modulation (PFM). Both require the measurement to be encoded, to a binary code in PCM, to a variable frequency in PFM.

Telemetry data processing involves the reverse of these procedures. Information received on the ground must be decoded, decommutated, and calibrated in order to reconstruct measurement information in a digital representation of its original form. Figure 1 gives an example of a telemetry system which performs the operations described up to this point. At this stage the data is suitable for analysis. Several prescribed steps of data analysis may be included in the processing of telemetry data before the results are presented to the experimenter for his review and interpretation.

Telemetry data processing and analysis operations may be categorized as shown in Figure 2. Validation and reduction are activities typically supervised by a Data Processing Analyst. Their end product is data in a form meaningful to the experimenter. Interpretation of this data by the experimenter generally involves steps which cannot be completely specified in advance.

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VALIDATION	Data Editing Quality Checking Time Correction
REDUCTION	Conversion to Physical Units Basic Transformations Mapping of Data Accumulation of Data
INTERPRETATION	Examination of Data Scanning Data for Interesting Portions Analysis of Interesting Portions Trial of New Procedures Modification of Axes, Parameters, etc.

FIGURE 2   DATA PROCESSING & ANALYSIS ACTIVITIES

Telemetry data processing systems in current use generally employ a batch processing computer installation and depend upon a number of human operations.[7] For example, magnetic tape is carried from analog-to-digital conversion equipment and manually mounted on a computer tape transport. Processed data tapes are carried to a graphic plotting device. Plots are delivered to the experimenter. His requests for further processing are interpreted by a Data Processing Analyst and relayed to a Computer Programmer. The program goes to the Keypunch Operator then to the Computer Operator. The results are returned to the experimenter, who, after seeing the results, may issue instructions for another try.

In this batch mode of telemetry data processing, the ability to process and interpret space data is limited in two ways. First there are procedural time delays: for instance, the delay between the occurrence of an event and the presentation of the measurement of that event to the user. These delays are primarily caused by the division of the system into subsystems which require human

intervention to link them into an operating whole. Lags may be reduced by special action and careful planning for specific events. However, the system cannot respond to requests for immediate results over an extended period of time, or for immediate results for many users simultaneously. Secondly, the user's specifications for processing are subject to errors of interpretation, programming, keypunching and machine room operations. Errors propagate a waste of time in operations downstream from their source, and necessitate second efforts. In the worst case the experimenter does not detect the error immediately.

Processing delays may be overcome by dedicating a computer system to real-time telemetry data processing; a system in which the operations are integrated and in which each user has immediate access to information in any state of processing.

The error problem may be reduced by giving the experimenter direct control of processing, thus eliminating intermediary agents and reducing the time delay penalties for any errors which do occur. The desirability of having no more than one human interact with a controlled experiment has been attested to in similar applications.[8]

The concept of on-line real-time telemetry data processing seems promising for advancement of the ability to rapidly process and interpret space data.

2.2   A MAN-COMPUTER APPROACH

An on-line real-time computer system dedicated to telemetry data processing must be capable of performing its task with efficiency, power, and flexibility. Moreover, in a man-computer system several other attributes are essential if the system is to prove acceptable to the man. These attributes are forgiveness, fail-softness, convenience, simplicity, and transparency.

Forgiveness is the ability to recover from inherent user errors and system errors. A rule of thumb is to have a system capable of restoring conditions to the state which existed prior to the last computer action, and facility for the user to request restoration. Forgiveness not only implies that a means for recovery be provided but also that the user be informed of the recovery procedure. Fail-softness is the ability to discover a procedural error in the use of a system, recover as far as possible, and gently and politely inform the user of his error.[9] Forgiveness and fail-softness are attributes which must be considered in the design of the software.

In the design of the console and that portion of the software which services it, consideration must be given to simplicity, convenience and transparency. A current trend in the design of man-computer console equipment is toward complexity with a multiplicity of cathode-ray tubes and input devices in a single console. Complexity of design may be desirable in situations where the user is a trained operator with a well-defined job, but simplicity is indicated for the user to whom a computer represents an aid to creative thought. For this class of user the interface should be no more intrusive upon thought processes than a pen and paper. Closely related to simplicity is transparency: the user should be able to "look through" the system at the operations he is performing and not be overly distracted by awkward control requirements or artificialities in the display. Finally, the console should be convenient, preferably located in the experimenter's office where his reference materials and staff are close at hand. As a step toward assuring the incorporation of these attributes, the following constraints will be observed.

- •For the convenience of the users, the system will be controlled by remote consoles.

- •For simplicity each console will be limited to a single display device and a single input device.

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•For simplicity and transparency the input device
will permit the user to share a common working
surface with the computer, i. e. , the display
surface. This constraint rules out the choice
of a keyboard as the single input device, since
a keyboard represents a second working surace.

•For transparency the design of display-driving
hardware, software, and display data structures
will allow for natural appearing animation in the
display of data, as well as allowing for static
displays.

Control of the system is to be effected by means of these
remote consoles. As an indication of the control functions which must
be provided, Figure 3 presents an analysis of the anticipated dialogue
between the experimenter and the computer. This list is not neces-
sarily complete but should serve as a framework.

2.3   SCOPE OF WORK

It is required that the data processing system facilitate the
analysis of large volumes of data, received as a fluctuating flow of
digitized signals from telemetry equipment, or received in play-back
mode from a data archive. If the volume of data stored within the
system approaches the capacity limit, perhaps as a result of delays
involved in the analysis computations and displays being provided, then
well chosen actions must be taken to avoid the loss of data. Therefore
one primary function of the system will be data-flow management.

Another primary function of the system will be file manage-
ment. Since several users will be provided simultaneous access to the
system, it is reasonable to expect that their action programs (valida-
tors, operators, interpretation and analysis strategies) and image con-
struction elements might best be organized in user files. Other files
to be managed might include data archive files.

SIGN-ON	The user obtains access to the system and identifies himself.
BULLETINS	Announcements of general interest broadcast from computer central since last sign-on are displayed. These may be related to system status, satellite launch progress, solar activity, or other events affecting an experiment.
STATUS CHECK	Details may be requested by the user concerning status of a spacecraft or an experiment, current system loading, or a statement of his computer time account.
NEW STRATEGY	The user defines a new procedure for the analysis or display of his data and assigns an identifier to the procedure. This "strategy" is then stored in his program file.
DATA CALL	User requests data by specific identification or by correlative parameters. The data may be current or archived, and in any state of processing. Single or multiple sets may be called for discrete or superimposed display.
INTERROGATE	The user may request a list of the procedures which have been applied to the data he is viewing.
MANIPULATE	A strategy is designated by the user. The system applies this strategy for the processing and display of data.
STRATEGY LIST	The user requests a list of strategies in his program file. He may request further details about one or more of these.
WRITE-UP	The console is used for preparing a report. Text is constructed and edited, and display plots are inserted. Computer central produces hard copy and delivers it to the user.
SIGN-OFF	The console is released.

FIGURE 3   SEQUENCE OF MAN-COMPUTER DIALOGUE
FOR TELEMETRY DATA INTERPRETATION

These considerations have been applied in designing a tentative outline of system organization based on process flow (Figure 4). This design is tentative in the sense that it contains certain assumptions regarding the configuration of equipment. However, this design serves as a reference for defining the scope of work to be undertaken.

The scope of work includes only that portion of the DMS in Figure 4 which starts with the box labeled "reduced data" and ends with the box labeled "final data". The modular nature of the entire DMS, as shown, should readily permit later expansion of system concepts to facilitate validation and reduction operations. The extent of these operations may be affected in the future as advances are made by NASA in the development of on-board-the-spacecraft computers. The present effort concentrates upon the data analysis and interpretation activities which represent the goal of all other data handling activities.

The scope of work also includes the first two activities of the FMS shown in Figure 4, i.e., action (program) file and display file management. Archive management, which implies archive file design, is not undertaken here.

Of necessity, highly specialized research areas such as computer adaption, heuristics, and pattern recognition, will be avoided in order to allow proper concentration on studies of data display and manipulation techniques.

DATA-FLOW MANAGEMENT SUBSYSTEM (DMS):

1 Validation

2 Reduction

3 Interpretation
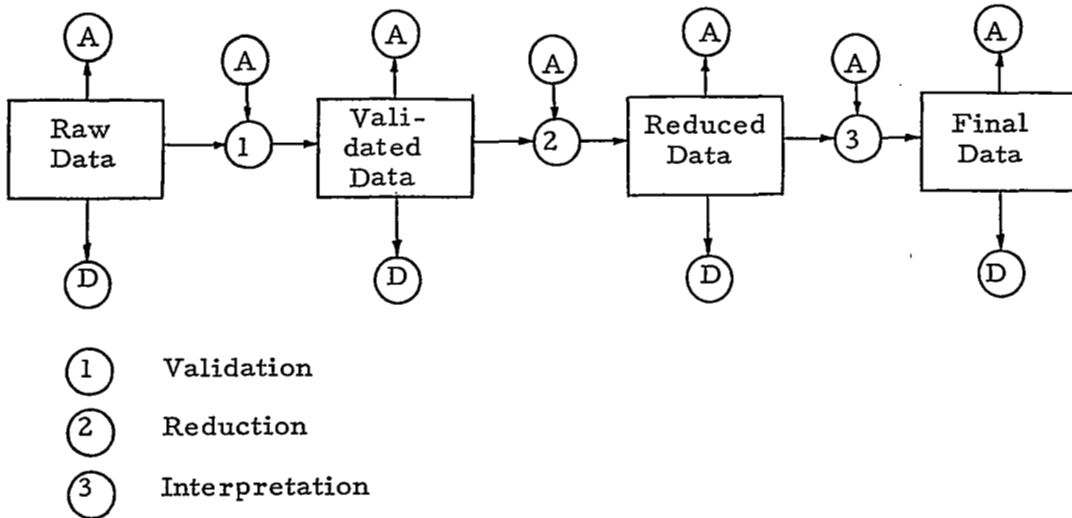
FILE MANAGEMENT SUBSYSTEM (FMS):
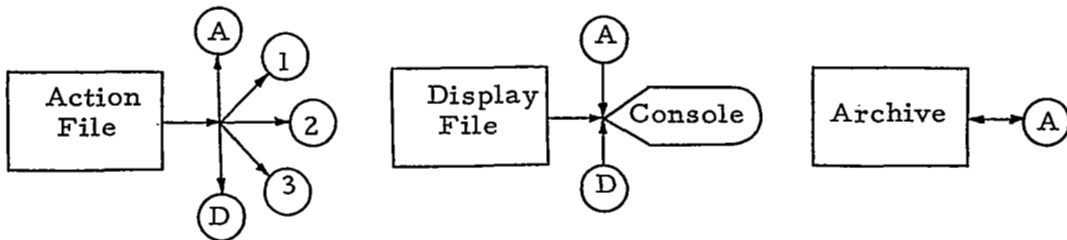
FIGURE 4   PROCESS FLOW AND SYSTEM ORGANIZATION

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3. THE CONSOLE

In this section design criteria are developed for the man-computer communications console in a telemetry data processing system. Consideration is given to the display and input functions which establish the man-computer loop. Consideration is also given to means for relieving the computer of some of its burden in servicing this loop. Recommendations are made for the specification of equipment.

3.1 DISPLAY

The purpose of computer display is the transfer of information in visual form to the user. In the present instance the computer output information is expected to include alphanumerics for program code, program identifiers, assorted labels, various statistics and other numeric values. The primary information output, however, is expected to consist of plots and other graphical representations of large volumes of processed experiment data.

The information transfer capability of a display device may be measured in terms of image capacity, image quality, the speed with which an image may be changed, and information coding power. All but the last of these measures will be taken up later under equipment specifications. The information coding power of a display device, as determined by its available subset of coding modalities, appears to be a key attribute upon which the others are to some degree dependent, and which may be specified most directly in light of the given application. The coding modalities which are appropriate for the visual transfer of information are listed in Figure 5.

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BASIC CODING MODALITIES. These are used in the basic synthesis of an image and are usually programmable with available equipment.

POSITION	LINE LENGTH
SHAPE	LINE STRUCTURE
SIZE	NUMBER
MOTION	ORIENTATION
SHADING	

SUPERCODING MODALITIES. By superimposing these in the display of an image, additional information transfer is possible. Special-order equipment is generally required.

LINE WIDTH	FOCUS
INTENSITY	DEPTH
FLICKER	COLOR

FIGURE 5   VISUAL INFORMATION CODING MODALITIES

In the interpretation of experiment data many instances arise where maximum display power is desirable. For example, consider the problems of three-dimensional data surface representation; the problem of distinguishing members of superimposed data sets; or problems such as how to convey the quality or confidence information associated with plotted data points without cluttering the display with numeric labels. It may be concluded that the display device for this application should incorporate supercoding modalities, as referred to in Figure 5.

Of the supercoding modalities listed, line width would seem the least useful, color the most useful. Line width modulation is most appropriate in computer-aided design applications where the display is typically used to represent line-drawings, but will not be considered further for the present application.

3.1.1 Color

Color modulation involves three variables: hue (wavelength), saturation (pureness), and brilliance (intensity). The relationship of these variables is illustrated in Figure 6 (taken from Webster).

White

Tints

Blue ——— Red

Brilliance

Saturation

Green ——— Yellow

← Hue →

Shades

Black
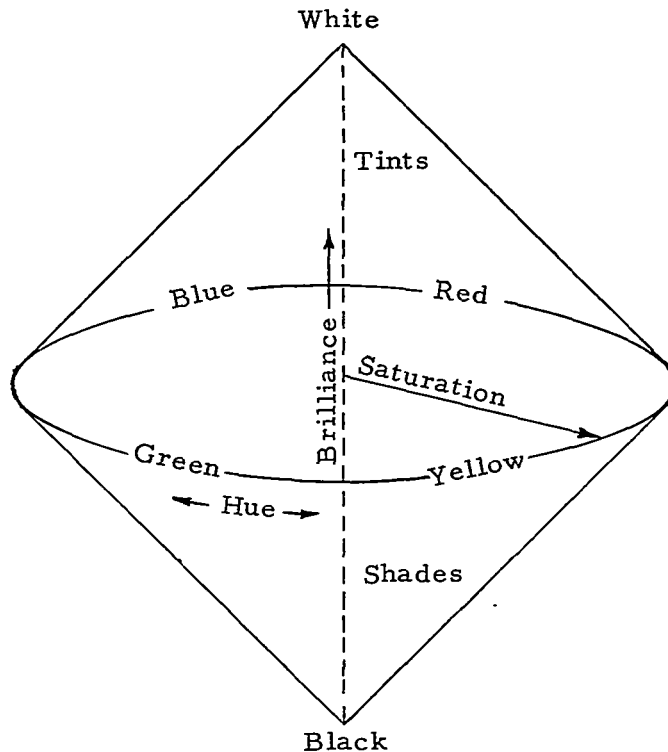
FIGURE 6 CLASSICAL COLOR SOLID

If a color T.V. cathode-ray tube is used to produce the display, then color is obtained by mixing the three additive primaries, red, green, and blue, the intensity of each being variable.[*] For programming purposes then, it is more convenient to think of the color

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[*] This is the technique used in the DX-1 color equipment at AFCRL. The only other known instance of a digital computer color display is the experimental equipment at IBM which was used in preparing the cover photograph for the September 1966 issue of Scientific American.

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solid as a cube, with three orthonormal edges establishing a coordi-
nate system based on the programmable intensities of the three pri-
maries, as shown in Figure 7.
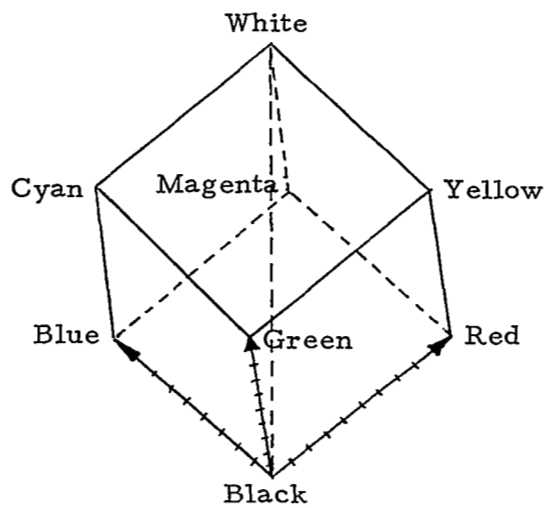
FIGURE 7   COLOR PROGRAMMING SOLID

Every possible color mixture may be represented by a
three-intensity coordinate point in the solid.   The number of mixtures
is determined by the number of primary color intensity levels.   The
color value of each mixture is determined by the choice of phosphors
and the calibration of intensity scales.

Assuming that the intensity scales are properly calibrated,
it should be possible to analytically prescribe any desired color for
information coding purposes by using tristimulus color mixture curves
for fully saturated spectral hues, or the Maxwell triangle for any
color. [10]   In practice, however, it is more convenient to construct
color scales with discriminable "notes" by the computer-aided cut-
and-try approach.

The maximum number of discriminable "notes" which can be incorporated in a color scale may be used to measure the power of color for supercoding, An experiment has been conducted (Appendix I) which indicates a distribution of this power as shown in Figure 8. This map of color coding power should be interpreted in the relative sense, e.g., approximately three times as many discriminable notes may be expected along the red to yellow edge as along the yellow to white (hidden point) edge. The discussion in Appendix I gives reasons for not interpreting these coding power values in the absolute sense.
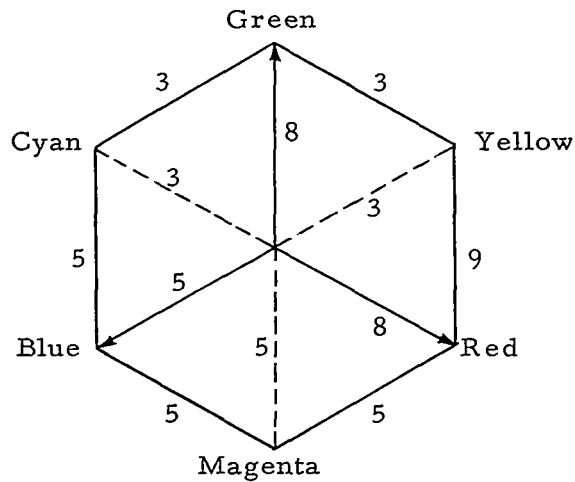
FIGURE 8 RELATIVE CODING POWER MAP FOR THE COLOR CUBE

By making a gross assumption regarding the linearity of color interactions within the color cube, an estimate of the number of discriminable points within the cube may be obtained as follows:

$$G_{avg} = (9 + 10 + 6 + 6) \div 4 = 7.75$$

$$R_{avg} = (9 + 6 + 4 + 4) \div 4 = 5.75$$

$$B_{avg} = (6 + 4 + 4 + 6) \div 4 = 5.00$$

Product of averages = 222 discriminable combinations.

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The numbers of coding levels used in this determination are one greater in each case than the numbers appearing in Figure 8, which represent numbers of intervals between levels. The product, 222, represents an estimate of the total coding power of color, taken, once again, in the relative sense.

3.1.2   Black and White

If a black and white display is to compete with a color display in terms of supercoding power (i.e., if something in the order of 222 coding levels is to be available) more than one supercoding modality will be required in that black and white display. Intensity alone offers only eleven discriminable coding levels (Appendix I) as determined in the same manner that was used for determining color coding power.

The combination of focus, flicker and intensity seems a likely candidate to represent the case for a black and white display. According to Barmack and Sinaiko[11] brightness (intensity) and flash rate (flicker) are each capable of producing four coding levels that can be identified in isolation (rather than merely discriminated when displayed side by side). Assuming the same scale factor for flicker as for intensity in converting the number of identifiable levels to the number of discriminable levels one arrives at a figure of eleven discriminable flicker levels. This is consistent with the findings of a flicker study which has been undertaken (Appendices II, III), although the conditions under which this study was made were different from those of the color study.

According to the same source[11] focus is capable of yielding two coding levels that can be identified in isolation. Applying the same scale factor once again, one arrives at a figure of five or six discriminable focus levels.

These figures have been used in constructing Figure 9, a focus-intensity-flicker solid (similar to the color cube) the coordinate

origin of which might be labeled "chaos" (where no focus, no intensity, and no repetition of the display image exist). Here intensity represents one axis or edge of the cube, whereas in the color cube the intensity scale occurred along the internal diagonal from black to white.

Full
Intensity
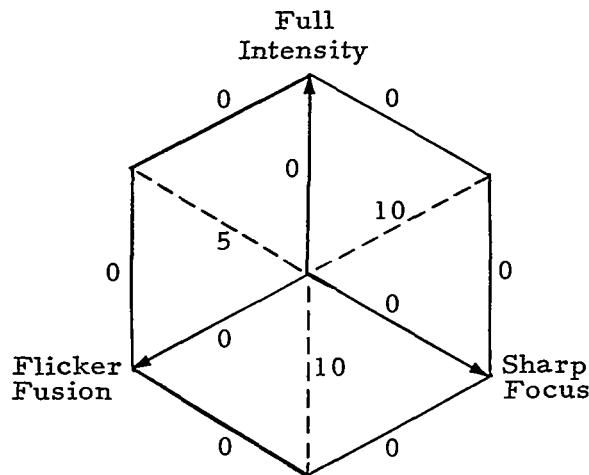
FIGURE 9   RELATIVE CODING POWER OF FOCUS-INTENSITY-
FLICKER

        The zero coding level counts are deduced logically as follows. The plane shared by the fusion and focus axes represents zero intensity and at zero intensity no display image will be seen. Likewise, a display image modulated with values in the zero c.p.s. (flicker) or zero sharpness (focus) plane will not be observable. Therefore, no discriminable levels exist in these planes.

        Optimistically, a quantum jump in human response might occur at slightly non-zero values of these variables. Pessimistically, extreme interactions may be expected within the cube among the variables. For instance, as the flicker rate approaches the fusion frequency, apparent intensity increases (Appendix III); as intensity

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increases apparent flicker increases (Appendix II); as focus sharpens the apparent intensity will increase. Assuming these considerations cancel each other, one might evaluate the total coding power as follows:

$$I_{avg} = (10 + 0) \div 2 = 5.0$$

$$Fl_{avg} = (10 + 0) \div 2 = 5.0$$

$$Fo_{avg} = (5 + 0) \div 2 = 2.5$$

Product of averages = 62 discriminable combinations.

The numbers of coding levels used in this determination are equal to the interval counts shown in Figure 9. In other words, one coding level has been discarded for each variable as a means of "shaving off" the zero planes.

The product, 62, represents an estimate of the total coding power of the focus-intensity-flicker combination and may be compared directly with the value of 222 obtained for color. The comparison indicates that color offers almost four times the supercoding power of the suggested black and white combination.

It may be concluded that color is a preferable choice in the specification of a display device, based on information transfer considerations at least. Cost considerations show little difference between a color display and a variable focus-intensity-flicker display (Appendix IV).

In a situation where a significant percentage of the intended users suffers some degree of color blindness, the preference could swing towards black and white, but based on the work reported here, a color display is recommended for use in the interpretation of space data.

3.1.3 Depth

A number of techniques for depth representation are possible using a cathode-ray tube display. These are listed in Figure 10.

```
Two-Dimensional Display:

    Projections (usually oblique views)

    · Isometric
      Perspective
      Contour-block

  Optical Illusions

      Superimposed image stereographs
      Separated image stereographs
      Single image projections

  Three-Dimensional Display:

  (c.f. Appendix V)
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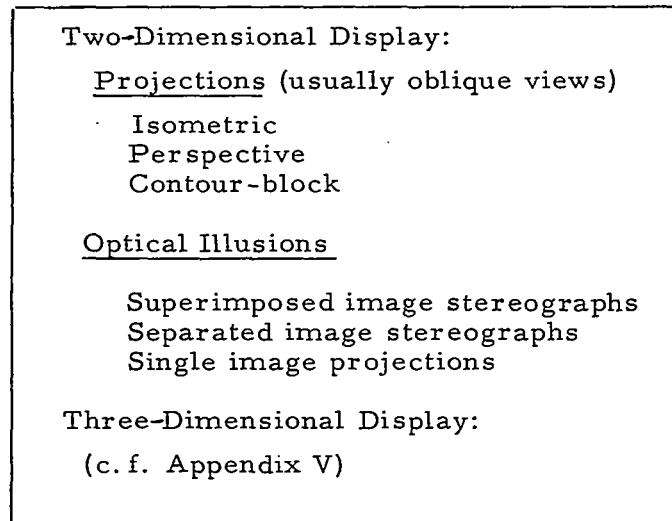
FIGURE 10   FAMILY OF DEPTH CODING
TECHNIQUES

Two-dimensional projections and optical illusions may be excluded from the present considerations of console design since they represent transformed combinations of basic coding modalities, rather than additional supercoding power. Thus, projections are composed of shape and orientation. The visual perception of depth is an optical illusion if its implications do not stand up when tested (for example one might try placing a real object between two objects seen at different depths through a stereoscope). Included in this category are stereographs (which are indeed no more than a combination of shape, orientation, and number) and fool-the-eye single image projections, the depth illusion of which may be enhanced by motion, focus, and intensity modulation.

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Three-dimensional displays may also be excluded from consideration since they have yet to be developed to a useful degree (c.f. Appendix V). Before leaving the subject of depth coding however, a few observations and remarks are in order.

Two-dimensional projections are likely to prove quite useful for viewing space data of certain types. An example employing the isometric projection is given in Appendix VII.

Superimposed twin image stereographs must be viewed through special glasses in order to perceive a single image in depth. Some work has been done with the color display equipment of the AFCRL DX-1 installation[12], using red and blue images and corresponding eyeglass filters. Satisfactory effects were obtained but the project was abandoned because the depth coding power realized was far less than the color coding power sacrificed. Sylvania has recently introduced a cathode-ray tube to the market, which is capable of red and green image display: given a pair of adequate filters (and with red and green rather than red and blue this may pose a real problem) this product could prove feasible for stereographic displays.

Separated image stereographs require special apparatus (a stereoscope) for image viewing. Some useful work has been done with position separated image pairs[13], employing a simple optical stereoscope. No work appears to have been done with time separated image pairs (an alternating image concept which would require synchronized stroboscopic alternating ocular viewing).

3.1.4 Display Design Considerations

Within the present state of the display device art, the tricolor shadow mask cathode-ray tube appears to be the best choice for computer generated color displays. This design has reached a high level of development, offers good color purity and registration, and is available at mass production prices. Other tube types, although

theoretically superior in some ways, have not been as completely developed. [14] The tube type which comes closest is the Chromatron (Appendix VI), a design which offers greater image brightness than the shadow mask tube, and which at the time of this writing is being used in some of the television receivers manufactured by Sony Corporation. In the Chromatron, however, phosphors are deposited in parallel strips: this design is well suited for parallel line scan displays, but its suitability for random beam positioning in computer generated displays is debatable.

3.1.5 Resolution

Typical 21-inch tube shadow masks are circular screens with 357,000 perforations through which the three electron beams may pass. This figure is the equivalent of about 337 perforations on a 10.5 inch radius, or 477 perforations on the 14.8-inch side of an inscribed square. Since one of these perforations corresponds to the smallest possible spot size, the specification of beam position in the horizontal or vertical direction is meaningless beyond approximately nine binary digits of precision.

Actual image resolution is determined by the size of a focused electron beam spot on the phosphor screen, although contrast may also be a factor. The spot does not have a definite edge but decreases in brightness from the center. Spot size is generally expressed according to the "compressed raster" definition, that is, the distance between two points on opposite sides of the spot center, at which the brightness is half that of the center. When spots are displayed in a matrix (on a non-shadow mask tube) with this distance separating the spot centers, the spot structure practically disappears. In a shadow mask tube, beam spot size is designated to accommodate the display of a 525 line television scan raster, and in this sense is consistent with perforation spacing and with nine binary digit precision.

Resolution is not as simply defined or agreed upon as once assumed. "The number of distinguishable lines per inch" encounters difficulty when one tries to define what is distinguishable. If one specifies some percentage of contrast as prerequisite for distinction between lines and space, others might not agree on the percentage or the methods for determining contrast. It is circular to compare photocell outputs, one looking at the lines and the other spaces, for this presumes resolution.

Various approaches to defining resolution are shown in the drawings. There is some overlap in these approaches, but they illustrate the problem. Perhaps resolution cannot be adequately expressed as a single number, but rather some sort of function such as 9, 13, 14. These functions are analogous to those showing the properties of amplifiers. The approaches are as follows:
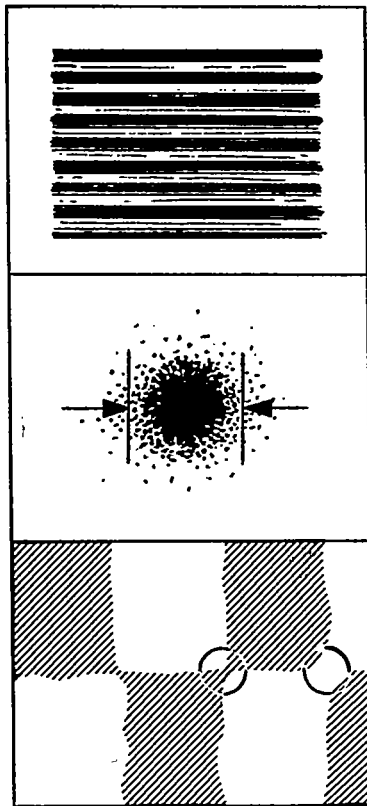
1. lines per unit distance with 50% contrast between darkest and brightest lines,

2. spot width as measured at 50% of spot center brightness,

3. circle of confusion diameter (the circle which can be drawn around any area requiring more clarification in a programmed image pattern),

23
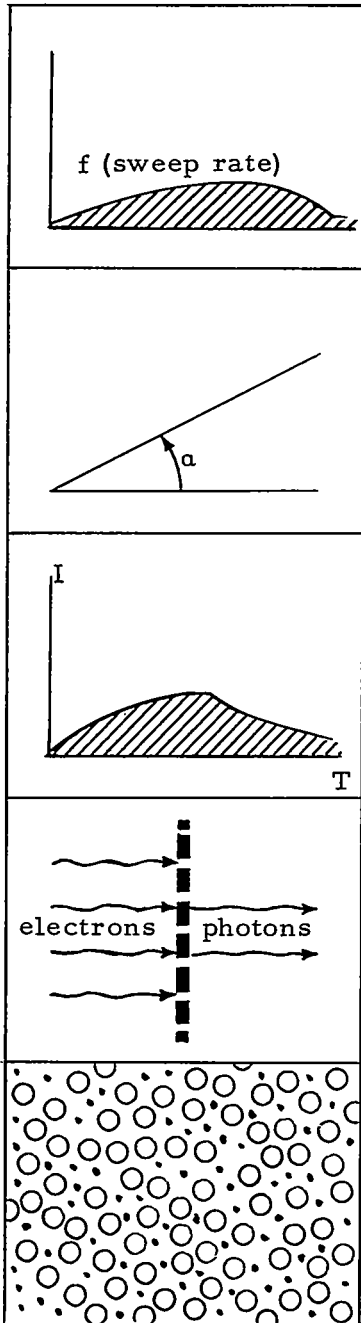
4. modulation transfer, a spread function similar to the linearity of an amplifier during modulation of a carrier,

5. seconds of arc, the angular measure of the smallest observable spot in a given pattern,

6. brightness vs. time, the fall-off in intensity of the smallest observable spot in a flourescent-phosphorescent display,

7. quantum efficiency per element, the number of photons generated per electron in a display device,

8. signal to noise ratio, intentionally displayed area to unintentionally illuminated area,

24
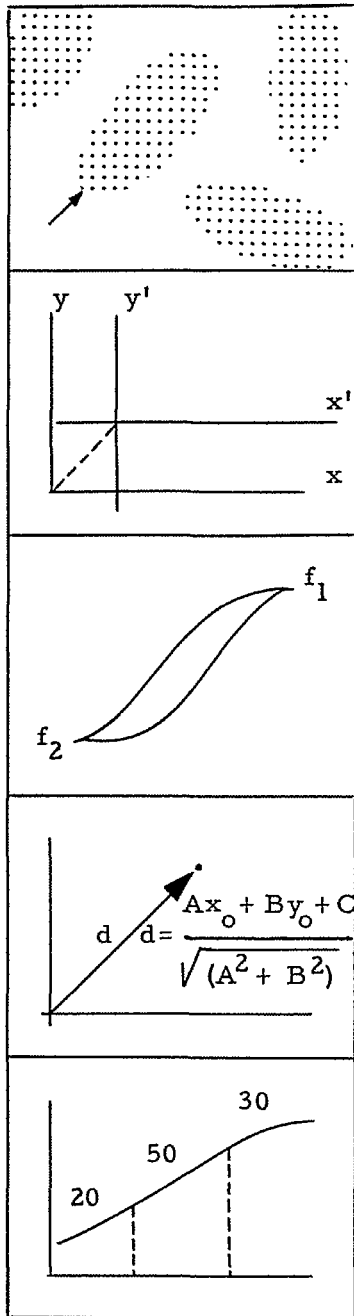
9. graininess, the irreducible size of display medium grain,

10. incremental (position) resolution, the smallest detectable change in location of an image element,

11. repeatability (focus hysteresis), the irreducible change in position of an objective lens to bring into focus first the center of a given display, then the extremities,

12. absolute accuracy, a mathematical computation of the ideal distance between two barely distinguished points,

13. percentage flatness or linearity of transfer, similar to the instance of "high fidelity" amplifiers,

$$d = \frac{Ax_o + By_o + C}{\sqrt{(A^2 + B^2)}}$$

100　　50　　0
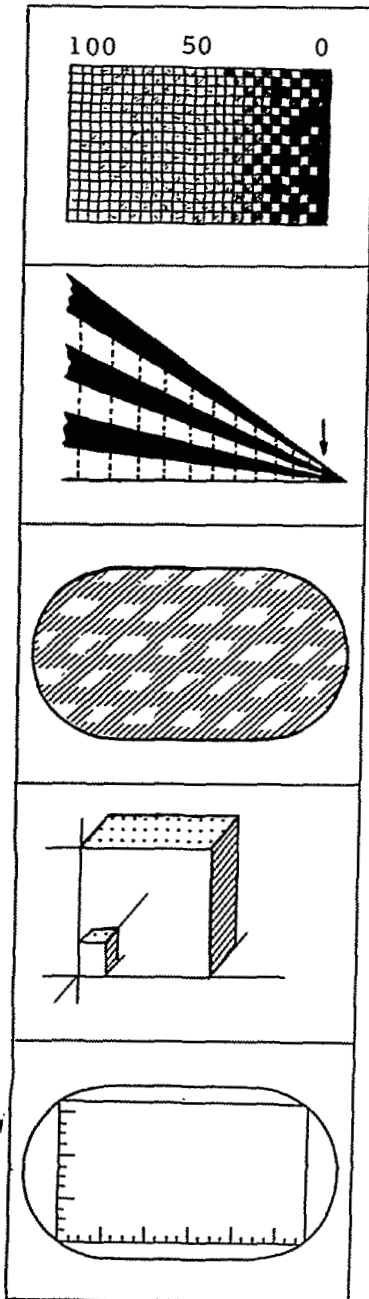
14. quality number (average of three or more most desirable properties),

15. resolution wedge, as measured at the smallest thickness at which light and dark regions can be distinguished,

16. area resolution (total area displayed per resolvable element), similar to 8., but expressed as a ratio of distinguishable to indistinguishable areas,

17. coordinate resolution (total volume of display per resolvable unit volume), a three-dimensional form of 8.,

18. positional resolution (number of discrete elements per side of display).

One implication of using a 21-inch shadow mask tube with 512-point resolution is that reasonable quality text characters created with a 20 x 30 matrix of display points will be approximately one inch high.

3.1.6 Writing Speed

Because of several engineering considerations including control of beam spot size, the shadow mask tube employs electromagnetic rather than electrostatic means for deflecting the three electron beams to a desired spot on the phosphor screen. Typically, electrostatic deflection is ten times faster than magnetic deflection. The slower writing speed of magnetic coils is usually not a problem in scanned applications such as television, but electrostatic deflection plates (or a combination of the two means of deflection) are usually specified for random positioning applications such as computer generated displays.

The fact that the shadow mask tube is used in television receivers indicates a writing speed capability of 330,750 inches per second (525 lines x 21 inches x 30 repetitions per second). In a random positioning system, the DX-1 at AFCRL, it has been determined that as much as 167 microseconds must be allowed for the generation of a 1.5 inch line segment following the execution of a display command, for the sake of acceptable display quality. This is the equivalent of 9,000 inches per second, a minimum figure. Some improvements in available color display equipment may be expected in the near future; it is understood that Electronic Associates Incorporated is developing a color tube with higher deflection speeds and 1,024 point resolution for DuPont, and that I.T.T. is developing improved color equipment for the M.I.T. Research Laboratory of Electronics.

As an indication of what can be done at the slowest writing speed quoted, see Appendix VII which describes experience using color display equipment for analysis and interpretation procedures with data from a space science experiment.

3.1.7   Human Factors

What should be a trifling problem in fact turns out to be a widespread one, namely the control of eye strain inducing factors in displays. These factors are flicker, contrast, and console glare. Console glare can be reduced if the tube face or shield is "non-reflective" glass or plastic. Console glare and contrast may be reduced by mounting the tube at an angle such that the viewer sees the reflection of a uniformly illumined flat surface (contrary to MIL-STD-803 which requires the tube face to be perpendicular to the line of sight). Contrast and flicker can be reduced by operating the display at a reduced brightness or intensity level (the shadow mask design is often criticized for lack of brightness). Flicker can be eliminated by maintaining an image repetition rate in the range 30 to 60 hertz, the value depending upon other conditions (Appendix II).

A potentially dangerous problem associated with cathode-ray tube displays is the possibility of soft x-ray radiation. Two solutions to this problem are proper shielding and the use of phosphors which do not require extremely high accelerating voltages (Appendix IX).

3.2   INPUT

Given an adequate display device, some means of input whereby the user may communicate information to the computer is required in order to close the interaction loop. Since the user in this case is a space science experimenter engaged in drawing meaningful conclusions from his sensor data, it is of paramount importance that the operation of the input device provided should not distract the user from creative thought.

In a man-computer display and data processing system input and control devices are necessary for manual (machine-aided) and semi-automatic operations such as image construction,

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specification of procedures, and monitoring and guidance of data processing. Manual control in automatic operations involves merely the start, interrupt, and terminate functions. Some devices which have been developed for use in man-computer display systems are shown in a hypothetical control console (Figure 11), implicitly illustrating a number of input and control principles.

For the present effort the design of a console is constrained to a single display surface and one input device. No reason is seen why this design cannot do the job of the equipment illustrated in Figure 11, provided sufficient thought is given to the programming for its use. Inherent advantages of the simple design are lower costs of equipment and engineering. Potential advantages to be maximized include less user training and greater system "transparency." Potential disadvantages to be minimized include higher costs of programming and computer time for any of the input and control functions.

System "transparency" may be enhanced by reducing distractions. Since the use of the display surface as a common working area for user and computer obviates attention shifting from work area to work area, embodiment of input and control elements in the display image is indicated. Since alternating displays of output information and input-control elements would represent a distraction, the display space should be shared for these functions. This severely limits the number of input-control elements being displayed at one time, making it essential that these elements be rather powerful in relation to the amount of display space they require. One concept which may prove useful under these conditions is that of the "light symbol", particularly in its multiple-choice forms. The name and concept of the light symbol derive from several prior efforts.
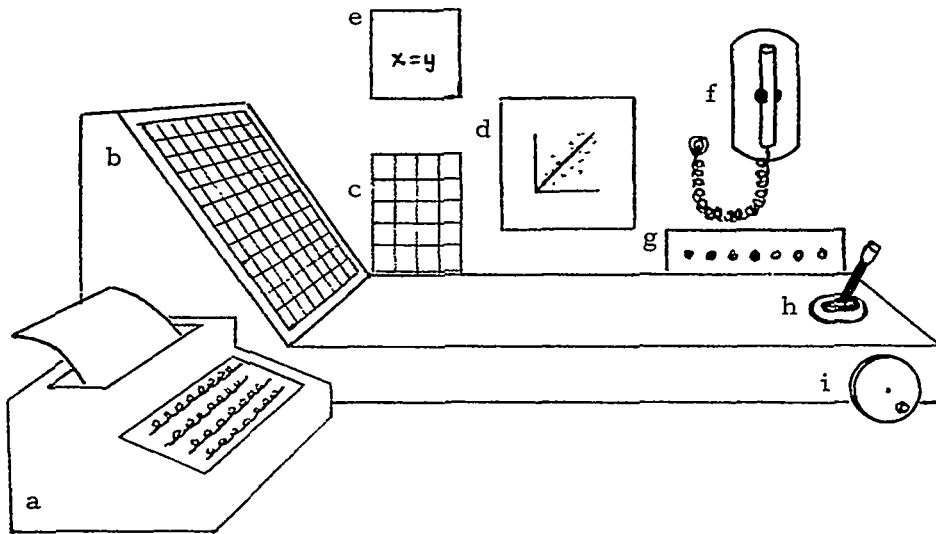
a. text input, sequence recording typewriter,

b. programmed function keys, labeled overlay,

c. fixed function keys,

d. primary display surface,

e. secondary display surface,

f. light pen for designating and tracking,

g. status and error indicator lights,

h. "joy stick" for position control,

i. encoder knob, value and scale control.

FIGURE 11   A DISPLAY CONSOLE

3.2.1 The Light Symbol

The light gun*, grandfather of several graphic input devices, was originally used for designating targets of interest on an air-surveillance display.[16] By aligning the optical axis of the gun with a target "blip" (a spot of light) and squeezing the microswitch activating trigger, timing information which determined the coordinates of the "blip" was fed back to the computer. This concept of light gun usage was later transferred to applications in which a light button replaced the target "blip". Examples include the On-Line Real-Time Programming System[17], DOCUS[18], and AESOP[19], in which alphanumeric items displayed in lists are selected by light gunning the light button (a point or an asterisk) displayed beside an item. In these examples the meaning associated with a light button is designated by an alphanumeric text label. Other forms have been implemented in which the light button is an unlabeled mnemonic shape (e.g., the square root symbol). The light button may be defined as a single-choice light symbol, analogous to a push button.

At the Bell Telephone Laboratories problem oriented light button shapes were found to be so convenient and powerful as control elements that their use increased and the programmed function keyboard fell into nearly complete disuse.[20]

Beginning around 1965 isolated examples of multiple-choice light symbols began to appear in the literature. A system in the design stage at Control Data Corporation's Digigraphic Laboratories[21] featured a geometric light symbol with which a point, a line, or a conic section might be light pen selected for use in graphic construction (Figure 12). At the Lawrence Radiation Laboratory[22] a "gas pedal"

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*   Invented in 1948 by Frederick F. Slack[15] while working under Benjamin F. Greene, Jr. on the VOLSCAN Project, the light gun was first used for input to an analog computer. In 1950 it was adapted for use with a digital computer, the M.I.T. WHIRLWIND, by Robert Weiser and Howard Kirshner. Miniaturization efforts produced the light pen.

light symbol was developed which facilitated changing the values of parameters by applying the light pen to the gas pedal; left or right designated decrease or increase, and distance from center determined the rate or increment of change (Figure 13).

FIGURE 12   GEOMETRIC LIGHT
SYMBOL AND CODE MEANINGS

D   Dot
L   Line
C   Circle
E   Ellipse
P   Parabola
H   Hyperbola

FIGURE 13   GAS PEDAL
LIGHT SYMBOL AND EXPLAN-
ATORY NOTES

minus zone   0   plus zone

pedal set for "medium forward speed"

The geometric light symbol might be used for evoking image elements during image construction, or for imposing geometric constraints (forcing a closed figure to assume circular shape; bringing two line ends to meet at a point; etc.) The gas pedal might be used during time series data monitoring to control the direction and speed at which the data plot progresses across the display surface.

As an indication of light symbol advantages let us picture a user examining a plot of data as shown in Figure 14. He decides to try fitting a conic section curve through the data and selects the parabola. With the Culler-Fried system[4] the procedure would have been to turn to the programmed function keyboard, find the appropriate plastic overlay and place it over the keys, depress the parabola key, and turn back to the display. With the DOCUS system[18] the display would be interrupted with one or more labeled light button lists. Assuming a simple expression for the parabola (x^2 = 4 py for purposes of the example) and appropriate scaling, the next display might appear as in Figure 15, with an initial value p = 1 and the sum of the squares of the deviations calculated.

$$x^2 = 4 \, py$$

$$p = 1.00$$

$$\Sigma = xxx$$
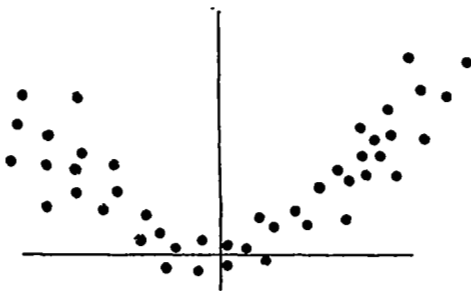
FIGURE 14   A DATA PLOT   FIGURE 15   CURVE FITTING
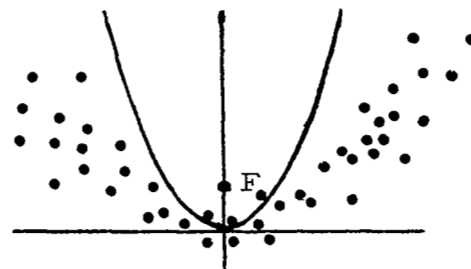
To improve the fit in the least squares sense the user might next elect to vary the value of p and monitor the calculated sum of the squares for a minimum value. In the light symbol approach he would designate p by pointing the light pen at "p" then at the gas pedal

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(Figure 13) for varying the coefficient value (it has been observed that the natural inclination of a display console user is to point at the output display first and select the operation second[23]). A shaft encoder knob could serve as a hardware substitute for the gas pedal light symbol or the value of p might be changed (a step at a time) at the typewriter.

The display application used as an example here might be adapted to the more significant purpose of obtaining a good first approximation in problems such as non-linear parameter estimation or differential equation solution. Appendix VII contains an extension of the concept to surface fitting.

To digress briefly, a very attractive console technique was deliberately omitted in the example, but deserves mention. Specifically, the value of the coefficient p might be varied (and the shape of the parabola correspondingly altered) by light pen controlled displacement of the focal point along the principal axis. This would of course be a sensitive adjustment requiring a steady hand. Taking the horns by the focus in this fashion is quite the opposite of typing in discrete values of p, which illustrates that a pure control technique can sometimes achieve the same end as a pure input technique.

Light symbols related in concept to the gas pedal and shaped like arrows have appeared in programs recently released by IBM[24, 25]. In one instance (Figure 16) the image displayed may be moved on the display surface and its scale factor changed, in increments determined by the segment of an arrow selected with the light pen, starting and stopping under keyboard button control. In another instance variable values may be displayed and controlled with an 8-choice arrow, a scheme of digit underlines and overlines, or a dial and pointer (Figure 17).

225

move
175 picture
up

125

75

25

move   move
picture   ⟨————————————————————⟩   picture
left   right

                              move
                              picture
                              down

.25 increase
     picture
.5   size

.6

.66

.8

1.25

1.5

1.66
                decrease
2.0 picture
     size

4.0
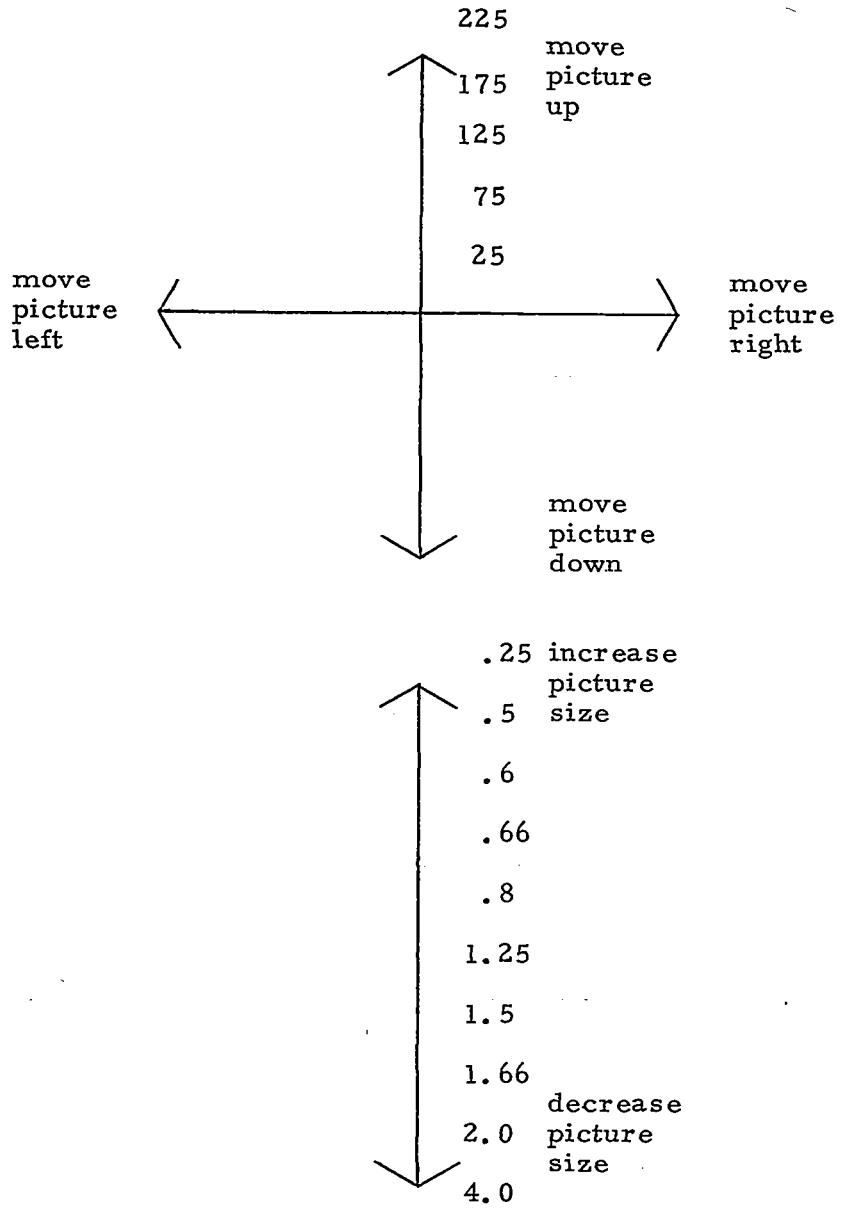
FIGURE 16   GPAK WINDOW CONTROL LIGHT SYMBOLS

Meter

light pen

49.01234   50.01234

light pen

50.01275

Arrow

light pen

0.   0

60   15   60   light pen   15

45   30   45   30
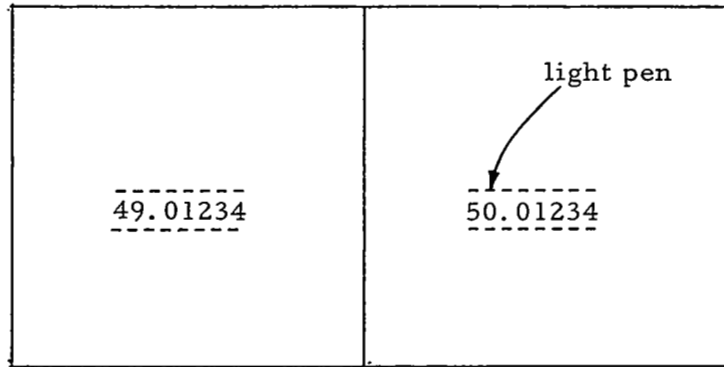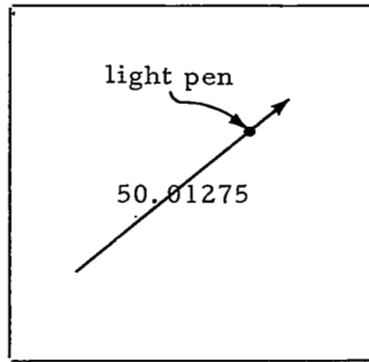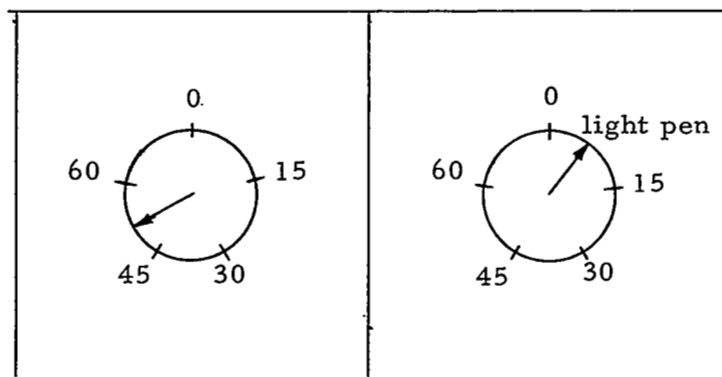
Dial and Pointer

FIGURE 17   GFS VALUE CONTROL LIGHT SYMBOLS

Another light symbol might be a light pen positionable marker displayed on a vertical scale, used perhaps for altitude region constraint in selecting data to be displayed from an experiment package aboard an eccentric orbit satellite.*

Several tentative observations can now be made concerning light symbol characteristics. These may prove helpful in the invention of appropriate light symbols for specific applications.

- A light symbol may incorporate one or more than one selectable option. A single option symbol (light button) may be a mnemonic shape or a point with a label.

- A line or other element within a multiple option light symbol may contain one or more than one selectable option. In a multiple option element, position within the element serves as a coding modality (e.g., the gas pedal). Single option elements may be most appropriate for explicit specification, multiple option elements for variable control.

- Three coding modalities seem suited to mnemonic representation in light symbols. These are shape (the square root symbol), position (the GFS meter) and orientation (the GFS dial and pointer). Other coding modalities may be useful also (c.f. Figure 5 for list).

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*   Suggested in private conversation by T. P. Gorman, NASA Goddard Space Flight Center, Code 565.

•Symbolism may be problem oriented (the geometric
light symbol), fixed function oriented (GPAK window
control), or abstract (gas pedal). Light symbols
may be used for control, input, or specification
purposes. These schemes of classification may be
useful in conjuring up new symbols but may restrict
the imaginative application of established symbols.

•Some operating instructions may be necessary re-
garding the use of specific light symbols, but once
used their mnemonic nature will probably assist
the user in recalling the techniques for their use.

A broad application for light symbols may be found in the
realm of programming and the specification of procedures.

At the assembly language level of programming a likely
candidate for the application of light symbols is Wolf Research and
Development Corporation's proprietary "programming at the scopes"
concept.[17] In this system strings of instructions are constructed by
light pen selection and their operation is simulated for immediate
checking purposes. Rather than represent operation codes by alpha-
betic abbreviation, mnemonic light buttons might be used for individual
codes or macro-codes. For more powerful display representation,
related sets of instruction codes (arithmetic set, logical set, transfer
or jump set, input-output set) might prove amenable to the use of
multiple option light symbols.

At the problem oriented level the non-programmer user
might be given a primitive set of procedure-specifying light symbols;
a SKETCHPAD-like capability for constructing (and shrinking) new
light symbol shapes; and a Culler-Fried style capability for defining
a new symbol with strings of primitives and/or other previously de-
fined symbols. This hierarchial approach would be used in developing

data analysis strategy files. One example of accomplishment in this direction is the work of William Sutherland. [26]

Examples of trial use of light symbols are given in Appendices VII and X.

3.2.2 Devices and Functions

Graphic input device functions may be organized into the categories of pointing, drawing, and text input.

Pointing is involved in picking or selecting a light symbol, an element of a drawing, or a data point. A _display sensing_ device such as the light pen is specifically designed for this function.

Drawing is a function for which the light pen is not especially suited. The technique usually employed involves a hardware or software generated "tracking cross"[27], the constituent points of which are sensed by the light pen and then relocated so as to align the center of geometry of the cross with the computed principal axis of the light pen. Tracking cross generation, if performed by software, is usually rather time consuming. Typical complaints with tracking crosses are disruption of the background display during periods when the cross is being displayed; constraints on the rate at which the pen may be moved across the screen without leaving the cross behind; and the artificiality of having to "ink-up" in order to acquire the cross with the pen.

As a solution to these problems, _position sensing_ stylus devices including the voltage pencil[28], the RAND tablet[29], and the magnetic tablet[30], are available. Characteristically the position of the stylus is immediately available regardless of positions of the CRT electron beam, and hence these devices are well suited for drawing. In order to be used for pointing at a displayed image part, however, coincidence detecting hardware or software is required.

The device which is specifically engineered for text input is the typewriter. Since turning from the display to a keyboard represents a very real distraction from creative activity, several techniques have been developed for text input with a stylus device. For display sensing devices these techniques are generally to display a character set from which individual characters may be selected in sequence. This approach is not usually as fast as typing[11] but a probabilistic variation has been devised (Appendix XI) which represents some improvement. For position detecting stylus devices the trend in text input techniques seems to be toward hand printed character recognition, an approach which is certainly slower and more demanding of computer time than the pointing approach.

Space data analysis and interpretation as practiced on-line with a computer will primarily involve the pointing and text input functions. Drawing (as in computer-aided design) will be employed to a somewhat lesser extent. Of the input devices cited, therefore, the light pen is probably the most appropriate. Another display sensing device, the beam pen[31], senses the electron beam directly, offering better time resolution (discrimination between successively displayed points) than the light pen but poorer space resolution (field of view) and signalling delay. With further development this device might be preferable to the light pen since it is fast, insensitive to room lights, and able to "see" through tracing paper.

There is another device which is recommended above all of these. This is a phase tablet as exemplified in the recently developed Sylvania Data Tablet, DT-1. With this tablet a high degree of freedom from distraction is possible since the user's finger may be substituted for a pointing stylus. For the present application this user convenience is considered adequate compensation for the fact that the phase tablet, a position sensing device, requires special coincidence detecting provisions.

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3.2.3 Light Finger

In the technique reported here the human finger rather than a light pen or other stylus device is used for pointing and drawing lines on a cathode-ray tube display. This is accomplished by transmitting finger position information through the human body. The technique was demonstrated to the authors by Dr. Roy Sallen of Sylvania's Applied Research Laboratory on June 14, 1967, in connection with a demonstration of Sylvania's Model DT-1 Data Tablet. Since the paper describing this tablet has not yet been published, a few remarks about this device will be given before discussing the "lightfinger" technique.

The DT-1 tablet consists of a transparent conductive film of tin oxide sandwiched between sheets of glass, and may be mounted in front of a cathode-ray tube display, or placed on a horizontal surface for uses such as tracing drawings.

Time varying voltage fields are applied to the conductive layer, and coordinate information at any point on the surface is derived from the phases of the traveling signals. Through capacitive coupling these signals are sensed by a hand held stylus and transmitted through a cable to an electronic device which converts the signals to x and y coordinates (12-bits each), a z coordinate (4 levels), and sets a data ready flag.

Thus, the DT-1 may be compared with several similar devices. Like the voltage-gradient pickup variety of conductive film systems, it employs an analog signal, but the film is protected from scratches and smudges; and because signal phase rather than voltage-gradient carries the desired information, coordinate positions are insensitive to spurious amplitude variations. Like the RAND Tablet the DT-1 employs capacitive coupling, but has the advantage of being transparent. Like the Lincoln Wand[45] it detects a z coordinate, but only to a very limited degree (which might however prove useful for defining writing and erasing regions above the tablet). Like each of these devices, the DT-1 when compared to the light pen has an advantage for

drawing (no need to generate a "tracking cross" display) but requires coincidence detecting programs or circuits to identify stylus position with electron beam position in the "pointing" mode of use.

The position accuracy of the DT-1, at 1% now (Sylvania hopes to guarantee around 0. 2% in the near future) lies between that of the light pen and RAND Tablet. When the DT-1 is mounted at a short distance in front of a cathode-ray tube, a parallax condition exists, but one is able to adapt quite well to this after a few moments of use. A more disconcerting effect might be the multiple reflections of the display image created by the several glass surfaces. The use of a circularly polarized filter might alleviate this problem.

A more detailed description of the DT-1 is contained in Sylvania's brochure SES-ARL DT-1-4-67-2. 5M.

The demonstration model of the DT-1 at Sylvania's Applied Research Laboratory is connected to and mounted in front of an oscilloscope for display purposes. It is also equipped with a metal canister which is connected to the signal conversion equipment in place of the hand held stylus. If this canister is held in one hand (or placed in a pants pocket) and a finger of the other hand is pointed at the data tablet then finger position determining information is passed from the data tablet and through the body to the signal conversion equipment. In the demonstration equipment the oscilloscope beam is deflected according to finger position coordinates, causing the beam spot to follow the finger as it moves to various locations on the display surface.

Operating in this "lightfinger" mode a fair amount of jitter was observed in the slaved display point: according to the manufacturer a sensitivity adjustment would correct this condition. One other problem was observed: in certain graphic operations, such as line drawing or (conceivably) the use of height regions above the DT-1 tablet for programmed purposes, it is inconvenient if the finger or stylus is detected while approaching a start point or withdrawing from

an end point. Modern light pen designs incorporate actuators, button operated shutters or microswitches in order to get around this problem. The DT-1 design should include a conveniently located button which temporarily breaks the signal detecting circuit when pressed.

On the plus side, the advantage of not having a cable dangling from the pointing device is obvious. Such cables are prone to damage and have been known to work loose from their connections, an intermittent trouble source which is difficult to locate. If the cable is protected by a coiled spring shape, as in telephone handset cords, the resultant tension may be tiring during extended use.

Early customers for the Sylvania DT-1 include Ivan Sutherland at Harvard and William "Bert" Sutherland at Lincoln Laboratory. Accordingly it may be expected that techniques for the use of this device will be thoroughly investigated in the near future, and that any worthwhile developments will be published.

3.3   PERIPHERAL DEVICES

The display and input devices, appropriately interfaced with a computer, represent a minimal console configuration. There are, however, a number of console support functions such as image rotation or (for the light pen) tracking cross generation which can be performed more efficiently by console peripheral devices than by the computer and its programs. The criteria for proceeding to implement these functions in hardware should include considerations of whether the functions are likely to be called upon frequently, and whether their defined procedures are subject to change. For instance, there would be no savings in image rotation hardware if none of the users rotated their images; or in single image rotation hardware if the users suddenly became interested in looking only at double image stereoscopic displays.

3.3.1 Display Memory

One function which is required frequently and which can be rather well defined is image regeneration. Direct view storage tubes are available which need only be refreshed every few minutes (or when a change in the picture is required) but these are not compatible with color display nor are they well suited for precise user interaction. Therefore, it may be assumed that a 30 to 60 c.p.s. refresh rate is required.

Display memory is the storage facility for the file of display commands which determine the actions of the electron beam. This display memory may reside in computer memory or in a storage buffer device. If computer memory is used for this purpose, the computer has more rapid and easier access to the display commands for alteration purposes, but the computer-to-display channel will be in almost constant use. If the control section of the computer is involved in transmitting data over this channel, virtually all of the computer's time will be devoted to this output operation. For example, if a point display program loop, including load, store, output (and possibly wait) commands requires 50 microseconds, only 666 points can be displayed at a 30 c.p.s. rate, and most display users will want at least this much information displayed.

An automatic data channel (which "steals" cycles from the control section of the computer, during which time data is "snatched" from the computer memory) makes the use of computer memory for the storage of display commands a somewhat more feasible proposition. Using this type of equipment, raster scanning, and a specially designed display control unit which accepts beam on-off commands rather than beam position commands (giving a claimed 96% reduction in the amount of core memory required to store display data), Brazeal and Booth[32] achieved a display rate of approximately 6 microseconds per point, for points in a closely spaced matrix. In another instance of display memory incorporated in computer memory, the

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Digital Equipment Corporation's Type 338, the plotting rate for a similar display is 8 microseconds per point.

Display memory may reside in a storage buffer device. This relieves the computer of the "cycle-stealing" time penalty but does not generally improve the point plotting rate. The IBM 2250 III for example, requires 9 microseconds per point of closely spaced data[33], and the BR 90 requires at least 5 microseconds[34] (both systems employ electromagnetic deflection).

Thus the useful capacity of display memory appears limited to the number of points in a flicker-free frame (less than 7,000 at 30 c.p.s. and 5 microseconds per point in the black and white case) times the average number of display command words per point. The reason for using the closely spaced point plotting rate here, rather than a vector generation (line length) or character generation rate, is that point plotting is considered more appropriate to space data analysis.

For large volumes of space data a 7,000 point display may prove inadequate at times. For example, a 256 x 256 matrix of data values is generated by the Isotopic Abundance Experiment referred to in Appendix VII. In order to examine this much data at a flicker-free rate a system such as described in Appendix VIII is required. This system, the C.D.C. tonal display system, presently displays 100,000 intensity modulated points at 30 c.p.s. and is being modified to display approximately 250,000 points.

For the space data application it is recommended that at least one console (economics determining the number) have access to a high data rate drum (or other cyclic device) such as the C.D.C. tonal display system employs, but modified for color display. Further, it is recommended that this console be time multiplexed between the drum and a second display memory within the computer, alternating from one to the other 60 times per second. In this way dynamic and static digital data displays may be mixed. For example the user may use the input device (communicating with the computer) to draw curves or

superimpose labels on the large volume background display from the drum.

It may be assumed that a reasonable amount of on-line data analysis and interpretation time will be devoted to dynamic data scanning (looking through a small "window" which moves across a large volume of sequential data). Since computer memory is more suitable than a storage buffer when the display commands must be altered frequently, the use of a small computer's memory is recommended for general display memory purposes in the console design.

3. 3. 2 Input Device Support

Since the recommended input device is a position detecting tablet rather than an image sensing device, the problem of identifying which display point the user is pointing at arises. The programed solution might be to compare input device position coordinates with the coordinates of points in display memory, at some reduced degree of precision, but this approach is inherently wasteful of computing time. Therefore, it is recommended that coincidence detecting circuits and a related cursor generator be included in the console equipment. Coincidence detecting circuits would compare input device coordinates with beam position coordinates at a reduced degree of precision, and issue an interrupt signal to the computer upon coincidence of these coordinates. The cursor generator would produce a display symbol, perhaps a square box the width of which corresponded to the reduced degree of position precision, which would be slaved to the input device position. This cursor symbol would solve any parallax or alignment problems in mounting the transparent data tablet in front of the display screen by giving the user positive visual feedback of the detected input device position. A useful option would be a knob on the data tablet for control of the number of low order binary digits ignored in coincidence detection. This precision variation control would also determine the cursor symbol size corresponding to "point-capture" area.

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3.3.3 Character and Vector Generation

Reexamination of Figure 3 and Section 3.2.1 indicates that characters and straight lines will receive frequent use in this application. Accordingly consideration must be given to including character and vector generators in the console design. Poole[14] gives fairly comprehensive coverage of these devices. Assuming color display, and origination of character and line commands from the computer rather than from the high volume drum, the choice of character generator (according to Poole's treatment) should be a writing rather than printing or scanning device, and in particular a stroke or Lissajous Figure generator. The defined procedures of a character generator (i.e., the character set) are however subject to change. One space science experimenter may use a particular system of symbolic notation extensively, another may wish to prepare a report in Russian. Therefore, a compromise between programmed characters and wired characters is recommended; an approach in which the bit pattern of a character display command is interpreted by the character generator for the sequential generation of strokes or curves. A programmable generator such as this could be used for short segment vector generation (with important cost reductions indicated by Stotz and Cheek[35]), and conceivably for curve generation.

3.3.4 Other Functions

It is recommended that all other functions, such as Rotation, Scaling, Blinking, etc., be performed by computer programs since a case cannot be established to show that any of these functions will be used frequently and in a well defined manner.

3.4 COST ESTIMATE

Based on conversations with Digital Equipment Corporation regarding their experience with color displays; C.D.C. Digigraphic Laboratory regarding ultra-high capacity drums; Sylvania regarding the DT-1 Data Tablet; and study of prices for available components and

systems; the following estimate has been developed for the cost of a console as recommended. The figures are based on limited quantity production (in the order of ten units) and include engineering development and overhead costs. The confidence in these figures is ± 33%. Interfacing of the major items is included.

Item	Estimate
Color console, control unit, automatic data channel	$ 120,000.00
Character and vector generator	15,000.00
Data Tablet DT-1 with extra features	15,000.00
Coincidence detector, cursor generator	5,000.00
Basic Console	$ 155,000.00
High capacity buffer, and modifications to basic console for tonal display or mixture of vector beam driving and tonal display	$ 162,500.00
High Capacity Console	$ 317,500.00

4. SOFTWARE

The price usually paid for software flexibility is com-
plexity of usage. One solution to this problem, which is developed in
this section, is a hierarchical approach such as exemplified by the
work of Culler[36] in the area of on-line numerical analysis. In this
approach, the user's strategy language is developed from a set of
basic graphical and mathematical primitives. The feasibility of the
primitive set developed in this report was tested by using it to develop
strategies for two sample cases of data analysis and display: Dr.
Ludwig's Isotopic Abundance Experiment (Appendix VII) and Charlton
Walter's Data Attribute Extraction Experiment.[37] The results of this
test, presented in Appendix XII, indicate the inclusiveness of this set
of primitive and control operators.

Since the set of primitives defined below is extensive, a
typical non-programmer user should not be presented immediately
with the full set. Rather, it is recommended that his first tools con-
sist of strategies developed from these primitives, and that the full
set be gradually unveiled to him at a rate depending upon his interest.
It is further recommended that, as much as possible, the displayed
operators which call the strategies be symbols rather than alphabetic
abbreviations such as are used below for ease of exposition.

4.1 SYSTEM SOFTWARE FUNCTIONS

The functions provided by the hypothetical software system
can best be discussed in terms of the control operators that represent
these functions. As previously stated, the aim here is to design a
flexible but easy to use system. In response to this requirement the
design described has three major system modes of operation. One of
these has several sub-modes for accomplishing the more detailed work.
The modes of system operation are shown in Figure 18. The path in-
dicated by the hashed line is the one most likely to be used by the ex-
perimenter once he has defined the strategy of mathematical sequences

ooo   Detailed Create Path
ı ı ı   Data Analysis Path

Sign-on

Data Mode — Yes / No

Specify Data To Be Analyzed

Analysis Mode ? — No

Create Strategies ? — Yes → Combine Sequences And Displays To Form Strategy Operators → ①

No

②

Apply Strategies To Data, Analyze Result

Yes ①

Create Displays ? — Yes → Construct Graphical Data Representation → ②

No

③

Create Data Manip. Seq. ? — Yes → Construct Data Manipulation Sequences → ②

No

③

Analysis Complete — Yes

No

Create Characters — Yes → Draw Unique Characters → ③

No

To Specify Add. Data Or Modify Strategies

Create Reports — Yes → Combine Text With Analysis Strategies & Results

No

Sign-off

FIGURE 18   SYSTEM MODES OF OPERATION

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and data display representation he intends to use in performing data analysis. The path indicated by the circled line represents the more complicated set of functions that provide the system flexibility features.

With this approach to system organization the novice user might ask his data processing assistant to construct strategies. Then the experimenter need only specify the data of interest and a strategy. Any changes desired in the strategies could be made by his assistant between analysis sessions.

The more experienced user will find through use of the system, that he can easily modify old strategies or construct new ones and have them applied immediately to his data for a view of the result. This should lead to a more rapid understanding of how the data is affected and should hasten the detection of procedural errors. Such an insight should facilitate new analysis approaches and meaningful conclusions in a relatively short time span.

With reference to Figure 18, the following description is given for each system mode and sub-mode. In this description and in the amplifying sections which follow, the term primitive operator denotes the basic element at the user level for use in specifying procedures; the term sequence denotes a named or labeled string of primitives which is incomplete in the sense that procedural and data specifying parameters must be specified for its use; the term strategy denotes a named or labeled combination of sequences and/or primitives which requires only the specification of data operands for its use. Note the distinction between the starter set of system primitives initially provided with the system and user primitives which are created and defined on-line by the user, and which may consist of strings of system primitives and/or previously defined user primitives.

• <u>Sign-on</u> is initiated when the experimenter sends a signal
to the computer system which indicates that a particular console is to
be used. The user then identifies himself to the system, and the sys-
tem provides the user with all current information (other than data)
collected for him since his last console session.

•<u>Data Specification Mode</u> - In this mode the experimenter
can specify the data set he wishes to examine or analyze. This is
accomplished either by specifying all data over a given time span
or by scanning the data values and indicating those of interest.

• <u>Create Mode</u> - This mode is further divided into an open
ended set of sub-modes.

      a. <u>Create characters and new operator symbols.</u>
In this sub-mode a user can draw new text
characters or symbols for use as names of
operators or variables. When operator symbols
are drawn the user has the capability of indi-
cating that different portions of a symbol will
indicate different functions. The functions are
defined and linked with these symbols in the data
manipulation or display creation sub-modes.

      b. <u>Create Data Manipulation Sequences.</u> In this
sub-mode the mathematical computations are
defined for doing data reduction or manipulation.
The syntax of the system primitive set is de -
signed to approximate standard mathematical
notation in order to encourage use by the ex-
perimenter who is unfamiliar with the algebraic
languages such as FORTRAN. Alternately the
user may define new primitive operators for
use in constructing sequences or strategies while
in this sub-mode. These user defined primitives
will be included in the users file for his use at
future console sessions.

      c. <u>Create Displays.</u> This sub-mode provides the
capability for specifying graphical representa-
tions of experiment data. There are several
two and three dimensional coordinate systems
given as a starter set and these may be either
modified or new representations defined by the
user.

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d. <u>Create Strategies.</u> In this sub-mode data manipulation sequences and graphical representations are combined to form a strategy.

e. <u>Create Reports.</u> This is a special sub-mode for the purpose of documenting the results of analysis performed using the various strategies designed in the other sub-modes. The experimenter can enter text from the console display surface and combine this with mathematical notation from data manipulation sequences as well as graphical representations of data.

• <u>Analysis Mode</u> - This is the mode where the experimenter directs the operation of his strategies upon the data sets of interest. The primary form of operation involves the application of strategies to data sets. There are secondary operations for obtaining intermediate results of computations and saving displayed results for future reference. The graphical representations may also be rotated and expanded for better interpretation.

• <u>Sign-Off</u> - The sign-off procedure provides the user with summary information about the amount of time used, for both the central processor and display console. At the user's option the system will also provide a list of any temporary information that will not be saved for future use.

4. 1. 1 <u>System Initialization</u>

When the experimenter picks up the stylus and makes contact with the data tablet surface, the computer will place the display console in the active status.

After the system receives the initialization signal from a display console, the words "EXPERIMENT I.D." are displayed with a list of satellites and a list of experiment-numbers that exist on any or all of the satellites (Figure 19). To identify his experiment, an experimenter points the stylus at the appropriate satellite name and the experiment number.

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EXPERIMENT ID

SATELLITES		EXPERIMENT NO.	
EXPLORER XII		1	7
EXPLORER XV		2	8
EXPLORER XXI		3	9
OAO	1	4	10
OGO	A	5	11
OGO	C	6	12
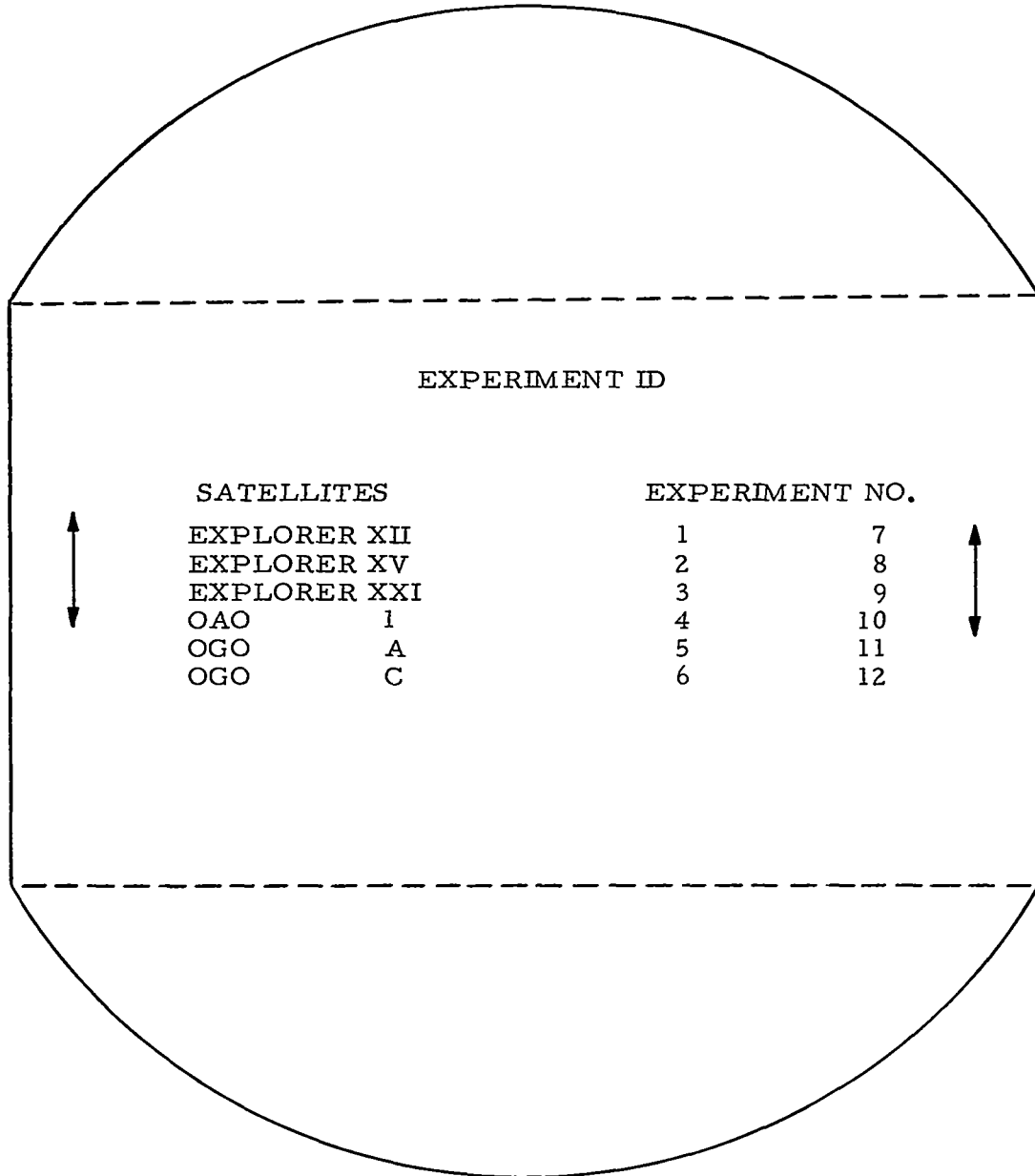
FIGURE 19   EXPERIMENT IDENTIFICATION

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The satellite name and experiment number identify the experimenter to the File Management Sub-System (FMS) which then "opens" the experimenter's file.

Next, the system will check the experimenter's file to see what pertinent information of general or particular interest has been generated since his last sign-in. · Typical kinds of information to be displayed would include satellite launch progress, solar activity, messages from other experimenters, etc.

If more information were available than could be displayed in one frame on the CRT, then a light button labeled CONT would appear at the end of the displayed information. When the experimenter had read the current display he would point to CONT with the stylus and the next page of information would be displayed.

At the end of the last page of bulletin information, the word END is displayed. Pointing to END with the stylus causes the following words to appear in the operator area of the scope. These may be used for obtaining system status information (Figure 20). The use of these operators would be optional and the experimenter could go directly to one of the other system modes.

SP/CR   Provide current status of the space craft carrying the experiment.

EXP   Provide current status of the experiment.

ACT   Provide experimenter's cumulative utilization log of computer and display time.

SYS   Provide the status of system hardware and current system loading with a qualitative statement for response time as being NORMAL or SLOW.

4.1.2   System Control Operators

After the display of system bulletin information, the primary modes of system operation that may be chosen are displayed in

DAT
CRE

SP/CR   ACT
EXP   SYS
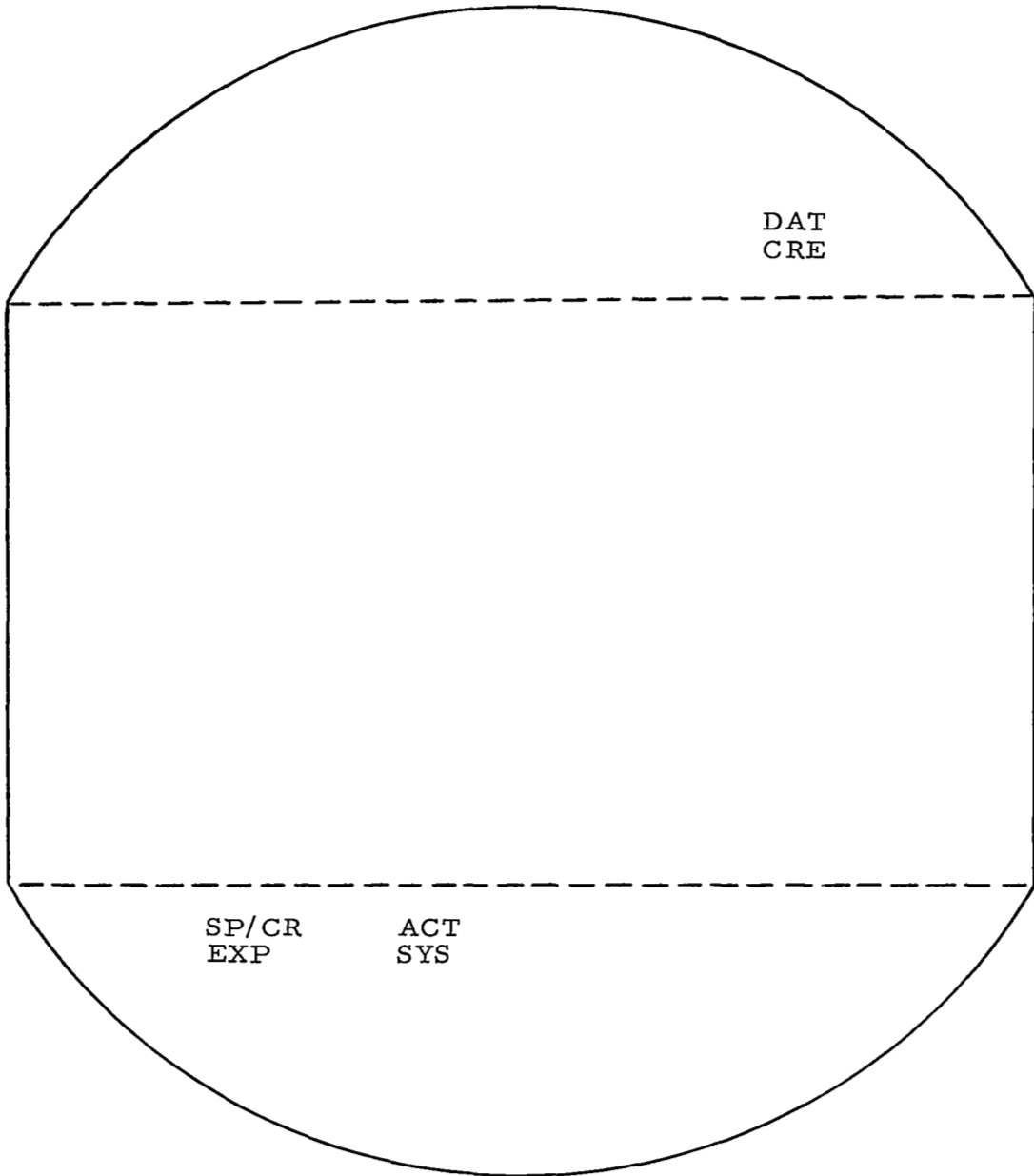
FIGURE 20   SYSTEM STATUS INFORMATION

the upper portion of the display scope (Figure 21). The modes are as follows.

DAT — This is the mode where the data to be used in conducting analysis is specified. In this mode the data may be dynamically scanned and data sets of interest can be identified for processing in the analysis mode.

CRE — This mode has several sub-modes which allow the creation of graphical projections, mathematical computation sequences, a unique character set, data manipulation strategies, or textual reports. A detailed discussion of the operation of each of these sub-modes is provided in subsequent sections.

ANA — After the data to be processed has been specified, a third mode appears with the two described above. This mode, ANALYSIS is where the experimenter directs the operations of various strategies upon his data.

OFF — At any time the console session may be terminated, entering the sign-off mode.

Also displayed are the following error recovery controls.

RE — Reset, canceling all actions taken in the current mode. All such actions are eliminated from the user file.

ER — Erase, eliminating individual characters or figures on the CRT working area and from the user's file.

CL — Clear, the CRT work area of all characters and figures (nothing is eliminated from the user's file.)

4.1.3 Data Specification Mode

The operators of this mode provide the experimenter with the ability to specify data he wants to process. When the data mode is chosen the system will provide a message specifying the time period for

```
                    ABCDEFGHIJKLMN
                    OPQRSTUVWXYZ
                    0123456789
        RE          - . , SP              ANA
        ER                                CRE
        CL                                DAT
                                          OFF
    ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

        DATA AVAILABLE FROM 8/1/66 to 7/3/67

        DATA VALUES RECORDED  E, ΔE


        BEGIN OF        NO. OF         DATA SET
       TIME PERIOD       DAYS            NAME
      MN  DY  YR
      10   3  66          15            DS-5




    ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─

        RAW         OTH         ALL         EDT
        PRC
        ORB
```
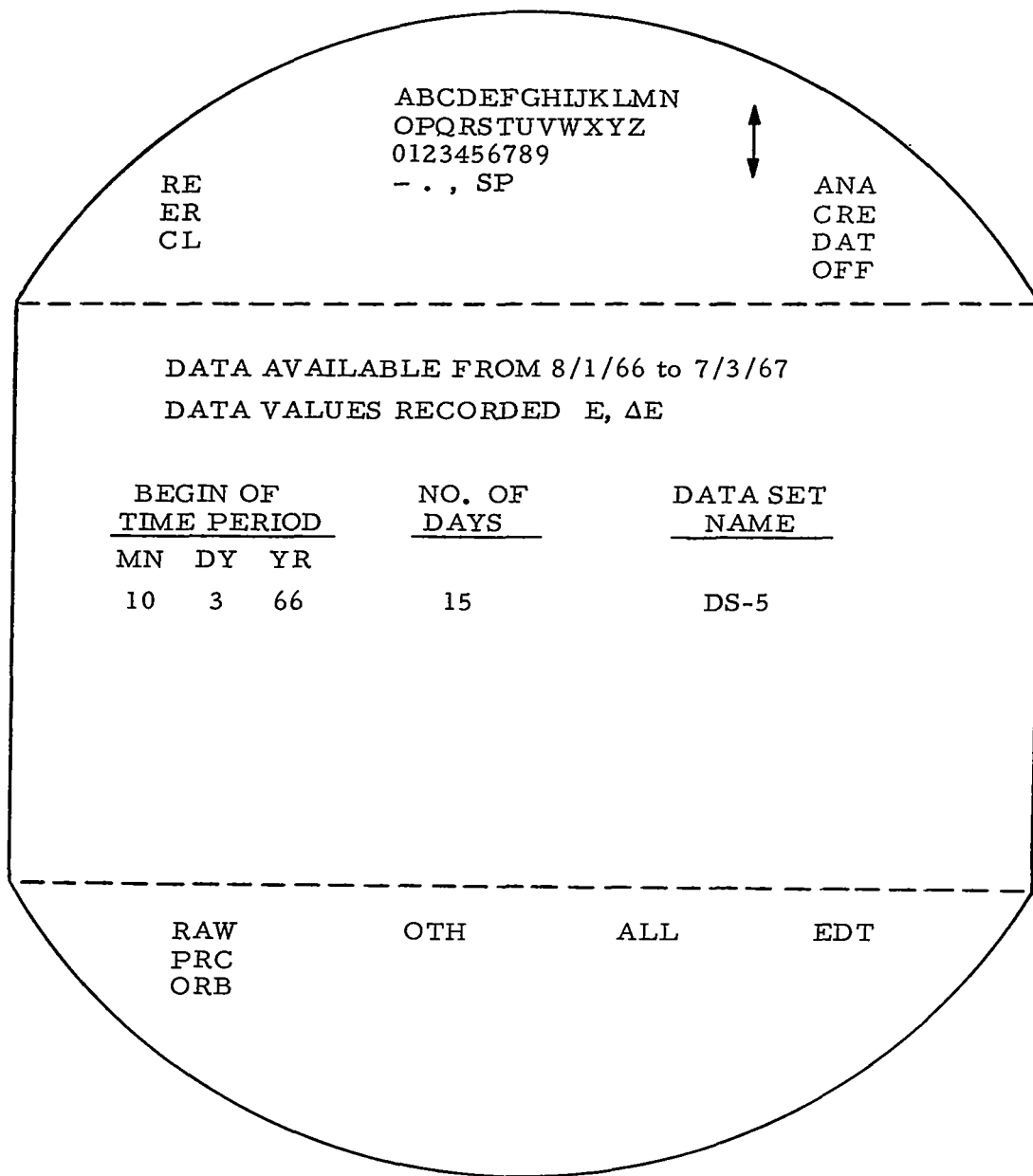
FIGURE 21   DATA SPECIFICATION MODE

which data is available. The system identifier for the data values will also be included. (See Figure 21). The experimenter then uses two operations defined below to specify the data in which he is interested.

The data scanning feature of the system has been included in this data specification mode in order that areas of interest can be identified, as they are encountered, for more detailed examination in the analysis mode. Single data values can be scanned individually in time sequence or two values can be viewed simultaneously for comparison purposes.

The following is a list of data specification operators.

RAW   Indicates unprocessed data.

PRC   Indicates processed data. Will give time period over which data is available.

ORB   For requesting orbital parameter data such as hgt, grd, trk, orientation, a, e, i, w, RA, t.

OTH   For obtaining data from another experiment for comparison.

ALL   To specify all data either processed or RAW to be used for editing or analysis.

EDT
(Fig. 22)   After the period of interest has been specified, an option for scanning the basic measurements on a magnitude-time scale is provided. Data points or a series of points may be excluded from the data to be processed or a series of points may be excluded from the data to be processed or a series of points may be specified for processing by the following operators.

     DEL   All data points indicated by the light pen are deleted from the data to be processed but are retained in the data set used as input to the editing process.

     SAV   All data points so indicated are stored in a data bank to be processed as input data. The data set used as input to the editing process is unaffected.

ABCDEFGHIJKLMN
OPQRSTUVWXYZ
01234567890
- . , SP

RE
ER
CL

ANA
CRE
DAT
OFF

10 - 13 - 66

255

175

ΔE

125

0

T_{DAYS} 1   2   3   4   5

DEL   SAV   (DATA SET NAMES, DSN)
SCA   LOG   LIN   VAL   DUL
PNT   LINE   TIM
            BAR   DY   SC
            EFN   HR
                   MN
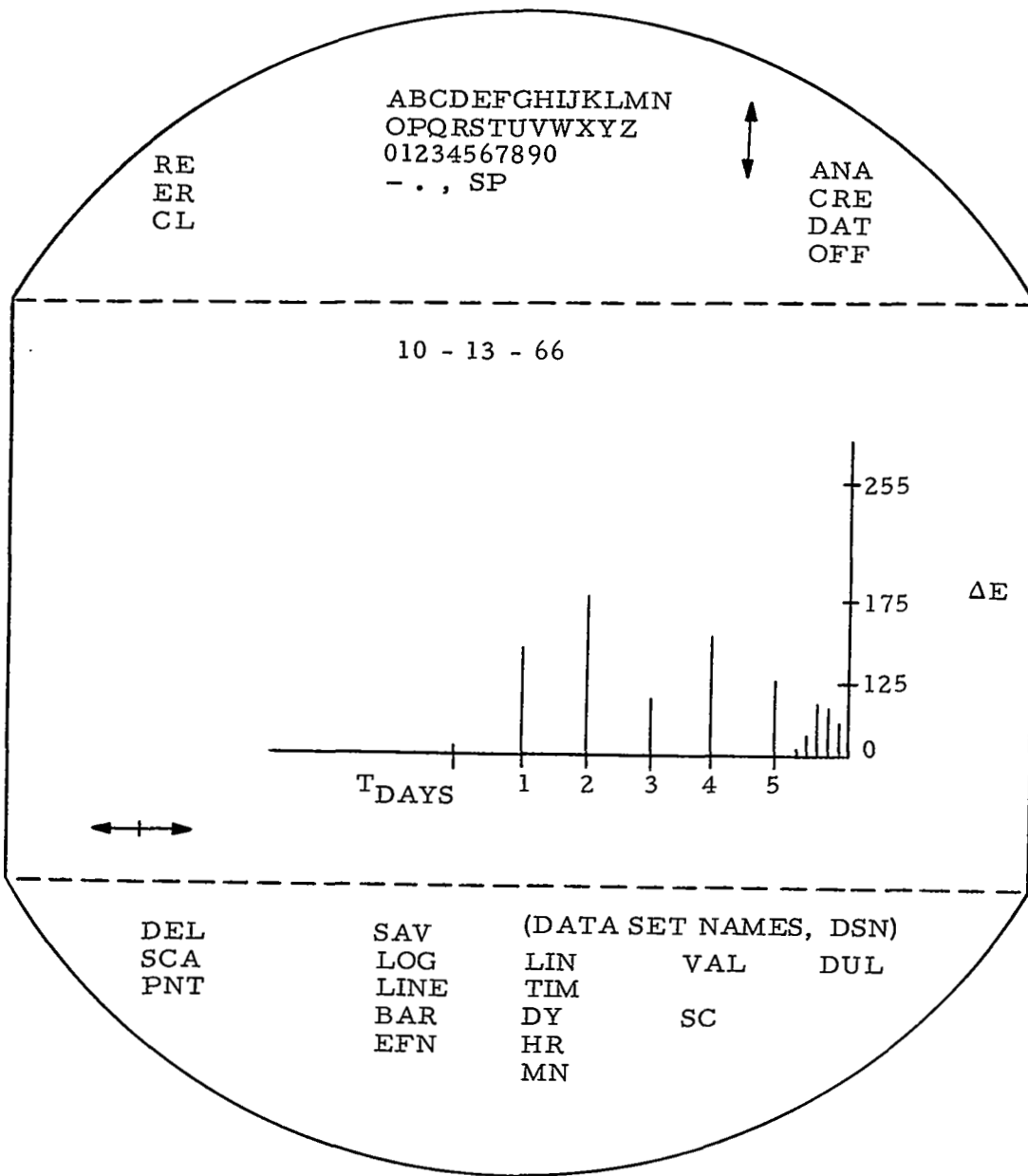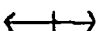
FIGURE 22   DATA EDITING SUB-MODE

SCA	Specify maximum value of amplitude expected for measurements.
VAL	By picking this operator and then a data point, the exact numeric value of the point will be displayed.
LOG, LIN (Linear)	Type of amplitude scale to be used.
LINE, PNT or BAR	To specify whether a continuous line of data is to be displayed or if individual measurements are to be displayed as points or bars.
TIM	To expand or reduce the time scale being used for data plotting this operator is picked first and then one of the following is picked as appropriate:

Dy	Days,
HR	Hours,
MN	Minutes,
SC	Seconds,

depending on the current scale, the time period is expanded or reduced relatively.

DUL	This operator is used to indicate when two sets of data for the same time period are to be scanned simultaneously.
EFN	The edited file name is assigned after choosing this operator.
←—┼—→	This light symbol is used to increase, decrease or stop the data scanning rate.

4.1.4 Create Mode

When the create mode is specified by the user, he is presented with a list of the create sub-modes as shown in Figure 23. He may then indicate the desired sub-mode by pointing the data tablet stylus at any portion of a sub-mode name appearing in the display.

ABCDEFGHIJKLMN
OPQRSTUVWXYZ
01234567890
- . , SP

RE
ER
CL

ANA
CRE
DAT
OFF

CREATE MODE

- SYMBOLS
- COMPUTATION SEQUENCES
- GRAPHICAL REPRESENTATIONS
- REPORTS
- STRATEGIES
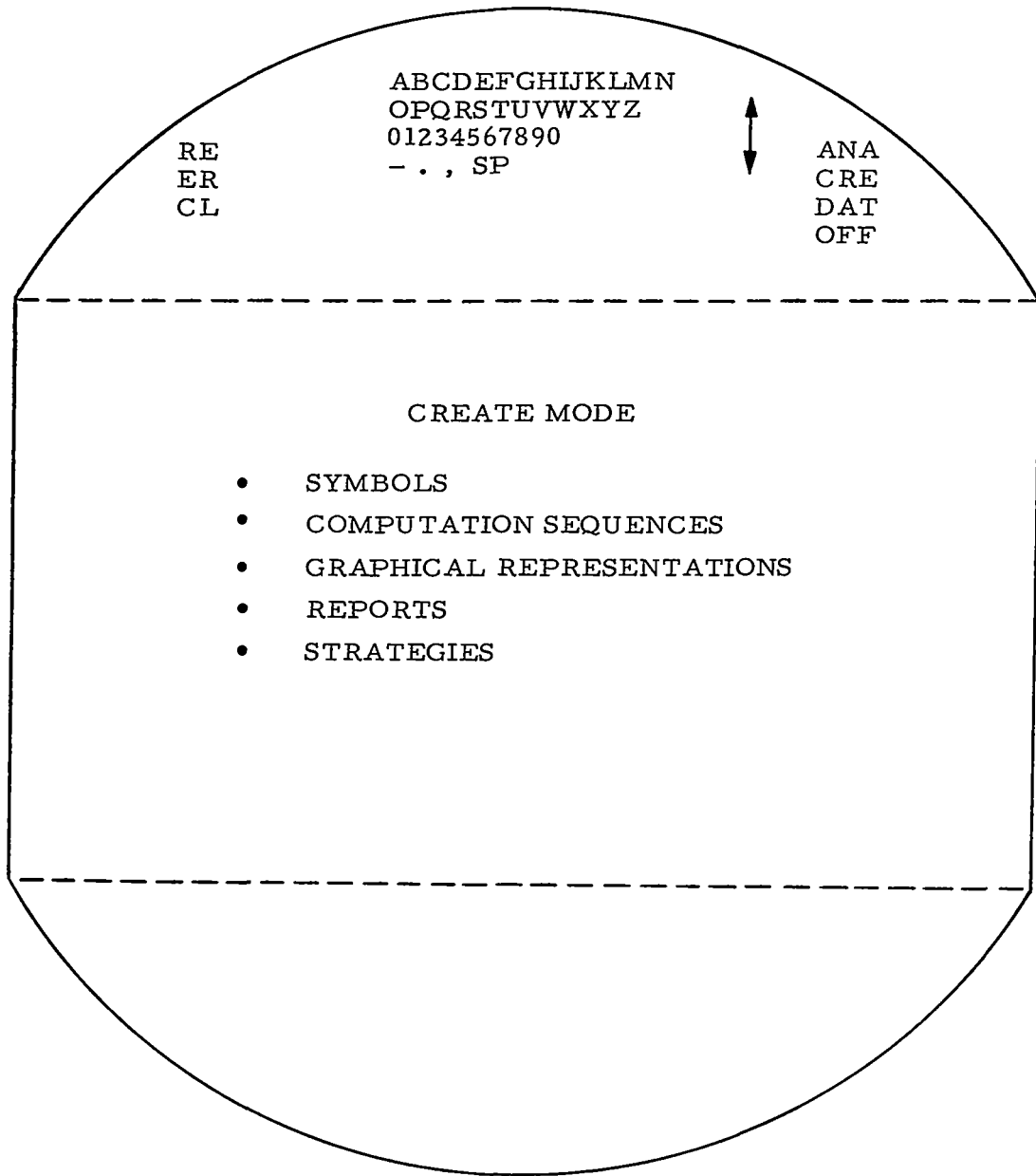
FIGURE 23   CREATE MODE

4.1.5   Character Set Generation Sub-Mode

There are four basic character sets provided by the system; these include the upper and lower case English alphabet, the upper and lower case Greek alphabet, digits 0 thru 9 and certain control and punctuation characters.

In the character set generation mode, the experimenter may use any of the basic character sets plus a free hand drawing capability to create his own unique character set.

Characters are created by free hand sketching in a box displayed on the screen as shown below.
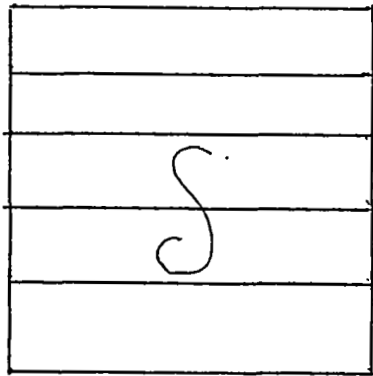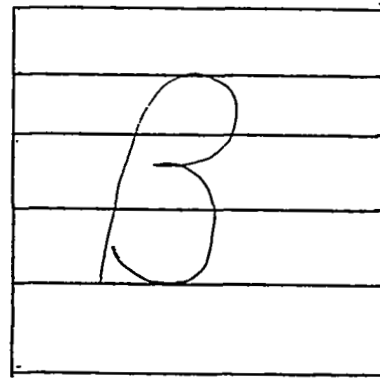
Lower Case Figure   Upper Case Letter

The guidelines are provided to enable the experimenter to indicate the relative size he desires for his character in relation to the ones provided by the system.   Thus, for example, a subscript and superscript generating ability is provided.

SET   When a constructed figure is to be included in
          the experimenter's character set, this operation
          is chosen.   The indicated character will then
          appear along with the other characters of the
          experimenter's unique set in a size proportion-
          ate to the basic character sets.

ABCDEFGHIJKLMN
OPQRSTUVWXYZ
0123456789
RE   − . , SP   ↕   ANA
ER   CRE
CL   DAT
                                           OFF

─── f(A)

SET   f( )
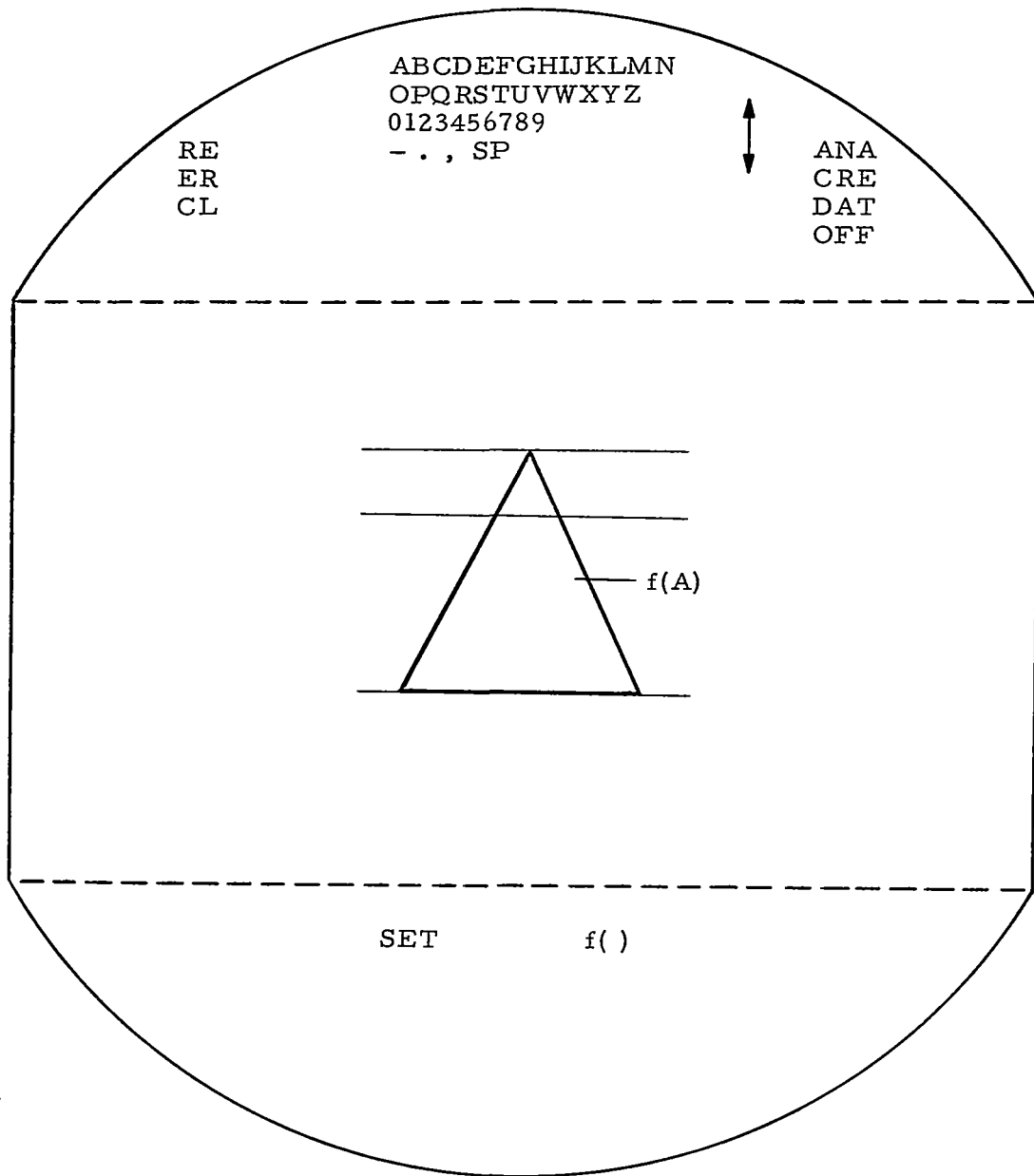
FIGURE 24   CHARACTER SET GENERATION SUB-MODE

f ( )   For specifying a special meaning to a part of a
                symbol where this meaning will be defined in
                either the graphic or math DEF SUB-MODES.

4.1.6   Mathematical Computation Sequences Definition Sub-Mode

This sub-mode provides a language for developing compu-
tational sequences for data manipulation and reduction. In order not to
require the user to learn a formal algebraic language computations can
be specified with normal mathematical notation. The feasibility of this
concept has been demonstrated[38] using a modified flexowriter. Al-
though the recognition problem is different for the CRT input method
using a data tablet, the language parsing problems are the same. In the
proposed language, the feature of implied array arithmetic provides a
powerful means for manipulation of large data arrays with a minimum
of program notation. See Figure 25.

+ (Add)   Calculate $X_i + Y_i$.

- (Subtract)   Calculate $X_i - Y_i$.

* (Multiply)   Calculate (X_i) (Y_i) if (X) and (Y) have the
                 number of elements, otherwise calculate
                 (X_i) (Y_1) or $(X_1)(Y_i)$ if (X) or (Y) consist of
                 a single element.

/ (Divide)   Calculate $(X)/(Y)$. If (X) and (Y) have
                 the same number of elements, $(X_i)/(Y_i)$
                 is calculated. If (Y) consists of a single
                 element then $(X_i)/(Y_1)$ is calculated.

↑   Calculate X^n. The operator does not
                 appear in the equation and the exponent
                 appears to the upper right of the number
                 and is smaller.

Σ   Calculate ΣX_i.

```
                    ABCDEFGHIJKLMN
                    OPQRSTUVWXYZ
                    0123456789           ↕        ANA
   RE               - . , : SP                    CRE
   ER                                             DAT
   CL                                             OFF
```

```
   √     +    <    SUB   | |    DL    EXP. OP.
   Σ     -    >    EXP   [ ]    SN    EXP. OP.
         /    ≤    LOG   ( )    IF    EXP. SQ.
         ↑    ≥    SIN   CY     BY
              =    COS   SQ     CA
              *    CL    SOP
```
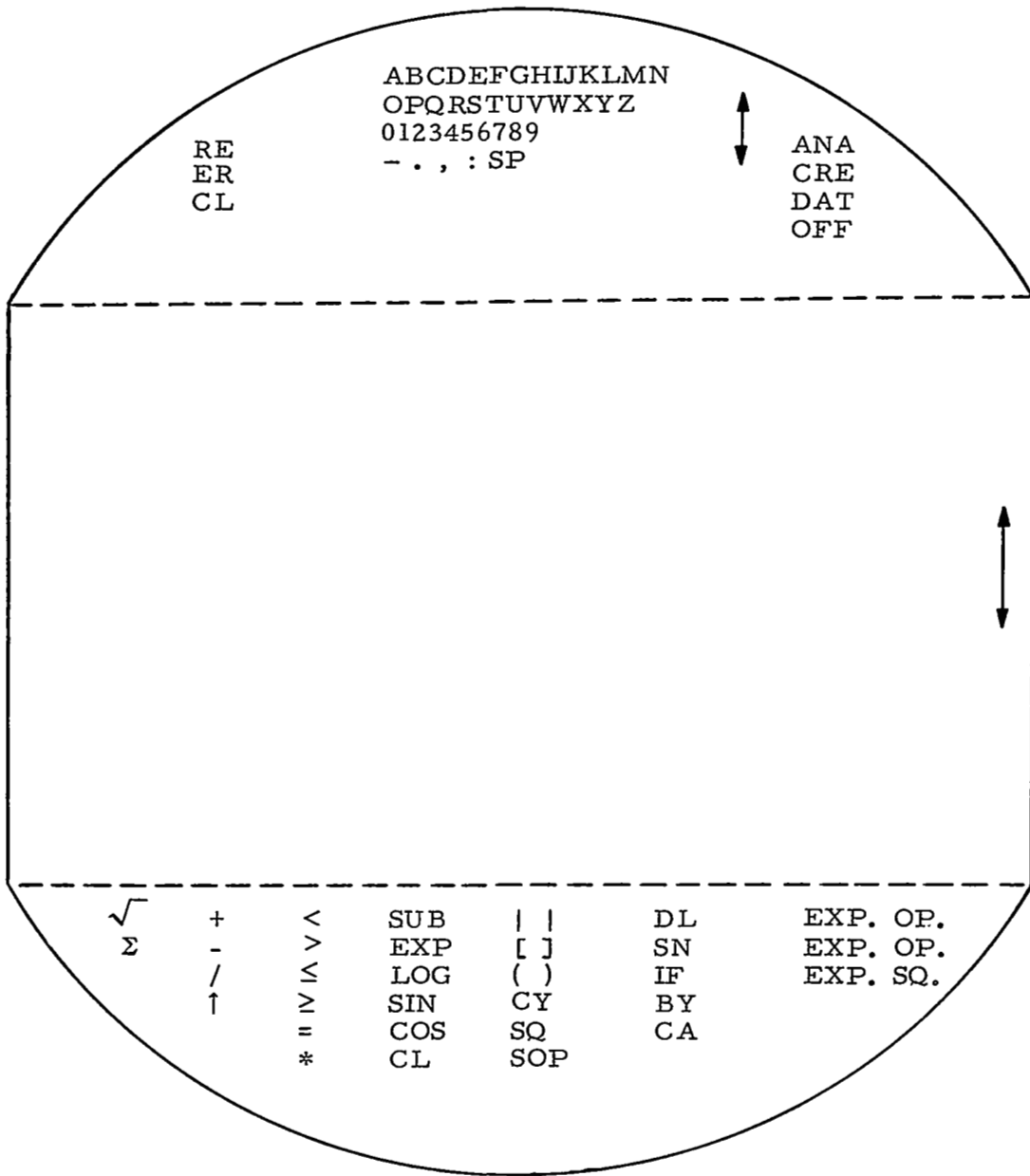
FIGURE 25   MATHEMATICAL COMPUTATION DEFINITION
             SUB-MODE

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SUB	Used to indicate a subscript for a variable.
EXP	Calculate e^{X_i}.
LOG	Calculate $\log_{10} X_i$.
LN	Calculate $\log_e X_i$.
SIN	Calculate $SIN(X_i)$.
COS	Calculate $COS(X_i)$.
SQRT	Calculate $\sqrt{X_i}$.
=	Equal.
<	Less than.
>	Greater than.
≤	Equal to or less than.
≥	Equal to or greater than.

$<$, $>$, $\le$, $\ge$: to specify limiting values for variables in an equation

| |	For specifying absolute values.
[ ] ( )	For grouping of variables and/or specifying order of operation.
C,Y (copy)	Used to cause the indicated character or group of characters to be reproduced where indicated with the light pen.
SQ (sequence)	For naming an equation or set of equations that perform a specific computation. After a sequence is created, it can become an operator for construction other sequences and strategies.

SOP	Special mathematical operators are created by first picking this operator and then identifying the symbol that will represent the operator and constructing a definition as follows: $\Delta : \ A \ \Delta \ B = A_{i+1} -A_i/B_i.$
SN	For numbering statements.
IF	The IF operator is needed for decision making during the execution of procedures. It is used to test for computational boundries and "if boundry conditions are met, control is transferred to the named statement".
Go To	(SN to transfer control to another area of a processing sequence.)
CA (catalog)	For indicating when a sequence or operator should be included in the experimenter's file.
DL (display library)	This will have the names of mathematical routines within the system library displayed and the experimenter can pick any of these for inclusion as an operator for himself or to have it expanded and explained by the system.
BY	For incrementing a subscript by other than + 1.

NOTE: Each line of code will be parsed as much as it is finished (i. e. , when the next line is started).   Any errors in construction of a statement will be indicated.   A period denotes end of a line of code.

4.1.7 Create Graphical Representations Sub-Mode

The graphical representation sub-mode permits the experimenter to construct the type of reference system in which he wants his data displayed. The operators in this sub-mode include many of the basic two- and three-dimensional coordinate systems plus a drawing capability for modifying these systems. Complex representations may be constructed through the use of the function operator (f ( )) with the mathematical definition of the function being made in the mathematical computations definition sub-mode.

Two-dimensional rectangular coordinate system (X, Y).

Two-dimensional polar coordinate system (ρ, θ).

Two-dimensional grid (X, Y).
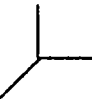
Three-dimensional rectangular coordinate system (X, Y, Z).
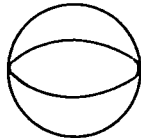
Three-dimensional polar coordinate system $(\rho, \alpha, \beta, \gamma)$.

Three-dimensional spherical coordinate system (ρ, θ, ϕ).
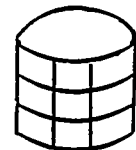
Three-dimensional cylindrical coordinate system (r, θ, Z).

Angle specifier between two intersecting lines.
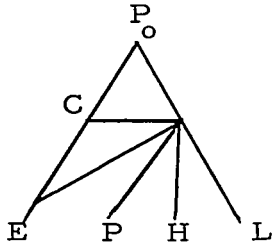
P - Parabolic. These symbols may be used to draw the indicated curves for constructing a graphic representation or adding curves for constant values to the standard re-presentations.

E - Elliptic .

H - Hyperbolic.

C - Circular.

P_o - Point plotting for use as a reference on a graph.

L - Draw line ___ to be used for construc-ting non-orthogonal representations or adding constant value lines to one of the standard representatives.

f ( )   For specifying a modifying constraint on a line or curve of a graph of a special type not given in the vasic representations above. The variable function will be defined in the Mathematical Computation Definition Sub-Mode.

NM (Name)   After a projection has been constructed it should be named in a general sense for future reference when constructing a strategy. In this way, once a basic pro-jection has been constructed it can be used in different strategies without going through the basic construction process each time.

CY   Copy a symbol at point indicated.

ABCDEFGHIJKLMN
OPQRSTUVWXYZ
0123456789
- . , SP

RE
ER
CL

ANA
CRE
DAT
OFF

f( )
NM

CY
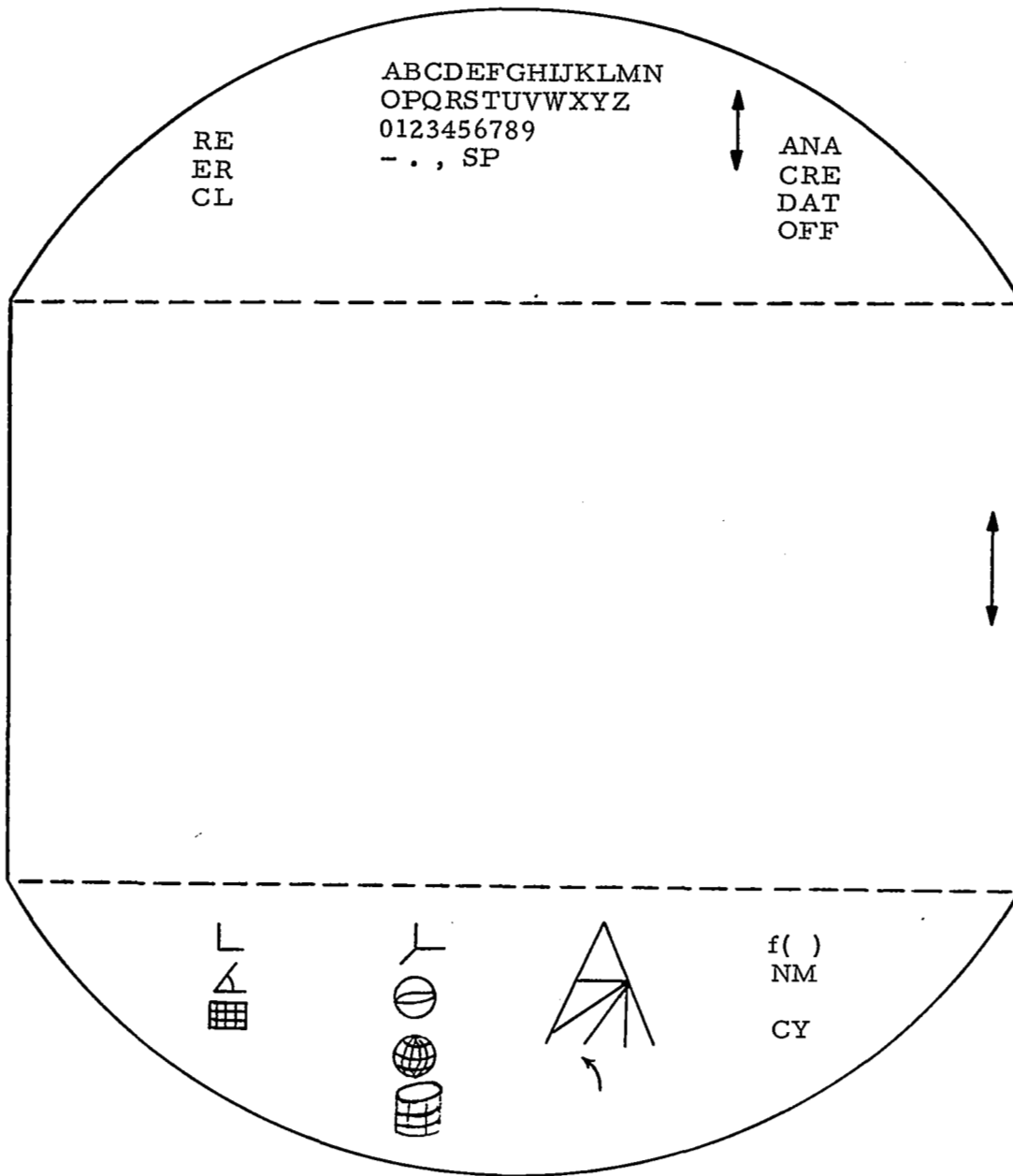
FIGURE 26   GRAPHICAL REPRESENTATION DEFINITION
SUB-MODE

4.1.8 Strategy Definition Sub-Mode

The purpose of this mode is to tie the data manipulation sequences (math computations) and graphic data displays into a logical grouping and sequence of operation. The sequences defined will serve as operators for conducting data analysis; therefore, the experimenter can control processing at whatever level he desires or make it almost automatic by including many sequences and displays in a single strategy operator. See Figure 27.

The strategy definition sub-mode has two sets of operators, one for tailoring and defining computation sequences and one for tailoring and defining graphic data representations.

After computation sequences and data displays are specified as prescribed in their respective sub-modes below, they may be combined to form various strategies in the master strategy defining mode.

This mode has as operators the names of all the computational sequences defined in the computational sequences sub-mode and the data display strategy sub-mode plus the following.

STRN   STRATEGY NAME - for naming strategies (linking a strategy to a symbol). After the strategy name is defined, all of the computational sequences and displays are chosen in their order of operation.

EXP   EXPAND - to provide the next level of detail for the indicated sequence or display.

CMP   Computation sequence operator symbols are displayed when this option is specified.

DDS   Data display strategy defining operator symbols are displayed when this option is specified. (Figure 28). These include the following.

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```
ABCDEFGHIJKLMN
OPQRSTUVWXYZ
0123456789
-.,SP
```

RE
ER
CL

ANA
CRE
DAT
OFF

COMP. SEQ.	DISP. REP.	STRN
COMP. SEQ.	DISP. REP.	EXP
COMP. SEQ.	DISP. REP.	CMP
COMP. SEQ.	DISP. REP.	DDS
COMP. SEQ.	DISP. REP.	
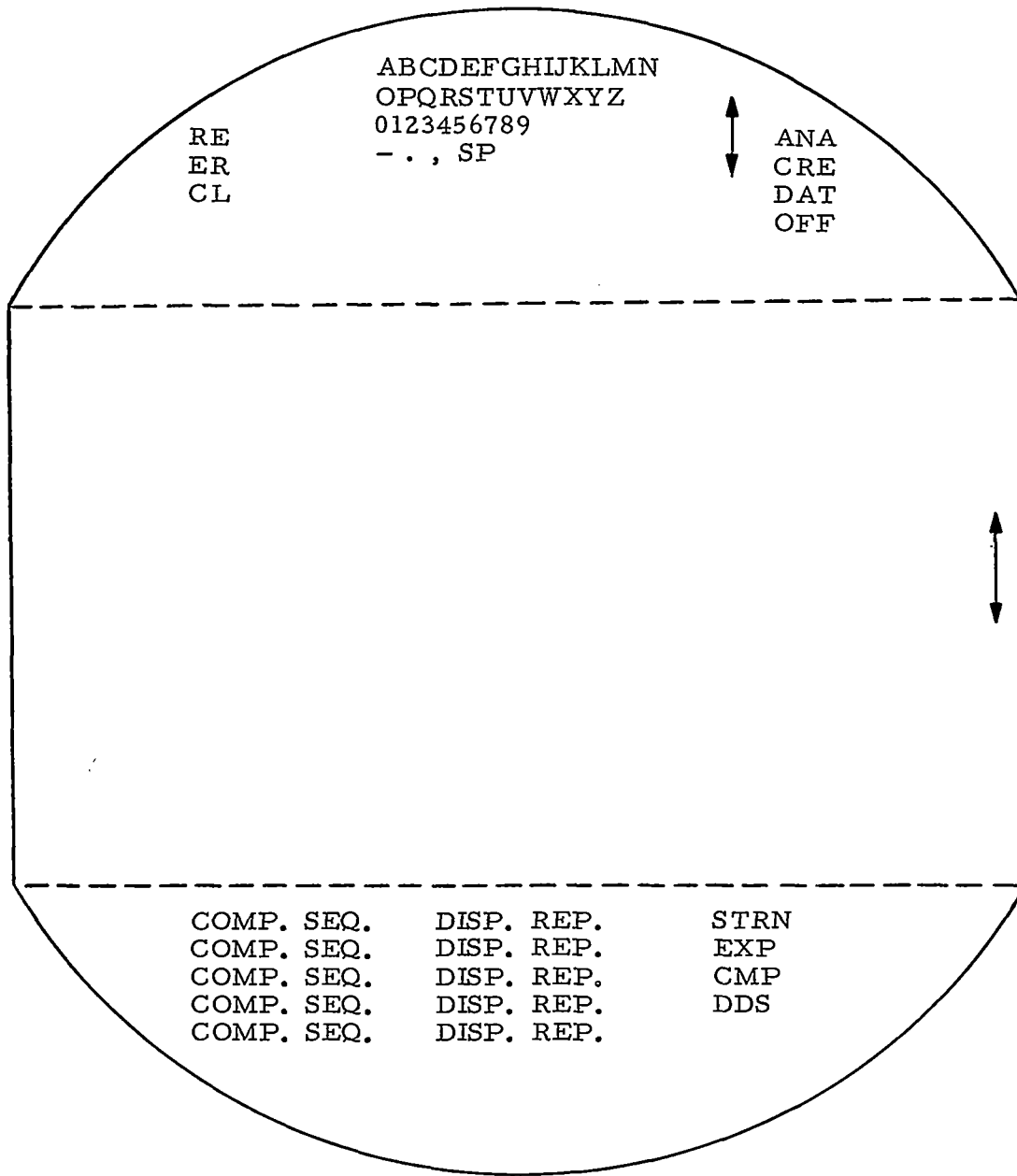
FIGURE 27   STRATEGY DEFINITION SUB-MODE

```
           ABCDEFGHIJKLMN
           OPQRSTUVWXYZ
RE         0123456789              ANA
ER         - . , SP               CRE
CL                                DAT
                                  OFF




DISP. REP.      RA                      DS
DISP. REP.      LO
DISP. REP.      LI
DISP. REP.      SPE
                CC
                LA
```
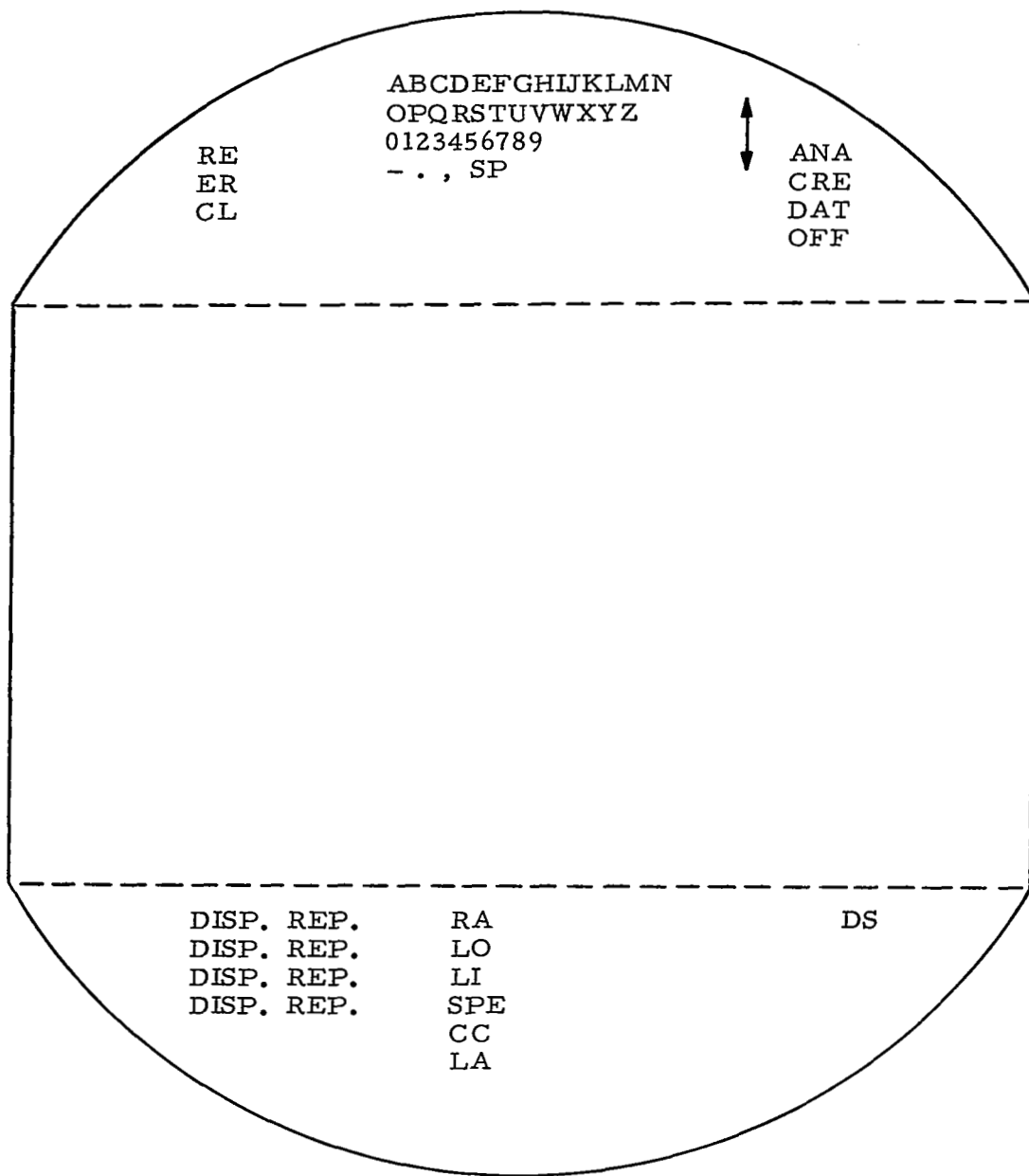
FIGURE 28   STRATEGY DEFINITION SUB-MODE,
            DISPLAY SEQUENCES

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	The graphical representations defined by the experimenter.
RA	RANGE of values to be plotted on a given axis.
LO LI	LOG LINEAR } Specification of type of scale to be used for each axis.
SPE	SPECIFY variables to be plotted on a particular axis.
CC	Color Coding data values of specified variables or other portions of a display.

The following is an example of the use of the color coding operator.

VARIABLE	COLORS	MAX VALUES
ΔX	– ϽȢ + Red Magenta Blue	–10 to + 10
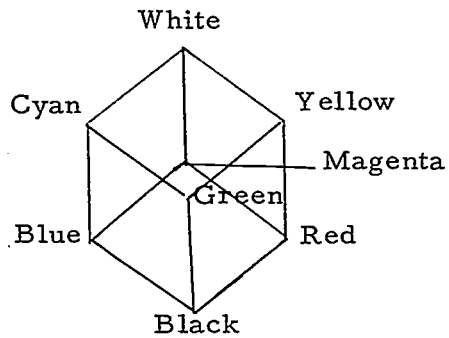
LA	LABEL of display for use in specifying its sequence in a strategy or referring to it during an analysis session.
DS	Specification of data source for values of variables to be plotted.

The data source operator will generate
the following operators for specifying the
method of data input:

EXEC - To be specified by the experi-
menter at the time of execution
of the strategy which would
provide manual plotting,

DATA - To be supplied by the system
from data specified by the experi-
menter in the DATA SPECIFI-
CATION MODE.

COMP - To be supplied as output from a
computational sequence.

Plotting mode of data is indicated by choosing either the

PT - POINT   or
LN - LINE   Operators.

To use a graphical representation to generate data for in-
put to a computational sequence the manual input option is specified for
input, and whenever the representation is encountered in a sequence it
will be displayed and wait for the appropriate operator action.

Computation Sequences strategy defining operators: Fig. 29.

_____ Sequences of computations defined by the
experimenter.

_____ The basic set of system math operators as de-
fined in Section 4. 1. 6

The experimenter's uniquely defined operators.

DS   Specification of data source for input to the
computation sequence for all data variables.

The data source operator will generate the following operators for
specifying the method of data input:

EXEC   To be specified by the experimenter at the
time of execution of the strategy.

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ABCDEFGHIJKLMN
OPQRSTUVWXYZ
0123456789
- . , SP

RE
ER
CL

ANA
CRE
DAT
OFF

EXP. COMP. SEQ.	$\sqrt{}$	$\leq$	| |	DL	DS
EXP. COMP. SEQ.	Σ	$\geq$	[ ]	IF	
EXP. COMP. SEQ.	$+$	$=$	( )	BY	
EXP. PRIMITIVES	$-$	SUB	CY		
EXP. PRIMITIVES	$/$	LOG	SQ		
	$\uparrow$	EXP	CL		
	$<$	SIN			
	$>$	COS			
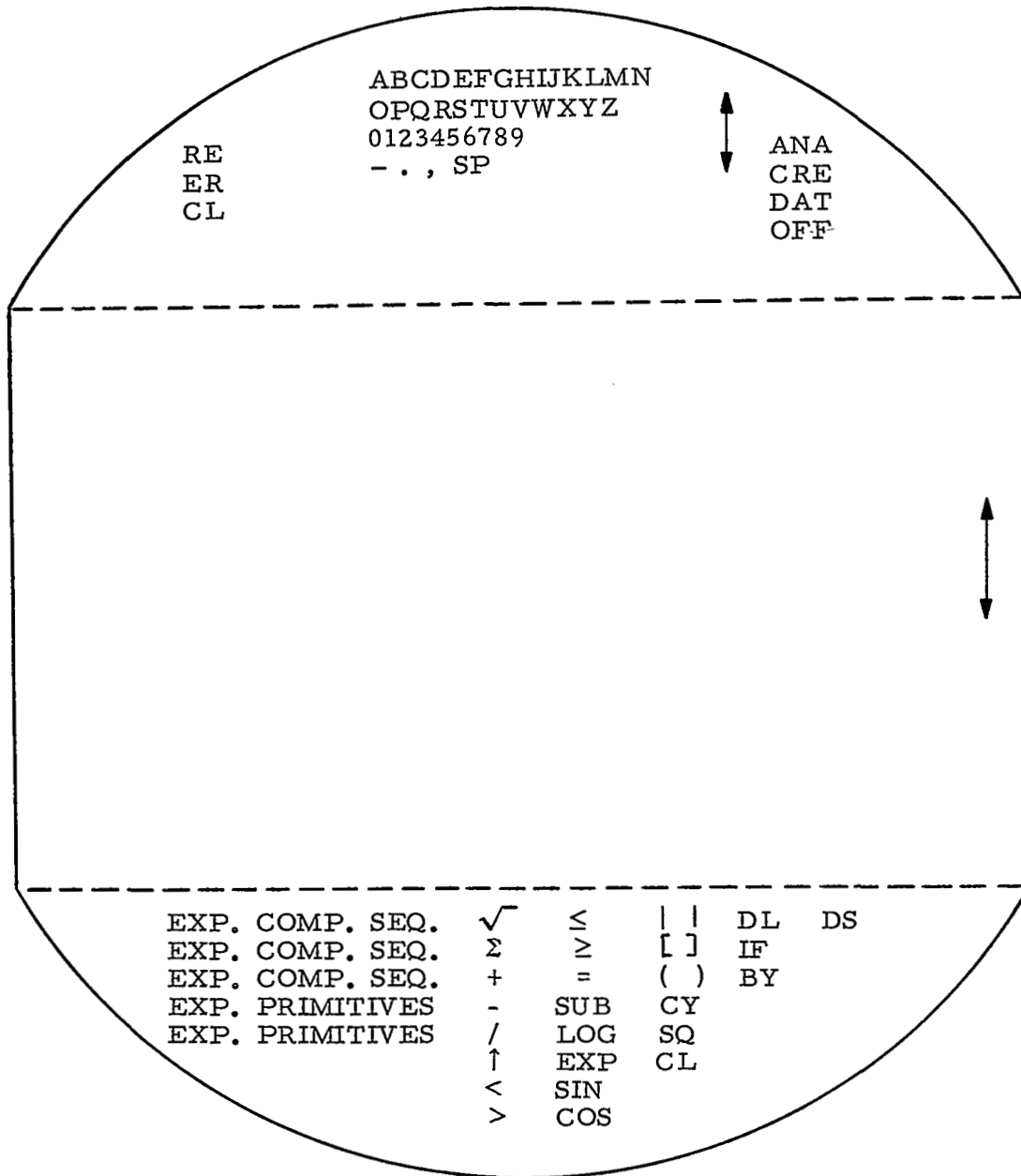
FIGURE 29   STRATEGY DEFINITION SUB-MODE,
            COMPUTATION SEQUENCES

DATA   To be supplied by the system from data speci-
fied by the experimenter in the DATA SPECI-
FICATION MODE.

GRAPH   To be taken from a graphical representation
which would generally be hand plotted.

COMP   To be supplied from the output of another com-
putation sequence.

4.1.9   Report Generation Sub-Mode

The purpose of this mode is producing printed reports of
the results of analysis performed using the on-line system.   The op-
erators for this sub-mode will include the experimenter's unique com-
putational sequences and data displays, the standard and unique mathe-
matical symbols, and an efficient method for generating text.

One method for entering text using a CRT to display
characters and an input device that can pick individual characters is
the "probability typewriter"[39].   For example, in the operator area of
the CRT shown in Figure 30 is a group of apparently unrelated letters.
The first letter M is the last letter entered in a line of text being con-
structed by a user.   The next five letters are the ones most likely to
be used after M based on a statistical survey of technical report text,
(Appendix XI).   The next operator, + , is picked by the user if the
letters displayed are not the ones he wants to use next.   (He could also
pick the appropriate letter from the alphabet displayed at the top of
the screen.)   The last operator in the group is a space character.   Al-
though this method of report generation is not as fast as a typewriter,
the error rate is low.   The capability to extend this technique to in-
clude graphical information and mathematical sequences that have been
previously defined is an added advantage.

4.1.10   Analysis Mode

In the analysis mode (Figure 31) the experimenter can
direct the operation of various strategies upon his data and view the

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```
       ABCDEFGHIJKLMN
       OPQRSTUVWXYZ
       0123456789
RE     - . , SP                 ANA
ER                              CRE
CL     : ;                      DAT
                                OFF
```

M	I	O	E	A	U	+	SP

```
MATH SYMB.    EXP. MATH SEQ.    EXP. DISP.
              EXP. MATH SEQ.    EXP. DISP.
              EXP. MATH SEQ.    EXP. DISP.
```
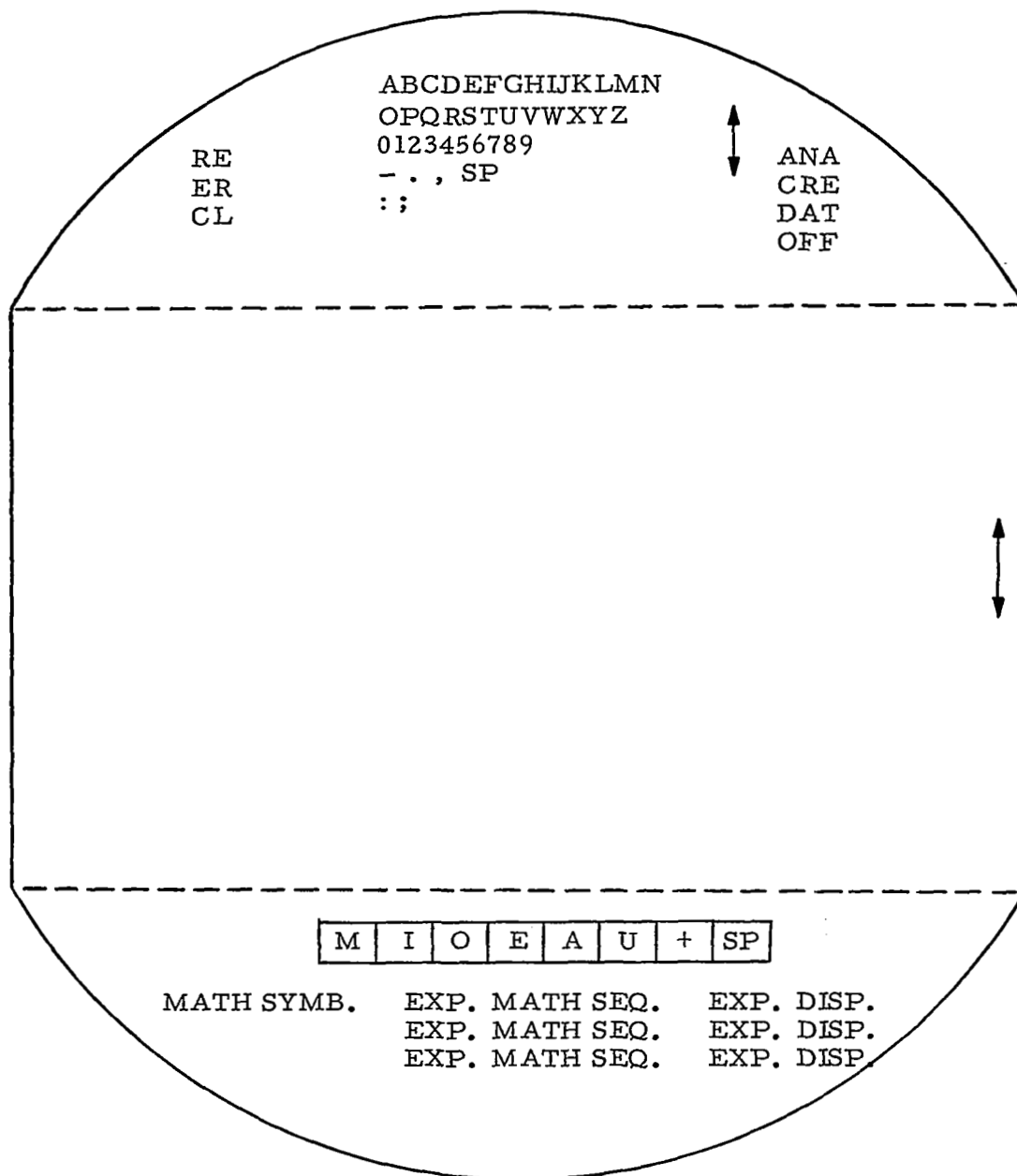
FIGURE 30   REPORT GENERATION SUB-MODE

ABCDEFGHIJKLMN
OPQRSTUVWXYZ
0123456789
- . , SP

RE
ER
TP CL

ANA
CRE
DAT
OFF

EXC   EXP. STRAT   EXP   VAL   MOD
       EXP. STRAT   SAV   MOV   ROT
       DATA NAMES   MAG□   - — 0 — +
       DATA NAMES   PRT
                            PLT
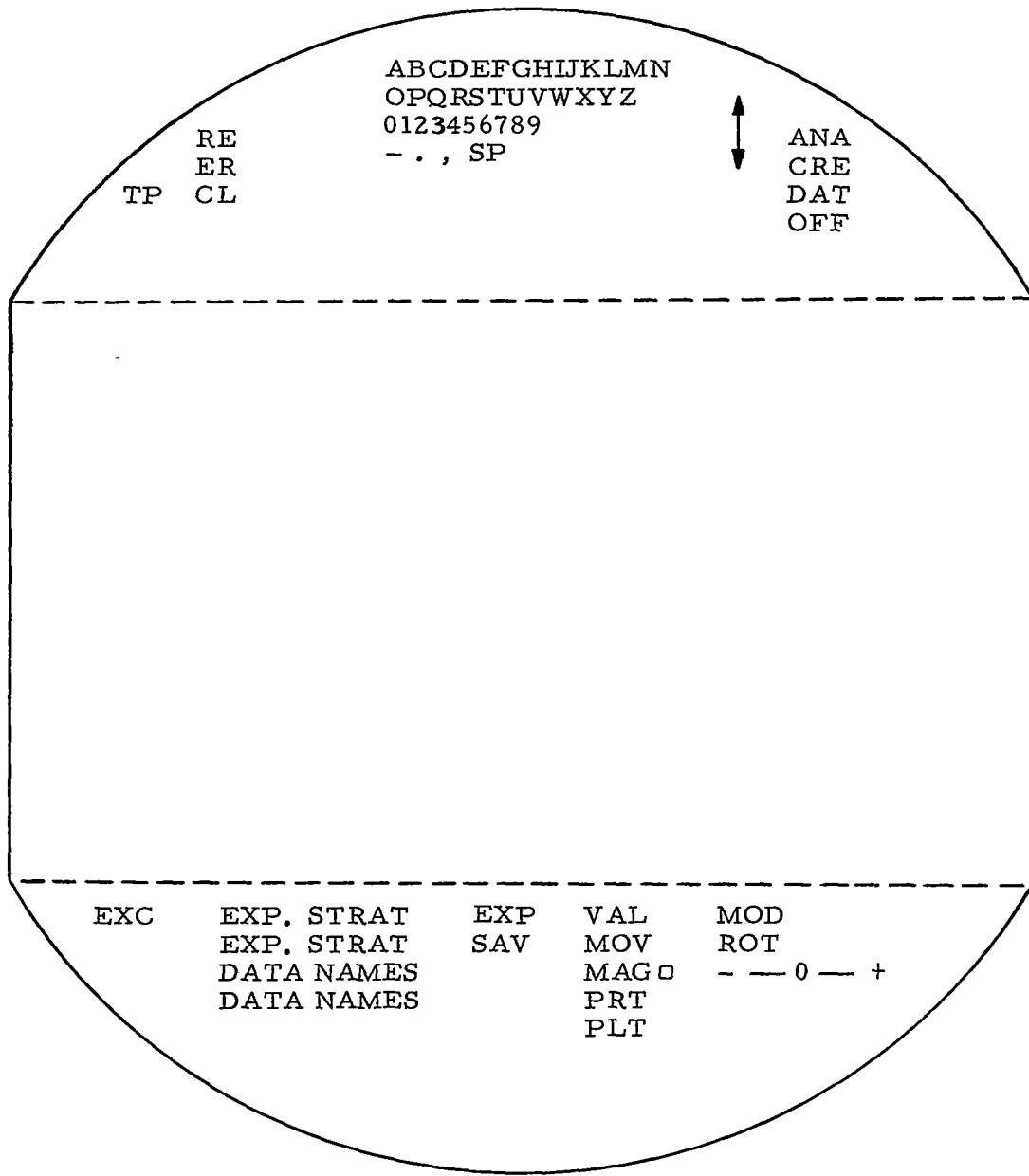
FIGURE 31   ANALYSIS MODE

results in graphical display form. This approach is similar to the menu idea explored by Goodenough[40], but has more flexibility for directing the operation of computations and viewing intermediate results. It is possible to obtain intermediate results as computations are performed and to even change parameters or operations before each execution of a computational sequence. The graphical display can be rotated about any axis and specified data can be magnified for closer observation. The operators for this mode are as follows.

_____ The experimenter's strategies.

EXP (expand)
Provides the ability to step through the components of a strategy (computational sequences and display projections).

VAL
By choosing this operator and then either a sequence name or variable name, its value will be displayed each time the strategy, sequence, or equation is operated.

MOD
When a computation sequence or a display projection has been expanded and this operator is chosen, the appropriate operators for constructing these items will appear in the operator area of the scope allowing the required change to be made.

SAV
This operator will cause the current results displayed on the CRT and the strategy (or strategies) used to obtain this result to be stored in the experimenter's reference file.

MOV
Move the indicated figure in the direction indicated with the pointing device. With this operator and the MAG operator a display can be

shrunk and moved to the side of the CRT to
allow display with another graph or equation.

ROT   This operator can be used to rotate a data dis-
play. For a two-dimensional display, the axis
of rotation is taken to be the one perpendi-
cular to the display surface. The (0, 0) point
of the x-y coordinate system will be chosen if
a point is not picked by the user. In a three-
dimensional representation, the axis of rotation
must be identified by pointing to it. The angle
and direction of rotation for either case is
specified by an arc-like movement of the point-
ing device.

MAG   To use this operator the window (□) is position-
ed, using the pointing device, and then expand-
ed using the gas pedal (-_____0_____+) until
the area of interest is enclosed within the win-
dow. The MAG operator is then indicated and
the gas pedal is used to indicate either a mag-
nification or reduction in size of the figure en-
closed by the window.

EXC   In order to have a strategy operate on a set of
data, this operator is chosen first and then the
strategy to be executed. The data set to be
processed is then identified. Also this opera-
tor is used to continue execution when operating
in the mode for viewing intermediate results.

PRT   To have the values of a data set of interest
recorded on hard-copy, this operator is chosen.

PLT   To have a graphic representation recorded on
hard-copy this operator is chosen.

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DN   Data Names .

——   TP   Save display file (everything on scope) for
                   off-line reproduction.

4. 1. 11 Sign Off Procedure

      This mode is entered when the user wishes to terminate a
session.   Rather than save every item of information created during a
session and have it put into the user file, the user is asked to select
those items which are important.   This prevents the user file from
becoming cluttered with unneeded data.

      Shown in Figure 32 is the first of three displays seen
during log-out.   The user is presented with lists of the four types of
data which he may want to save in his user file.   The options available
and procedures for saving files are discussed below.

      SAVE - The SAVE operator is used to tell the system
that "the following things pointed at should be
placed in my user's file." Once something to
be saved has been pointed at, it will be under-
lined.   This positive feedback assures the user
that he is being understood.

      PROCEED - This operator advances the log-out pro-
cedure to its next state (Figure 33).   Any items
which have not been saved can still be retained
by returning from that next state.

      EXPAND - The EXPAND feature allows the user to re-
turn to Analysis Mode where a full set of func-
tions are provided to examine an item in greater
detail.   When he is satisfied, a return to log-out
mode will bring him to the same conditions in
which he left it.

      The second display in sign-off is redundant but is in-
cluded to force the user to be certain that he has remembered to save

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DURING THIS SESSION YOU HAVE
CREATED THE FOLLOWING:

SYMBOLS   DISPLAYS   MATH SEG.   STRATEGIES

SAVE PROCEED EXPAND

FIGURE 32   SIGN-OFF FIRST FORMAT

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DURING THIS SESSION YOU HAVE
CREATED & NOT SAVED THE FOLLOWING:

SYMBOLS   DISPLAYS   MATH SEG.   STRATEGIES

ARE YOU FINISHED?

YES   NO

FIGURE 33   SIGN-OFF SECOND FORMAT

```
              YOU HAVE BEEN LOGGED OUT

FOR THIS SESSION:
     CPU TIME USED          _____
     CONSOLE TIME USED      _____

FOR THIS ACCOUNTING PERIOD:
     CPU TIME REMAINING        _____
     CONSOLE TIME REMAINING    _____
```

FIGURE 34   SIGN-OFF FINAL FORMAT

all items of interest. This display is shown in Figure 33. The user has only two options at this point. Either he recognizes that he forgot to save something and points to NO, which returns him to save-delete sub-mode, or, he is satisfied and points to YES.

Once the user is finished, the display shown in Figure 34 will appear. At this point final bookkeeping for this session has been made, and the user has been released from the system. Any further usage of the system will require logging in again.

4.2   USER LANGUAGE PROCESSOR

The experimenter will probably be operating in Analysis mode most of the time. Here, the commands to the computer are quite simple. They consist of pointing actions which can be stated in the English format: "Apply Strategy A to Data Set B." The available strategies and data sets appear on the user console in lists.

From a user point of view, strategies are a mix of computational sequences and display representations, which have been defined by user actions while using the create sub-modes. Presented in Figure 35 is a tree which shows a typical user analysis file. It contains three strategies one of which has been expanded to indicate its hierarchical makeup. One point of importance is that new functions (i. e., user defined primitives) are defined in terms of equations. But, since equations are made up partially of system primitives and/or user primitives the strategies have some form of recursive definition. This allows the user to build great power into the definition of a single symbol. The only constraint on definition of new functions is that they be defined in terms of previously defined procedures.

To understand the processing which must be done to execute the user's commands, we examine the structure of a hypothetical strategy as it would exist inside the computer. Since the user dialogue is a set of sequential actions, the user action file contains certain
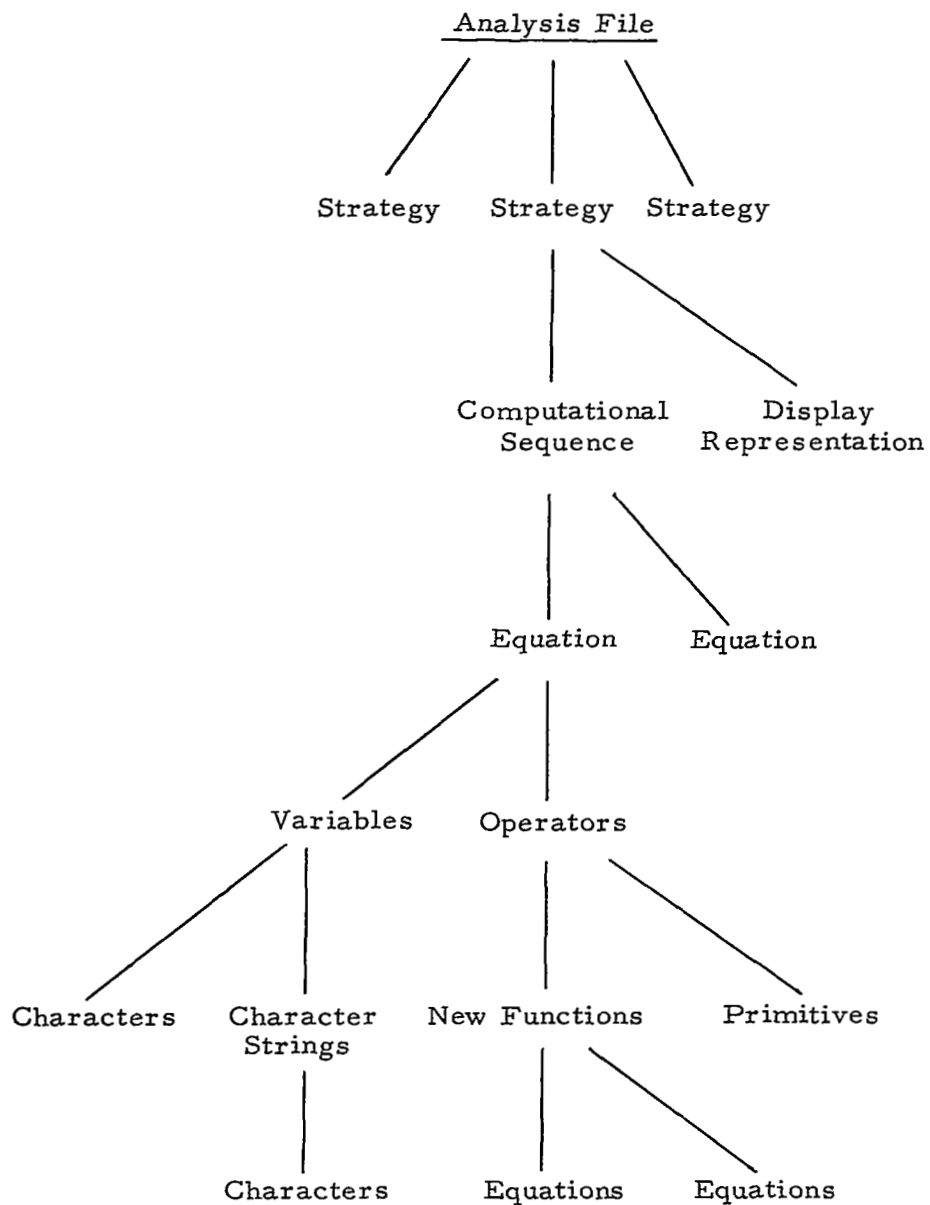
FIGURE 35   HIERARCHICAL MAKEUP OF TYPICAL
ANALYSIS FILE

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Strategy:

$$X \quad = \quad \Sigma \quad y \quad / \quad \sqrt{\quad} \quad Z \quad ;$$

Interpreter
Linkage

$= \quad \Sigma \quad VAR \quad / \quad \sqrt{\quad}$ Primitives

Subroutines for Primitives
(I/O, Math, Display):

| Circle | Ellipse | Axes | Perspec. | Transform |

Library Routines
(Provided by Manufacturer):

| Sin Cos | Sq Rt | I/O |
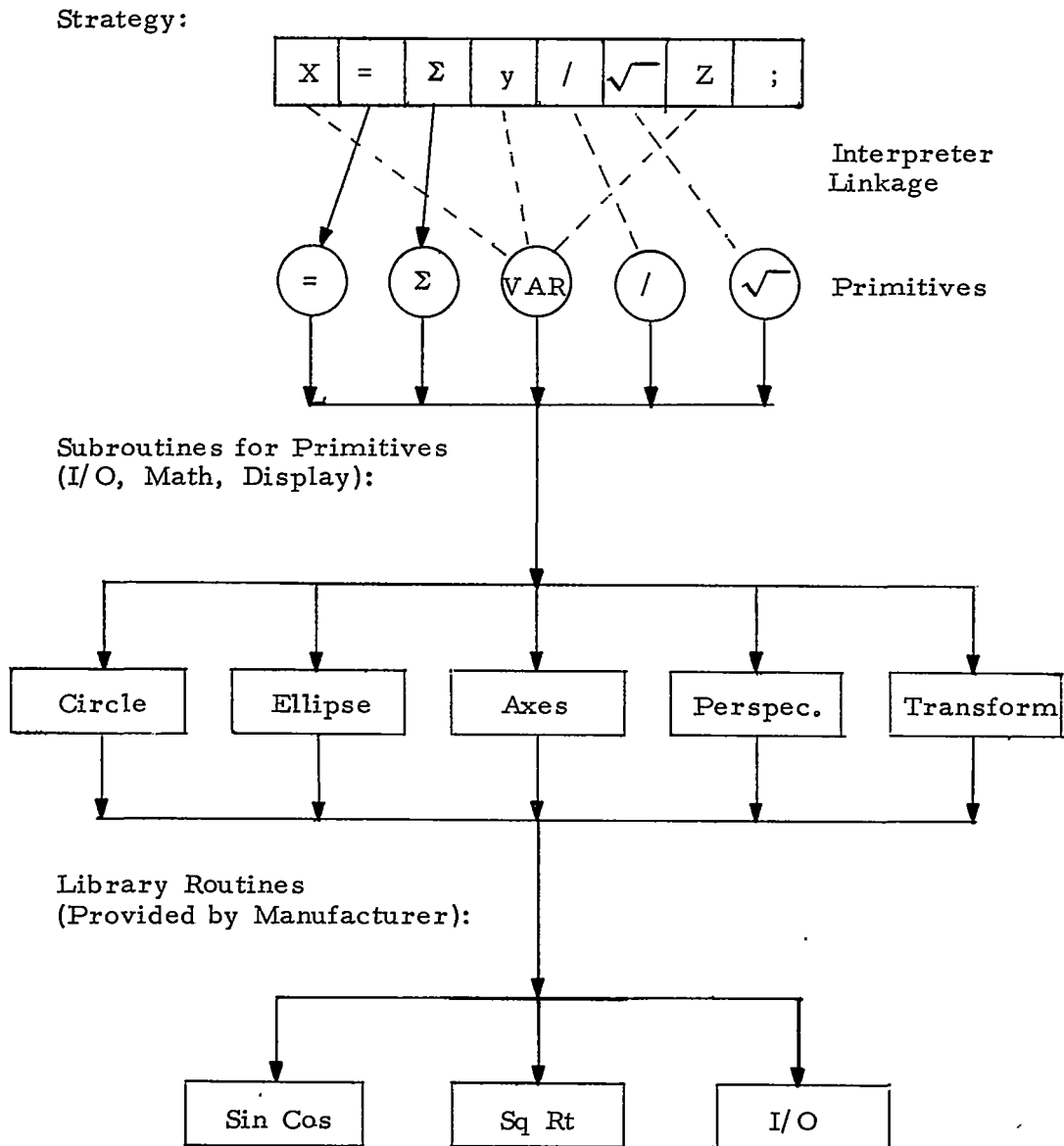
FIGURE 36   A STRATEGY AND ITS CONNECTIONS TO
SYSTEM SOFTWARE

control information which is not useful in language processing. A scan of the user action file is performed to develop a symbol string. This symbol string, plus certain parameters extracted from the user action file may be considered a strategy, as seen by the user language processor.

Shown in Figure 36 is a part of a strategy (i. e. , a partial symbol string) and the implicit connections to the rest of the system software. Each element of the symbol string is tied to a primitive routine with interpreter linkage. The system primitive routines are sets of machine language instructions which have been previously defined and compiled at the time of system development. Since user primitives must eventually be defined completely in terms of systems primitives, each user primitive will, in effect, be linked with many system primitives. Execution of the primitive routines takes place under control of the interpreter. Since there are many similar functions which each of the primitives may be called on to perform, linkages are provided to two. other sub-sets of machine language statements.

Necessary to most system primitives is a set of support functions. Since many primitives will generate displays, do mathematical manipulations, and perform certain I/O functions, a special set of primitive support routines are needed. The primitive routines will be provided with linkage to these routines, which will in turn be given linkage to call upon the library routines.

Most hardware manufacturers provide programming languages to support their equipment. Associated with these languages are library routines which provide computational support for commonly used functions. In the case of this system, they will be machine language procedures for performing commonly used mathematical functions.

4.3 USER-SYSTEM CONVERSATION

The software is designed to provide the on-line experimenter with a system that is easy to use and has very few restrictions in the areas of mathematical notation, data manipulation and data presentation.

To accommodate the design constraint of a single input device and a common working surface for input and display, the software system must anticipate user actions. This is accomplished by dividing the display surface into working and control areas and dividing the choice of control operators into functional groups. In trying to achieve the best mix of flexibility and requirements for user input, valid options are displayed as a list and the user need only point to the item expressing his choice.

For certain types of input, it is not possible to present the user with a list of choices. When content dependent information is necessary, the user is asked to use a fill-in-the-blank type of input.

Finally, if the function to be performed is almost random as in the construction of mathematical equations, then the user is given a list of legal operators and a clean working area to construct whatever process he desires.

Illegal user actions will not cause catastrophic system failure as all of his actions are recorded in sequence and intermediate data is saved to allow efficient back-stepping to a previous condition. Errors detected by the system would be brought to the immediate attention of the user with an appropriate comment as to what would constitute a legal action. In cases where an action may be interpreted by the system in more than one way, an interpretation would be made and then a display generated, asking if the system's interpretation is what the user meant.

4.4 DATA FILES

The practice of data structuring although not extremely new, is not so old that standard terms and practices have become established. Enough has been done, however, to permit adequate definition and specifications for the data structure to be supplied. A structured data base is a collection of data, connected in such a way that the relationship of one item to another is explicit. Data is grouped together because it shares certain common properties or it possesses certain inherent hierarchical structures. The structure should be capable of dynamic growth and modification, and should be capable of being entered from many points. This allows the user (the programmer) to design systems in which subsets of the data can be accessed with a single request.

There exist processors such as CORAL[26], APL[41], and L6[42] which enable the user to arrange the data in specific and meaningful patterns or structures, then manipulate them as he desires. (The user here implies the system programmer or designer.) These can be thought of as systems which exist for building models (structures) to which can be applied transformations and algorithmic procedures.

4.4.1 Experiment Data Base

Presented in Figure 37 is a tree which shows the hierarchy of data which exists in the data base. Although the actual design of this structure is beyond the scope of this work, it seems that some discussion of the type of data available to the user is necessary. As can be seen, the lowest element on the tree is a data set and its associated parameters. It is sufficient here to state that some translation programs may be necessary to get data into a suitable format once it has been requested from the data base. The actual procedures used for this transformation cannot be supplied until time of implementation due to

Data Base

Satellite A   Satellite B   Satellite C

Experiments   Orbit Parameters

Exp #1   Exp #2 ..... Exp #n

Data Set ..... Data Set
#1   #n

1. Procedure Extraction
2. Units of Variable
3. Names of Variables
4. Length of Set
5. Time of Set
6. No. of Variables

Data Parameters
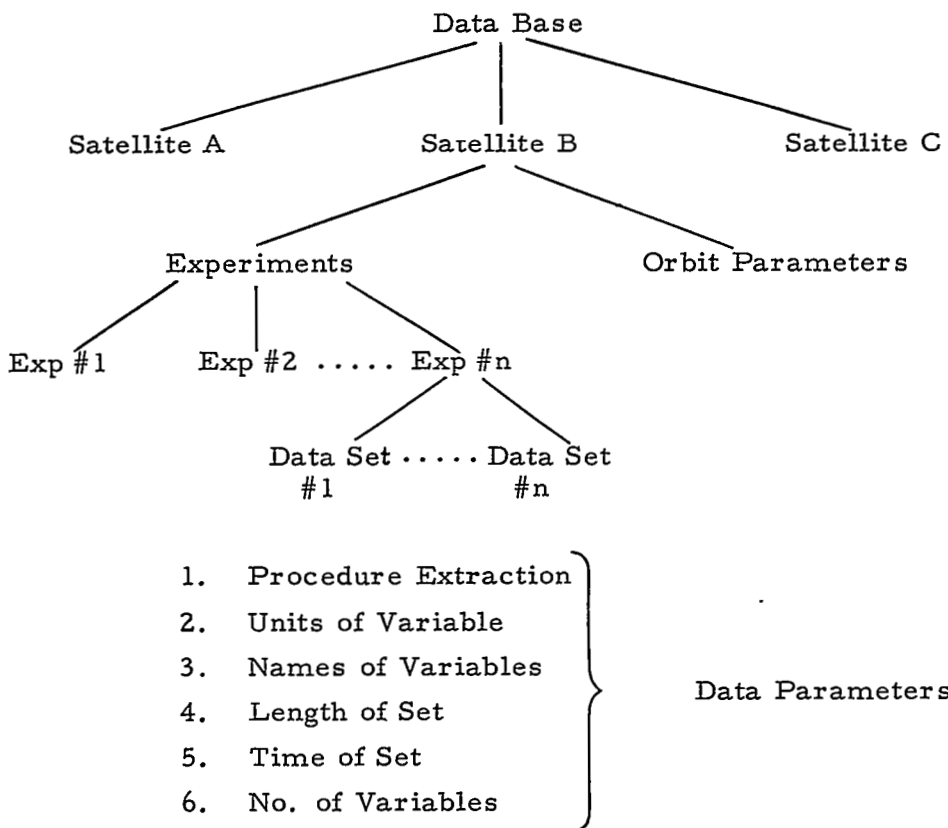
FIGURE 37   EXPERIMENT DATA BASE ORGANIZATION

dependence upon hardware configurations. It should be sufficient to state that description blocks can be supplied which adequately map the contents of the source format.

4.4.2   Display Data Base

In using the computer for graphical input and output, one must rely on the digital representation of drawings. If an active conversation concerning this picture is to take place between man and machine, certain data structuring requirements are necessary. Early work by Sutherland[2] and Ross[43] introduced multidimensional concepts wherein elements were tied to more than one symmetric list or ring. Later work by Roberts[44] refined the work of Sutherland in a list structure macro language.

Unfortunately, most of these structures are designed for application where picture structure is very important in itself. In a data analysis system, a structured display data base is not of equal importance. Structures which would be of help are those which allow the software to more easily process the display file.

4.4.3   User File

The user file exists to allow access to all permanently stored data and procedures which the user needs. These include user created symbols; language string definitions for these symbols; user strategies; and user created data sets.

By having the system fetch user-created symbols during sign-on, any console can be made available to any user. The structure necessary for any particular file can be seen in the tree structure of Figure 38.

The base of the user file tree ties all individual users together. Any particular user (i.e., user n, in Figure 38) can be

USER FILES

User 1............User n

Symbols   Strategies   Data Sets

Disp.   Char.   Oper.   Strat.
Rep.
                          Math   Display
                          Sequences   Representations
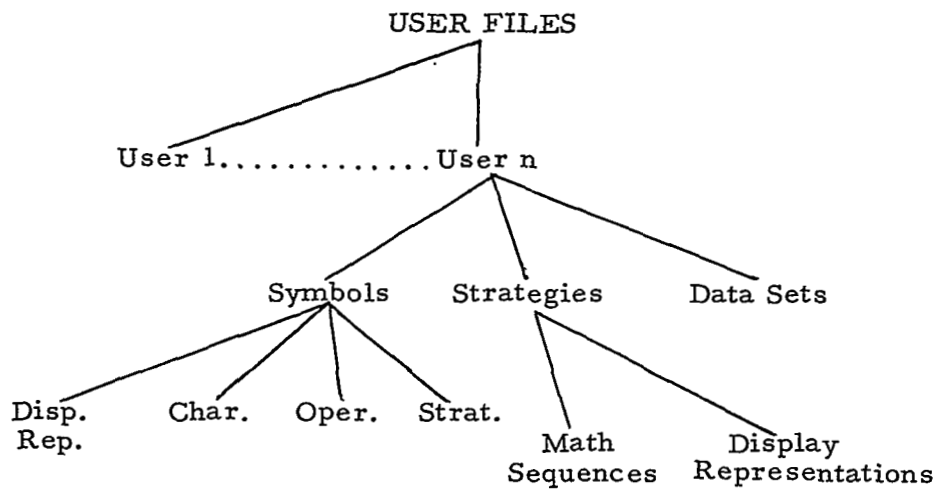
FIGURE 38   TREE STRUCTURE OF USER FILES

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accessed from this point. Each user has three types of information which he generates during a console session. These are symbols, strategies and data sets.

A symbol is any graphic entity or grouping of graphic entities. All symbols will have at least two common properties. There will exist for each, a unique character code (needed for identification during scanning of language strings) and a display command structure which tells the software how to present it on the display console. Symbols which have no definition will exist only in the user character set for use as variables, or in equations, or labels for graphs. If the user has provided definition, the symbol might identify a mathematical operator, a display representation, or a strategy. In this case, the symbol becomes the name of a user defined strategy. The user file must contain pointers to allow these definitions to be linked to the appropriate symbols. Strategies, as they exist in the user file, can be simply represented by a name or identifying symbol, and a list of pointers. These pointers will link the strategies to the individual mathematical sequences and display representations required for their execution. Similarly each unique mathematical sequence and display representation will exist in the user file as a list of pointers to the character and/or symbol strings which define them. It is important that the routines pointed at should be available in high speed storage.

The third main grouping in the user file will be an ordering of user created data sets. At the top of this branch of the tree there will exist a ring of blocks which contain basic descriptions of any particular data set. These blocks can be descriptions of data, similar to those provided in the data base specifications. Although the large data sets which may be required might not exist in the user file per se, pointers will be provided in the description blocks to allow access to them.

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4.4.4 Working File

The working file exists for intermediate storage. It is doubtful that all actions performed during a user session will be of permanent value. Although it is hoped that most sessions are productive, it is predictable that some of the approaches that the user might take will not lead to worthwhile results. Rather than having the user file become cluttered with unwanted procedures and data sets, a record of all actions performed during a session will be stored in the archives. At the end of a session, the user will be given a list of the items he has generated, and will be asked to determine whether he wishes to save them in his user file. If at some later time he decides that he should have saved something which he didn't, a method will exist which allows for re-creation of that particular session. This is accomplished by pulling from the archives the action file for that particular session and having the system re-interpret it. The structure of the working file is an exact copy of that of the user file, and need not be restated here.

4.5 SYSTEM APPROACH

The system presented here is a framework for implementation of the FMS portion of an on-line data analysis system. As shown in Figure 39, the system approach gives an overview of information and control paths which link the main elements of the FMS. The files shown consist of three types: those provided at time of system implementation (primitive system routines, primitive support routines, and library routines); those files created during system usage (working file, user file, and display data base); and the files provided by DMS (central system information, and data base). To discuss the system, we will look at the actions performed by the various system elements in response to user inputs. Given in Figure 40 is a use matrix which shows which files and system elements are needed during operation of the various user modes or sub-modes. Certain common system

elements are not shown here because they are used during every sub-mode and their inclusion in the table would only be repetitious.

4.5.1 User Input

Typically, the user inputs are statements of information or requests for information, and take the forms allowable for the various types of action which may be initiated at the console. These actions are initiated by the user pointing to light symbols or characters on the CRT face.

4.5.2 User Action Analyzer (UAA)

The user's main interest is the analysis of data. All functions (i. e., data formatting, manipulation, presentation and display) are of use only to gain this end. The UAA is the device through which the user talks to the data analysis system. There are two main system elements which are used, and three files which are built during usage of the system. The action decision table aids the UAA in making these choices.

During certain portions of system usage (e. g., building primitive lists), the user will be creating strings of characters and/or symbols which will be translated, interpreted, or compiled at some later time. The action of the UAA at this time is only to update the ULS (User Language String) and the UAF (User Action File) and transfer control to the CDR.

At such time as the user has completed building a primitive list, he will request an execution of these commands. This procedure is controlled by the User Action Executor (UAE).

During the time that input is being prepared for the UAE, the UAA must build up a data structure called the ULS. This is a sequential list of operators and variables in the form of language statements.
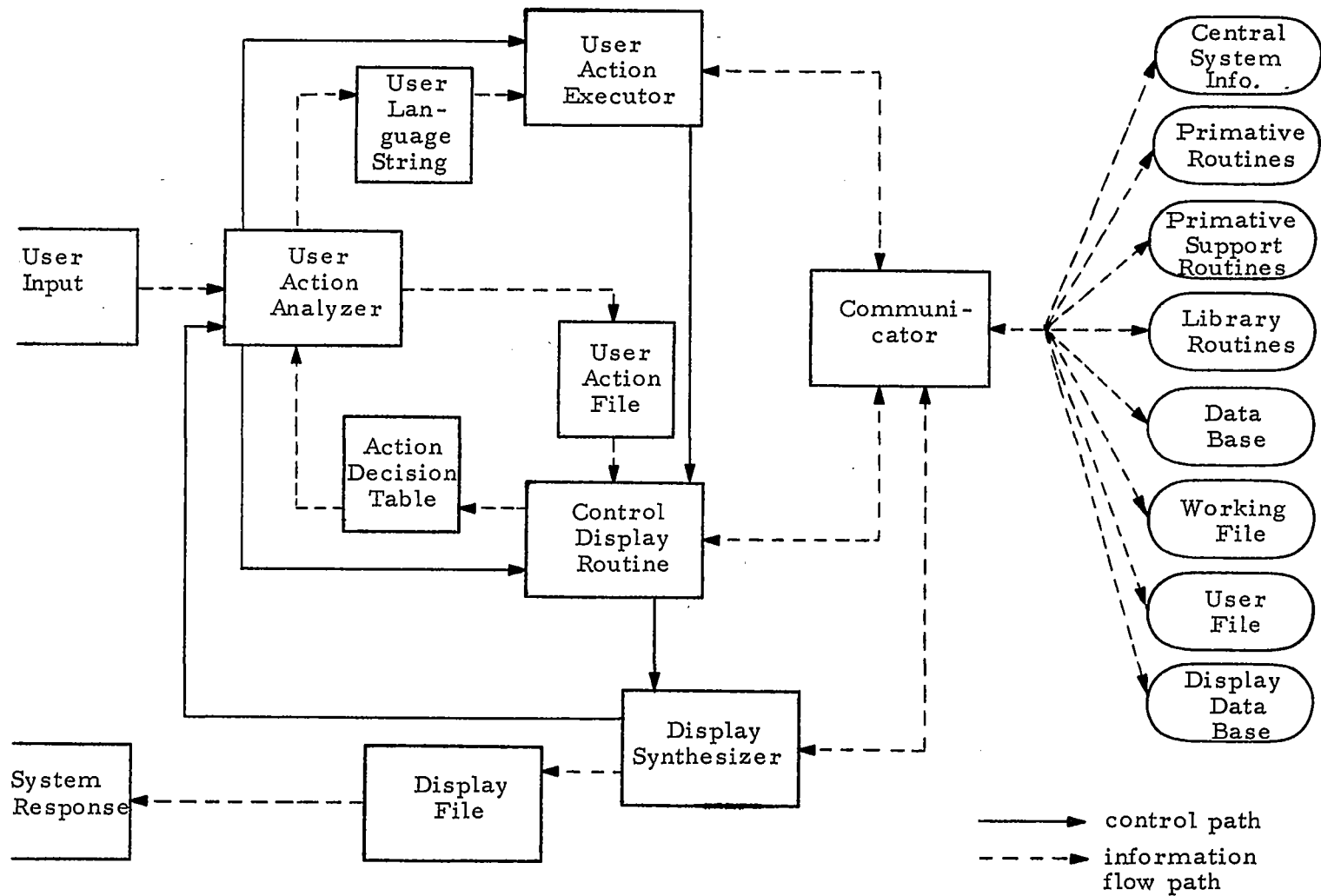
FIGURE 39   SYSTEM APPROACH (FMS)

	User Action Executor	Central Display Routines	Central System Information	Primitive Routines	Display Routines	Library Routines	Data Base	Working File	User File
Experimenter Identification		X	X						X
System Bulletins		X	X						X
System Status		X	X						
Data Specification		X					X	X	
Data Editing	X				X		X	X	
Character Set Generation	X				X				X
Definition of Mathematical Sequences	X			X		X			X
Definition of Graphical Sequences	X				X				X
Mathematical Strategies	X	X		X	X	X			X
Graphical Strategies	X	X			X				X
Strategy Mode	X	X		X	X	X			X
Analysis Mode	X	X		X	X	X	X	X	X
Log-Out Procedures		X	X				X	X	X

FIGURE 40   USE MATRIX FOR SUB-MODES OF OPERATION

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Every time a user action is noted by the UAA, a record must be kept. This data structure is the UAF. It is needed to aid the CDR in updating control displays. Eventually, this file would be kept in the system archives and could be used for system debugging and system usage studies. It would also aid experimenters in rerunning their analysis sessions if the need arose.

Because all inputs to the computer take the form of pointing actions, the task which the UAA must perform is very complex. To aid the UAA in deciding where process control should be transferred, the control display routines build and constantly modify the Action Decision Table (ADT) to reflect changes in action.

4.5.3 User Action Executer

Since the purpose of the system is data analysis, there must be a language in which the experimenter can express his analysis strategies. While working in the analysis mode of operation, the experimenter will request sequences of operations to be performed on his data. Since these sequences will be strings or lists of symbols which the experimenter has pointed at, a translator is needed to reduce them to a form which is compatible with the processing system which will do the data analysis. It will be noted in the system diagram that the UAE is provided with communication to all the files it may need. The system primitive and library routines are necessary for translation and execution of the ULS, while the data base contains the data to be analyzed. In any event, once the language has been translated and executed, the CDR will be called upon to reflect the results of such action. In the event of errors occuring in the ULS, diagnostic messages will be communicated to the user through direct communication to the display synthesizer by the UAE.

4.5.4   Control Display Routines

Because the system is constrained by a single input de-
vice, all user inputs are in the form of pointing actions.   To provide
the light symbols which can be picked at any given time, the CDR's
are necessary.   The first task performed is the generation of the dis-
play commands, which are interpreted by the display synthesizer and
must be inserted into the display file to generate applicable control
symbols .   It will also be necessary for the CDR to build the Action
Decision Table to allow response of control symbols whenever display
mode changes are warranted.   Such functions as intensity reassurance
messages, typewriter mode cursor, and user action anticipation
(i. e. , in the case of the probability typewriter) are also performed by
these routines.   The display file is properly updated when control is
sent to the display synthesizer.

4.5.5   Communicator

The communicator is provided to ensure that all informa-
tion and subroutines necessary for data processing can be obtained.
Because the software has been designed to be configuration independent,
the communicator will allow an interface to any or all types of exter-
nal storage systems.   It will send information upon request to the UAE,
the CDR, or the display synthesizer.   The files which the communica-
tor will retrieve from are shown in Figure 39 but will not be discussed
here because they have been described fully in other sections of this
report.

4.5.6   Display Synthesizer

The function of the display synthesizer is to insert the
necessary display commands into the display file to generate the re-
quested displays.   This allows the other system elements to work in a
display language, but never actually work with display instructions
directly.   Most of the updating of the display file by the display

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synthesizer will be done through interpretation of the display data base. Once the display file is updated, control is returned to the UAA, to await further user inputs.

4.5.7 Display File

The display file is a set of machine language commands which drive the display device. The commands are accessed by a data channel which in turn transmits the commands to the display console.

4.5.8 System Response

Since the only on-line output device available is the user's CRT, all system response and direct output will be through this device. Since changes in the display will be manifested through changes made by the display synthesizer upon the display file, the user will immediately be aware of all system response. He then completes the link between system output and user input.

5. HARDWARE

In developing a set of trade off guidelines to assist in the selection of the most efficient and economic configuration, it is necessary to consider the system requirements both from an overall viewpoint and from that of the individual users; to synthesize a number of possible configurations fulfilling these requirements; and to make comparative evaluations of the salient features of each of these configurations. Due to the evolutionary nature of the proposed system and the limited information regarding future system and user requirements, it is necessary to postulate these requirements in a generalized fashion to cover the widest possible range of system usage.

As the detail system requirements are specified the guidelines presented herein for evaluating the different configurations can be assigned weights according to their importance in meeting these requirements. Thus the optimum configuration selection can be made for developing the on-line experimenter's system.

5.1 SYSTEM REQUIREMENTS

Certain basic assumptions are made with regard to the system requirements and the resultant configuration. These assumptions are concerned with the general nature of data and file management functions being performed and with the man-machine interface implementation. It is assumed that the system will be implemented in an on-line time-sharing mode with the Data Flow Management Subsystem (DMS) processing being performed either in the background or in a separate processor and the File Management Subsystem (FMS) operating in the foreground servicing users at on-line consoles whose tasks will be both conversational and batch processing in nature. It is further assumed that the users will communicate with the computer via on-line graphic display consoles having but one associated input device namely a data tablet stylus, or similar pointing device. Figure 41 presents a system functional diagram showing the major functions to be performed.

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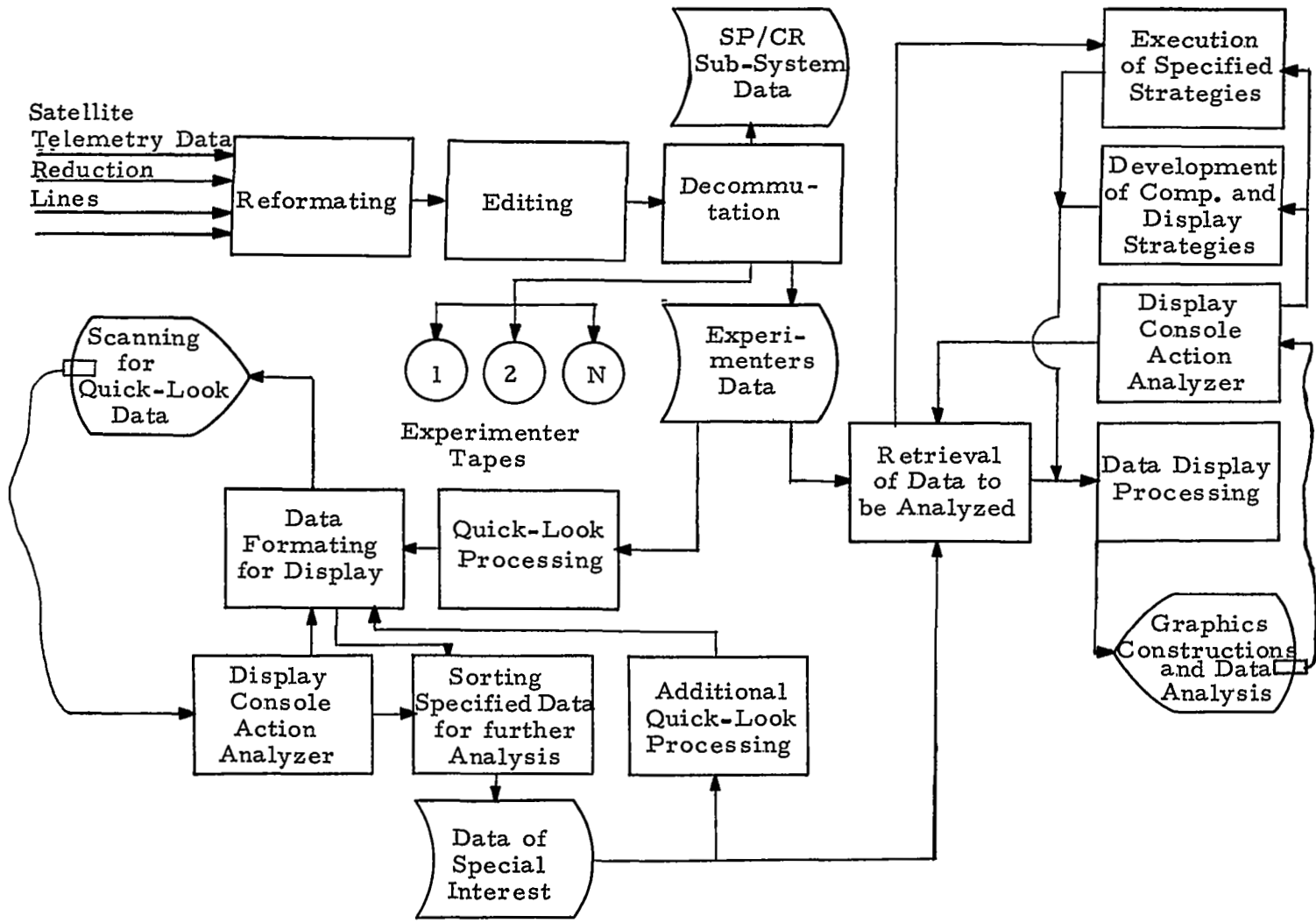
FIGURE 41   FMS/DMS SYSTEM FUNCTIONAL DIAGRAM

Without specifying the details of the configuration, it can be stated that the job mix of the over-all configuration whether it be limited to one processor or consist of several, will be comprised of two main components, the DMS functions which will include the management and storage allocation for all telemetry data and the FMS functions which will include the time-shared processing of user requests both of a conversational and batch nature and the scheduled presentation of quick-look and real-time displays of experiment data.

5.1.1   Data Flow Management Subsystem (DMS)

Spacecraft telemetry data will be received primarily in digital form from a number of telemetry data reduction lines. This data must be reformatted, edited, and converted to provide experiment data in a time ordered sequence for user analysis. Additional requirements exist for quick-look and real-time processing of telemetry data. These two forms of expedited processing take priority over production type processing but pose generally the same formatting, editing and conversion requirements. Some experiments will also require the preparation of attitude/orbit data tapes. The processing required to generate these tapes requires the merging of attitude data, obtained from the spacecraft systems data on the telemetry tapes, with orbit data from orbital data tapes.

● Processing Requirements

The processing requirements of these DMS functions and the anticipated data rates and volumes provide a measure of the throughput rates and file requirements of this function alone. These estimates, by themselves, can provide a measure of the minimum configuration requirements to which must be added the capacity to fulfill the FMS requirements. Thus, at least in the case of a centralized

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single CPU configuration, the DMS requirements can provide a guide-
line as to the minimum computing power requirements.

●Data Rates

       Input data rates of typical telemetry buffer tapes received
from the data reduction lines are generally of the order of 64 kilobits/
sec. although a rate of 128 kilobits/sec. has been used in POGO.[46]
Projections of data volumes to the 1973 era indicate that over 500
million data points per day will have to be handled.[6] Averaged over a
twenty-four hour day this results in a sustained data rate of about 60
kilobits per second. In order to maintain this average rate the peak
rate capability should be considerably higher, perhaps of the order of
three to ten times as high. This is particularly necessary if the data
is to be processed in something less than a three shift, seven day per
week operation. It is assumed, therefore, that the system require-
ment for processing digital buffer tapes will be about 600 kilobits/sec.
That is, the system should have the capability of processing simul-
taneously data tapes from as many as ten data reduction lines.

●File Volumes

       The file requirements for processing telemetry data in-
clude both a mass secondary storage requirement for buffering pur-
poses and an archival storage requirement.

       Secondary storage requirements are a function of data
volumes being processed, the organization of the processing programs
and the system configuration. Secondary storage requirements for
program segments will depend on the system organization. Archival
storage will be either in the form of experimenter magnetic tapes or
a higher density storage medium.

       An estimate of these storage requirements can be based on
the above peak input data rates. Assuming a maximum input rate of

600 kilobits/sec. and a requirement for secondary storage of ten to fifteen minutes of data input at this rate (equivalent to storing data from one orbit for each of ten spacecraft) results in a requirement for ten to fifteen million words. Peak archival storage requirements are estimated to be in the order of 350 experimenter tapes per day (assuming that there are approximately ten analog tapes per spacecraft per day), that the number of spacecraft will double, and that each experimenter tape will contain one day's worth of data.

5.1.2 File Management Subsystem (FMS)

The File Management Subsystem will contain all of the features to enable the on-line user to access data processed by the Data Flow Management Subsystem and subject this data to specific data analysis techniques. The FMS will provide the capability for the on-line construction of these data analysis techniques and for viewing the results of such processing.

There are several types of computations the the FMS will have to support in order to make on-line data manipulation and analysis possible. This processing includes user-system conversation, on-line sensor data analysis, graphical display manipulation, access to data and program files and the processing of lengthy batch type data analysis problems. These functions are discussed in more detail in the following paragraphs.

• User-System Conversation

The user will communicate with the system by pointing at symbols on the display surface. The system will have to analyze his actions and the order in which they are performed to determine what resultant action should be taken. The system will respond to his actions whether they are right or wrong in a manner such that the user will always be confident of his control of the process even when he has made a mistake. The processing required to support the conversational mode will require the processing of real-time inputs to determine

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what action is desired by the user and then the display by the system of its interpretation of the user's actions. Although the data volume for these inputs is low, being generated by the user at maximum rates of three or four per second, the determination of the meaning of each input can be quite complex. The typical type of conversation would consist of the user pointing to a light symbol on the display surface thereby interrupting the computer which would interrogate the display input channel giving the position of the pointing stylus. This position would then have to be correlated with the light symbol displayed closest to the indicated stylus position. An indicator would then be displayed to the user indicating the computer's interpretation of his choice. If the user does not indicate his dissatisfaction with the system's interpretation, then the action represented by the light symbol would be taken by the system. The system would then be ready to receive and process the next user input. Should the user take an action that violates a rule of system operation, then the appropriate error message would be displayed. A substantial reduction in processing time can be made by implementing a coincidence detection circuit and a cursor generator in the console hardware. This hardware-software tradeoff recommended in the console design section would eliminate the lengthy process of correlating stylus and display position data at the cost of somewhat increased complexity of console hardware.

•Sensor Data Analysis

The construction and execution of data analysis routines from the on-line console will require the execution of an interpreter which will provide diagnostic messages to the user as he is constructing his mathematical routines and will also control the execution of such routines with the specified data. After a set of routines has been developed and tested in the interpretive mode the user may wish to have them compiled for more efficient execution. The compilation of routines that are to be executed frequently or on large volumes of data would be desirable.

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- Graphical Display Manipulation

In order for displayed data to be meaningful to the maximum extent possible, the user requires the capability of easily manipulating data representations. This feature encompasses such functions as rotating a three-dimensional representation about one or more axes, enlarging or contracting a portion, or all, of a given display, and moving a set of data dynamically along an axis for rapid scanning. For display of large amounts of data these operations pose a formidable processing load as the entire display file must be modified several times each second to provide smooth motion of the display image.

- Lengthy Data Analysis Batch Type Problems

The FMS should have the capability of processing batch type jobs which are initiated from the on-line console but which will require an execution time which is so long that the user will not wait for the result, but will either come back on-line at a later time to view the results or indicate that he expects to receive hard copy of the results from an off-line device. The priority of these type jobs would be lower than the on-line interactive processing type and would be accomplished in whatever spare time the FMS computational system might have. The system will require the capability of performing lengthy mathematical computations such as inversion of large matrices and statistical analysis routines. The system configuration should be selected with sufficient excess computational power to allow for this type of processing to be accomplished in a timely fashion.

- File Retrieval and Updating

The key to the successful operation of the on-line experimenter system will be the rapid accessing of file data. Every user will have many data files in different formats as well as an individual user file containing information such as special characters and operators, computational sequences and display representations,

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system usage times, and textual information developed from many sources of input. The servicing of such files for many different users will create a processing load of ever increasing complexity.

5.1.3 Console Equipment

The user of an on-line system such as described in the preceding sections, is one of the primary considerations in determining the processing requirements of such a system. In that there will be many different individuals using the system with different educational backgrounds, varying degrees of understanding of formal programming languages and computer system operation, the system design should try to encompass the desires of all users but undoubtedly compromises will have to be made.

From the point of view of a space scientist user, the basic requirements for console equipment are that it provide a graphics capability and a means for specifying requests to the computer. The console design should further provide these capabilities through simple techniques that are easily learned. Also highly desirable are the attributes of fail-softness, transparency and forgiveness as defined in Section 2.

The console equipment considered here is that recommended in Section 3. This console and the associated software design presented in Section 4 fulfills all of the above requirements.

This console equipment includes the following features:

- Color console, control unit and high speed data channel.

- Character generator and vector generator

- Data Tablet DT-1 with extra features

- Coincidence-detector and cursor generator

Rotation, scaling and blinking functions will be performed by software.

5.1.4 User Location

The location of the user console becomes critical for distances where wide band communication with the computer cannot be implemented without the use of communications carrier facilities (about one half mile or less). In order to be able to meet the user requirement of fast response in the conversational mode from a remote console there would have to be some computing capability associated with the remote console to keep the communication cost from being exorbitant. Even with local computing capability within the remote console the data scanning and editing function as described in Section 4.1.3 will be limited without the use of wide band commercial communications. A discussion of the remote scanning problem is presented below, giving the various methods of transmission and the data scanning rates possible with each type of transmission and the associated cost.

The following assumptions are used for determining data scanning rates:

Display Timing

let f = refresh rate (frames/sec)

t = average time to display a point, vector or character

Then the total number, n, of points, vectors or characters that can be displayed per frame is

$$n = \frac{1}{ft}$$

The minimum refresh rate for a flicker-free display is taken to be 30 frames/sec.

The average time to randomly display a point, vector or character is about 50×10^{-6} sec. for present day CRT displays.

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Thus an order of magnitude estimate for n would be

$$n = \frac{1 \text{ Element}}{50 \times 10^{-6} \text{ Sec.}} \cdot \frac{1 \text{ Sec}}{30 \text{ Frames}} = 667 \text{ Elements/Frame}$$

The number of user symbols or characters required in the scan mode may be 150 - 200, leaving a display capacity for approximately 450 - 500 data points.

With a data transmission rate of 2000 bits/sec. which is available using commercial phone lines and assuming that it takes one 36-bit word to describe a data point, then 55 such point's could be received each second. For a 10" display with a maximum number of data points (450) existing within the time span represented on the screen, it would take (450/55) = 8.2 sec. for a data point to move across the viewing surface. From this discussion it becomes apparent that the limiting factor for remote data scanning is the communications link between the central data source and the remote display console with its own processor for display generation.

Figure 42 shows the various modes of data transmission with associated costs and real-time data scanning rates. Figure 43 lists toll charges for interstate transmission over the A. T. & T. switched message network.

Type of Service	Data Rate Bits/Sec	Real-Time Data Scan Rate (Data Points/Sec)	COSTS (All charges subject to additional 10% Federal Excise Tax)	
			Terminal	Line
Switched Message Network	2000	55	Bus. Serv. $ 8.80/mo/term Dataphone 201A 70.00/mo/term $78.80/mo/term	Standard toll charges based on Time and Mileage. See Figure 43
Schedule 4A Leased Wire	2400	66	Serv. Term $12.50/mo/term Chan. Cond. 10.00/mo/term Dataphone 201A 70.00/mo/term $92.50/mo/term	0- 25 mi $3.00/mo/mi 26-100 mi 2.10/mo/mi 101-250 " 1.50/mo/mi 251-500 " 1.05/mo/mi Each add'l mi .75/mo/mi
Series 8000 Wideband 48 khz channel (Formerly Telpak A)	40,800	1133	Term Ctrl. Arrangement $250.00/mo/term Voice Grade Serv. Term 12.50/mo/term Wideband Serv. Term 425.00/mo/term (including 300 Series Data phone) $687.50/mo/term	1-250 mi $15.00/mo/mi 251-500 mi 10.00/mo/mi Each add'l mi 7.50/mo/mi
NOTE: All mileage distances between terminals based on H & V coordinate system				

FIGURE 42 COMMUNICATIONS COST AND DATA SCANNING RATES FROM REMOTE CONSOLES

FIGURE 43 A. T. & T. INTERSTATE VOICE GRADE TOLL CHARGES
(Subject to additional 10% Federal Excise Tax)

Mileage	First Three Minutes	Each Additional Minute
25 – 30	.30	.10
31 – 40	.35	.10
41 – 55	.40	.10
56 – 70	.45	.15
71 – 85	.50	.15
86 – 100	.55	.15
101 – 124	.60	.15
125 – 148	.65	.20
149 – 172	.70	.20
173 – 196	.75	.20
197 – 220	.80	.20
221 – 244	.85	.25
245 – 268	.90	.25
269 – 292	.95	.25
293 – 316	1.00	.25
317 – 354	1.05	.30
355 – 392	1.10	.30
393 – 430	1.15	.30
431 – 468	1.20	.30
469 – 506	1.25	.30
507 – 544	1.30	.35
545 – 600	1.35	.35
601 – 675	1.40	.35
676 – 800	1.45	.40
801 – 925	1.50	.40
926 – 1050	1.55	.40
1051 – 1175	1.60	.40
1176 – 1360	1.70	.45
1361 – 1605	1.80	.45
1606 – 1910	1.95	.50
1911 – 2300	2.10	.55
2301 – 3000	2.25	.60

5.1.5   System Usage Requirements

•Response Time

From a user's viewpoint one of the most important sys-
tem features is rapid response to his actions or requests. The term
rapid response should be further clarified to mean a response time
that is proportional to the complexity of the user's request. The
user would expect that conversational actions such as drawing fig-
ures or picking light symbols would have an immediate reaction from
the system on the order of 1/2 to 3 sec. On the other hand, a user
would understand that a request for reducing a large volume of data
or performing a set of complex mathematical routines might have a
fairly long response time on the order of 10 sec. - 10 min. In
either case the equipment configuration should be selected in a way
that response times will be minimized as much as is economically
feasible.

•Ease of Use

The primary consideration for configuration selection in
order to make the system easy to use is to make it readily available.
In order to meet this requirement, it should be easy to add additional
consoles to the system and to place them in locations convenient to the
experimenters. In some cases the experimenter's location would be
at a great enough distance to require the use of data communications
between his display console and the central processing system.

Other factors affecting ease of use are inherent in the
console, and software designs such as simplicity of interface devices
and user languages.

•Frequency of Use

The determination of how often an experimenter intends
to use a display console may have an impact on the decision of where

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to locate the display consoles. Too much concern based upon initial usage estimates may defeat the goal of making the system readily available. The true measure of success for an on-line system is improvement in the productivity of its users. From the configuration selection standpoint, it should be easy to provide a new user with a console and (after a specified period of time) if it is not utilized sufficiently to justify its cost, the console should be easy to move to a more optimum location.

5.1.6 Computing Power

The "computing power" required for the on-line data analysis system can be determined by examining the types of processing to be performed. Computing power is defined in terms of the features of a computer which make it most suitable for a particular job, such as memory size and speed, word size, floating point hardware, index registers, transfer rates and interrupt capability.

• DMS Computing Power Requirements

The primary computing power requirement of the Data Flow Management Subsystem (DMS) is that it maintain an average throughput rate which will process input data sufficiently fast to prevent excessive backlogging. The primary processor and peripheral equipment features affecting efficient performance of these functions are:

- memory size and speed
- comprehensive instruction set including edit, logical, and character manipulation instructions
- index registers and indirect addressing
- number and speed of tape drives
- number of tape controllers
- capability for simultaneous reading from and/or writing on two or more tape drives attached to a controller

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- number of high speed I/O channels and I/O processors

- large capacity intermediate speed buffer storage for holding input data, partially processed data, and output data

Assuming a sufficiently fast processor, the DMS through-put rate tends to be limited by the magnetic tape input/output transfer rates. Conventional high speed tape drives have transfer rates in the order of 90,000 to 100,000 characters per second. Assuming two characters per telemetry word results in a transfer rate of 45,000 to 50,000 telemetry words per second or an equivalent rate of 405 to 450 kilobits per second (based on a nine bit telemetry word). Tape inter-record gaps and start-stop times tend to reduce these maximum rates by one-third to one-half. Tape handling and setup times further reduce the effective transfer rate for a given tape drive. A number of tape passes are required in reformatting, editing, and converting such that the throughput rate may range from one-fifth to one-sixth of the tape reading or writing rate. Since each tape drive will have an input/output rate of about 100 to 200 kilobits per second and a resultant throughput rate of about 16.7 to 40 kilobits per second, it will require anywhere from five to thirty-six drives to maintain a peak throughput rate of 180 kilobits per second to 600 kilobits per second.

- FMS Computing Power Requirements

The FMS functions include the on-line servicing of the experimenter's display consoles, the retrieval of experimenter's data and program files, and the processing of large data volumes by various mathematical programs. The type of processor features desirable for each of these functions is somewhat different.

The on-line servicing of display consoles requires real-time processing of user inputs and manipulation of the display data structure to provide a response to the user's action. These computational functions are primarily logical, therefore efficient bit and

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character manipulation instructions are desirable. Word sizes of 12 to 20 bits are generally sufficient to describe the display data base. If the display image is to be refreshed from the computer's core memory then a memory cycle speed of 2 micro-seconds or less is desirable to keep memory cycle stealing time to about 6%.

The processing of large data volumes by various mathematical programs implies the need of processor features different from those required to service the on-line console. The word size should be sufficient (30 bits or more) to maintain reasonable accuracy without resorting to double precision for arithmetic operations. Floating point instructions should be implemented by hardware in order that the execution times for arithmetic instructions be short enough to provide the on-line user with fast response to his request for data analysis. The manipulation of large matrices could be considered a fairly common problem in the type of data analysis system proposed.

The retrieval of data and program files requires no additional central processor or core memory capability than previously mentioned but the mass data storage devices and I/O controller processing capability would be compatible with the central processor configuration.

A rough estimate of processor utilization is derived as follows.

• Display refreshing at 30 frames/sec for a 1000 word display file residing in a 2 micro-second core memory would require 6% of the main memory cycles for each display console.

• The processing of user inputs must be handled as they occur in near real-time as must the display of the system reaction to these inputs. The manipulation of the displayed figures and characters includes the construction of graphic figures and textual information as well as their translation upon the display

surface. It is estimated that the accomplishment of these two processing functions would require up to 10% of a single processor's time per display console.

The data analysis programs, on-line conversational compiler or interpreter and file retrievals are estimated to require from 10 - 20% of the processing time per display console.

Therefore on the average, as much as 25 - 35% of a processing system's time could be required for servicing each display console in the system.

5.1.7   System Modularity

Terms such as modularity, expandability, and reliability are used rather loosely at times, but these terms do represent precise concepts. The system designers must consider such concepts in detail for a system such as the one discussed in this report. Some of the aspects regarding these concepts are discussed in this section as they relate to an on-line experimenter's system.

System expandability is affected by two related factors, the anticipated increase in volume of space data and the increase in the number of experimenters analyzing this data. The hardware system selected should be easily expanded in small increments to accommodate a new display console terminal or new I/O equipment for an increase in data volume. The problem of expanding system capability to maintain reasonable response times to the on-line users is difficult in that it is not generally apparent in time-shared systems as to what system component (i. e. , processor, mass storage, or I/O equipment) needs to be expanded. The use of a simulation model of the main processing system where the characteristics of each component and each concurrent job can be varied to find the optimum solution will be highly desirable.[47]

The problem of hardware reliability should be
approached from two points of view; a) what is the minimum
hardware requirement for accomplishment of the basic mission,
b) what is the hardware required to provide the on-line experimen-
ter with a capability to restart his analysis with a minimum of
repetitive actions when there is a hardware failure. The first reli-
ability requirement must be met since the reduction and analysis of
space data is obviously an integral part of very costly projects.
The second reliability requirement may be harder to justify. How-
ever, if an experimenter is to have faith in an on-line system he
must be let down gently when there are failures in equipment over
which he has no control. This feature of fail-softness requires an
integrated hardware/software approach which informs the user of
failures as they occur and instructs him as to the appropriate actions
to be taken in order to resume his work.

The commonality of equipment throughout the system
should be considered in meeting both of the preceding requirements
as well as in the design and development of the software system.
For example, in a configuration with a large central CPU and addi-
tional smaller processors for one or more display units, if the
functions planned for the smaller processor cannot all be performed
as estimated in the original design and the instruction set of the
small machine is a sub-set of the larger machine, then the transfer
of functions between the machines could be accomplished with a
minimum of effort.

5.1.8   Software Availability

The basic assumption in this discussion is that all
processors selected will have a minimum of one procedure oriented
language compiler and a comprehensive system of utility programs.
The following discussion is concerned with the subject of additional

software that is desirable for developing the on-line data analysis system.

An expanded procedure oriented language compiler which would include the capability for manipulation and display of graphical data structures would greatly facilitate the development of the on-line user console system. Currently no hardware manufacturer is providing this capability. However, there is a group within the ACM Special Interest Committee on Graphics (SICGRAPH) that has undertaken a study to determine the best language for such expansions. Some manufacturers are providing subroutines for constructing graphic figures that are callable by a procedural language such as FORTRAN. This approach should be considered as an alternative to a graphic procedure oriented language but not an optimum solution.

A basic graphics systems with the ability to construct graphical figures and manipulate such figures in conjunction with an applications oriented program would substantially reduce the amount of effort necessary to implement the on-line data analysis system. One such system has been developed by a computer/display manufacturer[48].

The on-line user monitor system consists of an operating system designed to facilitate interactive use of the system in a time-shared sense. The development of these systems are certainly undergoing many developmental pains at the present time. Such systems should be generally available for use in the development of an on-line data analysis system in the near future. The characteristics of these monitor systems should be evaluated carefully with respect to the equipment configuration and the intended application. The use of a simulation program as discussed in Section 5. 1. 7 could be extremely helpful in conducting such an evaluation.

	Hardware						Software		
	CPU	Memory	Peripheral Equipment				Monitor	Compilers and Assemblers	Graphics
System Features	Word Size / Instruction Exec. Time / Comprehensive Inst. Set / Floating Point Hardware / Index Registers / Indirect Addressing / T/S Capability / Multi-Processing / Interrupt / I/O Channels	Memory Size / Memory Access Time	Secondary Storage: Disk Capacity / Disk Access Time / Drum Capacity / Drum Access Time / Magnetic Tape / No. Controllers / No. Units / Speed	Card Equipment: Card Reader Speed / Card Punch Speed / Line Printer Speed	Display Consoles: Graphics Capability / Display Memory / Input Device / Data Communications		Timed Shared / Batch	Algebraic/Graphics Compiler / FORTRAN / PL/1 / ALGOL / Assembly Language	Conv. Lang. / Graph. Support

I DMS Considerations

1. Throughput Data Rates
2. File Volumes
3. System Expansion
4. Quick Look Processing
5. Real-time Processing
6. Number of Experiments
7. Attitude/Orbit Data

II FMS Considerations

1. Response Time
2. Complex Data Reduction
3. Graphical Capability
4. Data Scanning
5. Batch Processing
6. File Retrieval and Updating
7. Data Rates
8. File Volumes
9. Remote User Location
10. Number of User Consoles
    Single
    Multiple
11. Efficient Central Processor Utilization
12. System Expansion
13. Program Development

FIGURE 44 SYSTEM FEATURES/SYSTEM CONSIDERATIONS CHECKLIST

Along with the development of time-sharing monitor systems there is an effort by some manufacturers to provide conversational programs for on-line programming from remote terminals. These programs include functions such as diagnostic messages to the user and incremental compilation or interpretive execution of programs as they are written. Although programs such as these may not be essential to the development of an on-line data analysis system, they could be used to shorten development time or to include an additional capability in the system such as on-line programming from the display console.

5.2 CONFIGURATION MODELS CONSIDERED

Based on the system requirements of Section 5.1, three configuration models were developed. While each of these configurations fulfills the basic system requirements, the capabilities and limitations of each with respect to each of the major requirements are presented as system trade-offs in Section 5.3. In developing each of the configuration models, emphasis was given to those system requirements primarily affecting configuration features. A checklist relating these features to each of the major system considerations is presented in Figure 44.

The three configuration models developed for this investigation are: a large central multiprocessor system with on-line local consoles; a large central multiprocessor system with on-line consoles (both local and remote) each serviced by a small satellite computer; and finally a non-integrated system in which real-time access to data is sacrificed for the sake of increased data capacity. These three configurations referred to as Configuration A, Configuration B and Configuration C respectively, are described in more detail in the following sections.

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The functions assigned to configurations discussed in this section are compatible with the software system approach discussed in Section 4.

The cost estimate used for the display consoles in this section of the report is that of the basic color console presented in Section 3.4. Not included here are the costs for a high capacity buffer memory and the modifications to the basic console required for high data volume display. The cost for this type of console is approximately $317,500 (see Section 3.4). In order to include this capability in the configurations discussed in this section, a high data volume display console may be substituted for a basic display console and the differential in cost ($162,500) added to the total configuration cost.

5.2.1 Large Central Processor with Local Consoles (Configuration A)

This configuration as shown in Figure 45 consists of a large central multiprocessing system comprised of two CPU's and two Input/Output Controllers operating in a time-sharing mode to service a number of on-line consoles concurrently in operation. The consoles would have to be located in close proximity to the central processor due to the requirement that the display be refreshed from main memory and the resultant large data volume transferred. The interactive user-system conversation would be supported along with the operation of various data reduction and analysis programs and the management of system files. The Data Flow Management Subsystem functions would be accomplished as background processing with the foreground processing of on-line user requests by the File Management Subsystem having the highest priority.

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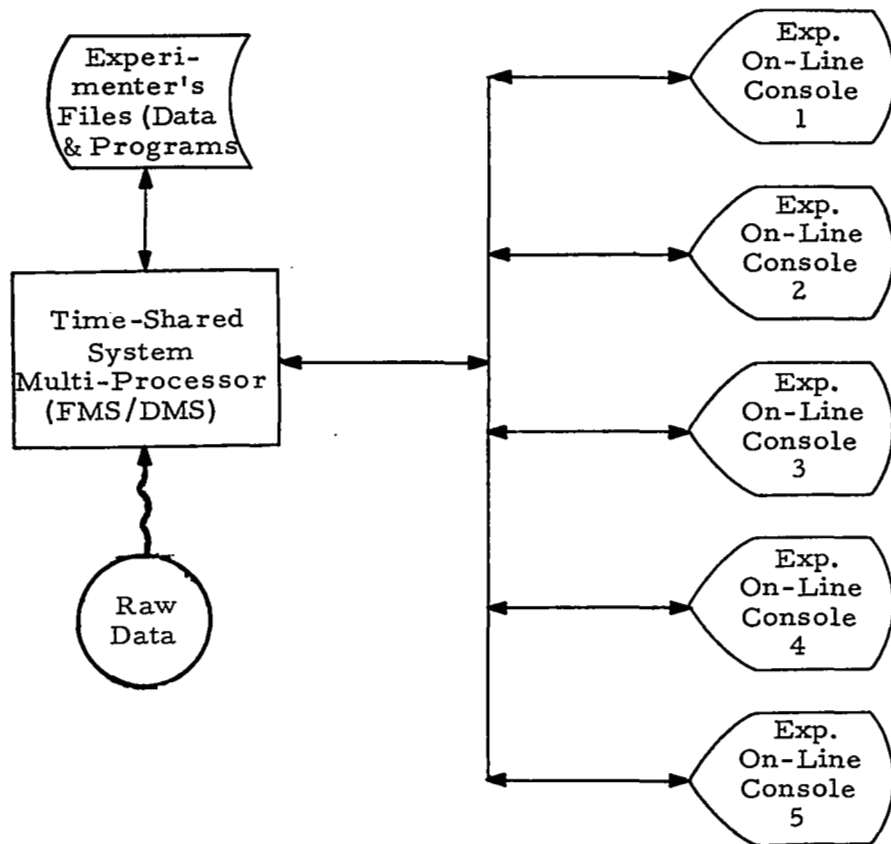
FIGURE 45   LARGE CENTRAL MULTI-PROCESSING
SYSTEM WITH ON-LINE LOCAL CONSOLES
(CONFIGURATION A)

Current experience with systems using on-line graphic consoles indicates that anywhere from one to five such consoles can be supported in a time-sharing environment. Project MAC at M. I. T. has on-line graphics consoles connected to the 7094 Compatible Time-Sharing System (CTSS) with the display being refreshed from computer memory (memory size is 65K). This system can support only one graphics console user while maintaining its normal time-sharing load with teletype users. The Lincoln Laboratory time-sharing system on the TX-2 computer has successfully supported up to five on-line graphics consoles with occasional system saturation. The displays are refreshed from computer memory in this system also (memory size is 115K and memory cycle time is 2.4 μsec.) It should be noted that both of these facilities are currently implementing display consoles with a small dedicated computer to do display refreshing and other routine display manipulation tasks.

Costs for a typical configuration of this type are presented in Figure 46 for currently available equipment.

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FIGURE 46 COSTS FOR CONFIGURATION A LARGE CENTRAL PROCESSOR WITH ON-LINE (LOCAL) CONSOLES

Component	No. Units Req'd	CDC 6500	GE 645	Purchase Price IBM 360/67	Univac 1108 II
Central Processor	2	$2,643,000	$1,383,700	$1,826,980	$1,702,600
(Including the following features: Word size 32 bits or larger Comprehensive Instruction Set Floating Point Hardware Storage Protection, Base Address Relocation, Program Interrupt, Clock, Paging and Supervisor Mode)					
Input Output Controllers	2	*	553,720	826,300	653,620
(Consisting of a minimum of 3 high speed data channels and 6 low speed data channels)					
Main Memory	1	*	1,103,480	840,130	989,820
(Consisting of 131 K words accessible to both CPU's and both Input Output Controllers)					
Peripheral Equipment Large Capacity Disk or Drum	1	266,000	740,400	140,120	399,160

and associated control unit
having minimum capacity of 30
million words and maximum
average access time of 150 msec.
* Included in price of CPU

FIGURE 46 (CONTINUED)

Component	No. Units Req'd	CDC 6500	GE 645	IBM 360/67	Univac 1108 II
				Purchase Price	
Peripheral Equipment (Con't)					
High Speed Drum and associated control unit having minimum capacity of 2 million words and maximum average access time of 20 msec.	1	$ 293,500	$ 543,200	$ 202,095	$ 421,995
Magnetic Tapes and associated control units having minimum data transfer rate of 90 KC, minimum packing density of 800 bpi and 9 channels	4 control units 24 tape drives	1,156,000	1,138,160	1,159,280	966,900
Card Equipment Card Reader and control unit (Min. speed 800 cpm)	1	77,500	59,000	92,140	65,565
Card Punch and control unit (Min. speed 250 cpm)	1				
Line Printer and control unit (Min. speed 1000 lpm, 132 print pos.)	1	76,500	60,000	44,200	73,515
Totals		$4,503,500	$5,581,660	$5,131,245	$5,273,175

FIGURE 46 (CONTINUED)

Component	No. Units Req'd	CDC 6500	GE 645	Purchase Price IBM 360/67	Univac 1108 II
Graphic Display Consoles	1-5		$155,000 -	$775,000	
Including high speed data channel, control unit, color CRT with graphics capability, vector generator, character generator, and pointing device for input					
Total Cost Range			$4,658,500 - $6,356,660		

5.2.2   Large Central Processor, Small Satellite Processor for
Each Display Console (Configuration B)

This configuration shown in the diagram of Figure 47
is similar to that of Configuration A, but differs in one very important
respect, namely, the use of a small satellite processor to drive each
display console.

The function of the small satellite processor would be to
converse with the experimenter and perform all display formatting
and manipulation functions.   The large central processor would per-
form in a time-sharing mode to process requests from the satellite
processors for data reduction and file information.   The requirement
for locating the consoles in close proximity to the central processor,
although desirable to support all system features economically, would
not be a necessity as in the previous configuration due to the lower
data volume being transferred.

The configuration of the large time-shared central proc-
essing system is the same as that of Configuration A except for the
display consoles, and in the case of remote displays, the communica-
tions terminals and channels.   That is, the price of the configuration
without satellite processors or display consoles would range from about
$4,500,000 to $5,600,000.

A range of costs for currently available equipment for a
typical configuration for the small satellite processor and display con-
sole is presented in Figure 48.

Thus, the cost of a typical configuration of this type would
be $4,500,000 to $5,600,000 plus $272,000 to $300,000 per local sat-
ellite processor display console combination.

In addition, if it is desired to remote one or more of the
satellite processor display console units, the cost of communications
channels for the large processor and each remote satellite processor
must be added to the above costs.   The cost of adding communications
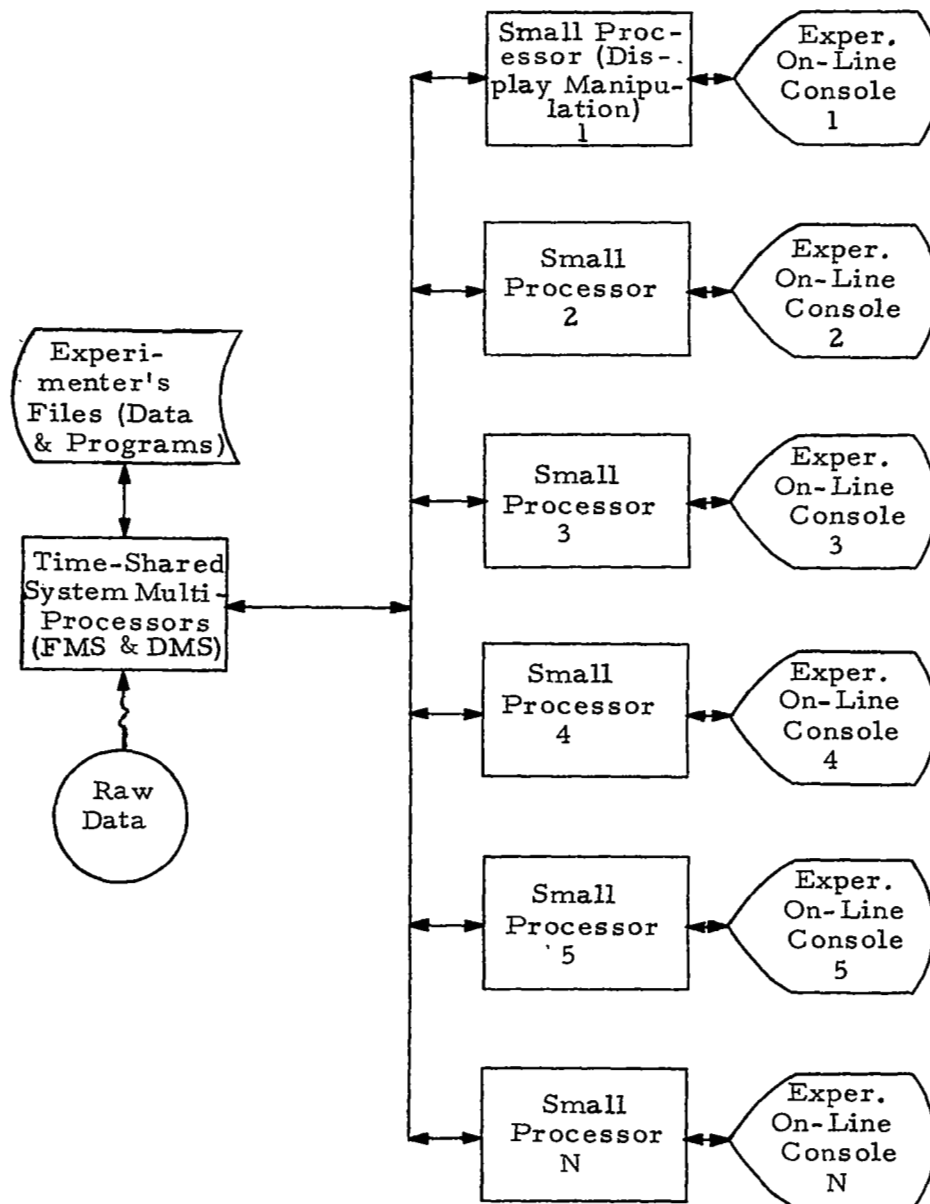
FIGURE 47   LARGE CENTRAL PROCESSOR WITH SMALL
              SATELLITE PROCESSOR FOR EACH DISPLAY
              CONSOLE LOCAL OR REMOTE
              (CONFIGURATION B)

devices (up to the data-set interface but not including the data set and transmission costs) to the large central processing system is tabulated in Figure 49 for each of four manufacturers for any number of terminals up to 16. In addition, the cost for the single communication channel (exclusive of data set and transmission cost) for each of the satellite processors is as follows:

Component	No. Units Req'd	CDC 1700	DEC PDP8	SDS Sigma 2
Communications Channel	1	$18,700	$3,000	$ 7,000

FIGURE 48 COSTS OF SMALL SATELLITE PROCESSOR FOR CONFIGURATION B

Component	No. Units Req'd	CDC 1700	Purchase Price DEC PDP8	SDS Sigma 2
Central Processor	1	$29,000	$22,100	$42,100
(Including the following features: Word Size 12 bits or larger Add Time less than 3.5 μs 2 Index Registers, single level indirect addressing and hardware multiply/divide)				
Input Output Controller	1	14,000	2,700	*
(Consisting of a minimum of 2 high speed channels and 2 low speed channels)				
Main Memory	1	40,000	55,700	69,500
(Consisting of 24K words having a maximum memory cycle time of 1.5 u secs.				
Peripheral Equipment				
Disk or Drum	1	27,500	43,600	26,000
And associated control unit having a minimum capacity of 262 K words and a maximum access time of 150 ms				

FIGURE 48 (CONTINUED)

Component	No. Units Req'd	Purchase Price CDC 1700	DEC PDP8	SDS Sigma 2
Paper Tape Read/Punch/Console Typewriter System (Consisting of a Model 35 ASR Teletype and Control)	1	$6,300	$ 4,000	$7,000
Graphic Display Console (Including additional high speed data channel from large CPU to satellite CPU, control unit, color CRT with graphics capability, vector generator, character generator, and pointing device for input)	1	-	155,000	-
Totals		$ 271,800	$ 283,100	$ 299,600

*/ Included in CPU price.

FIGURE 49

COMMUNICATIONS TERMINAL COSTS FOR LARGE
MULTIPROCESSOR SYSTEM

(Excluding cost of communications carrier data sets and communications channels)

Manufacturer and Model

No. Terminals	CDC 6500	GE 645	IBM 360/67	UNIVAC 1108 II
1	42,000	12,640	28,200	34,930
2		16,480	28,200	34,930
3		20,320	56,400	38,560
4		32,960	56,400	38,560
5		36,800	84,600	42,190
6		40,640	84,600	42,190
7		53,280	112,800	45,820
8		57,120	112,800	45,820
9		60,960	141,000	49,450
10		73,600	141,000	49,450
11		77,440	169,200	53,080
12		81,280	169,200	53,080
13		93,920	197,400	56,710
14		97,760	197,400	56,710
15		101,600	225,600	60,340
16	42,000	114,240	225,600	60,340

5.2.3 Non-Integrated System (Configuration C)

As an alternative to the integrated systems represented by
Configurations A and B, a non-integrated system, as shown in
Figure 50, has been considered. This system is non-integrated
in the sense that experimenter data tapes are used for the inter-
mediate storage of data. This alternative solves certain problems
of data capacity and should permit a larger number of user
consoles to be serviced by the system. The sacrifice involved is
the loss of "real-time" processing.

The DMS function of controlling the flow of data through
the system is terminated at the magnetic tape link in this config-
uration.

This configuration shown in Figure 50 consists of a sepa-
rate large scale single processor system to perform the DMS func-
tions which provides experimenter data tapes to a medium size proc-
essor that performs a portion of the FMS data management func-
tions. The rest of the configuration consists of a number of medium
size processors that support up to three on-line graphics consoles
each in a time-shared mode. The time-shared display processors
perform the FMS functions of data display manipulation, user-
system conversation, and the processing of data reduction programs.
The display consoles in this configuration include a local buffer
memory for display refreshing to relieve the medium size process-
ors of this task.

The detailed specifications for this configuration are
given in Figures 51, 52 and 53, along with manufacturer's prices
for each system component.
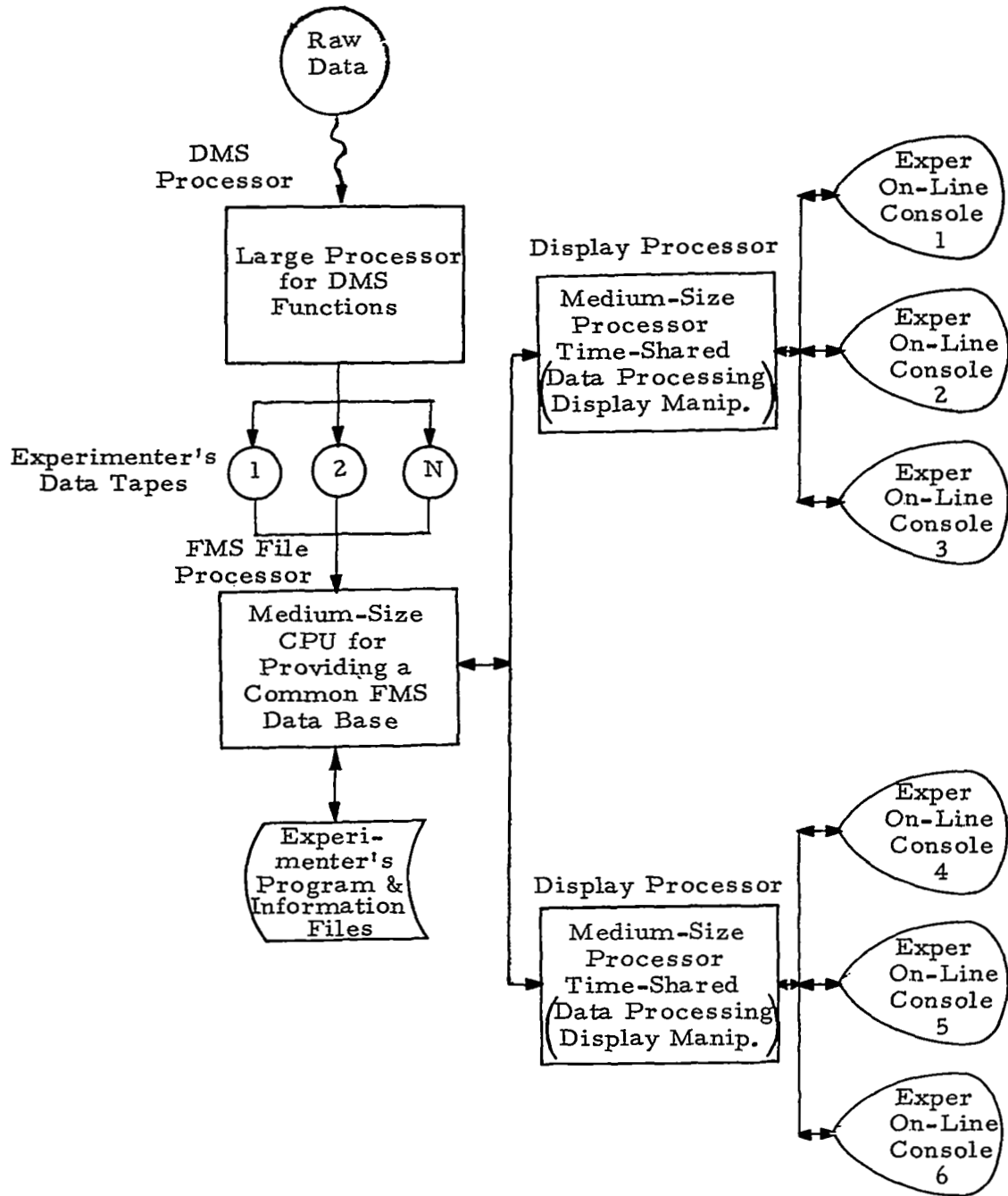
FIGURE 50   MEDIUM-SIZE DISPLAY PROCESSOR WITH
CENTRAL DATA RETRIEVAL SYSTEM
(CONFIGURATION C)

FIGURE 51   DMS SINGLE PROCESSOR OF CONFIGURATION C

Component	No. Units Req'd	Purchase Price			
		CDC 6400	GE645	IBM 360/67	UNIVAC 1108 II
Central Processor	1	$1,365,000	$673,000	$733,110	$ 646,800
(Including the following features:					
Word size 32 bits or larger Comprehensive Instruction Set, Floating Point Hardware)					
Input Output Controllers	1	*	241,040	157,370	21,000
(Consisting of a minimum of 12 low speed data channels)					
Main Memory	1	*	518,400	405,965	457,500
(Consisting of 65K words having a maximum memory cycle time of 1.0 μsec)					
Peripheral Equipment					
Large Capacity Disk or Drum	1	266,000	740,400	140,120	399,160
and associated control unit having minimum capacity of 30 million words and maximum average access time of 150 msec.					

* Included in price of CPU

FIGURE 51 (CONTINUED)

Component	No. Units Req'd	CDC 6400	GE 645	Purchase Price IBM 360/67	UNIVAC 1108II
Peripheral Equipment (Cont)					
Magnetic Tapes	4 control units 24 tape drives	$1,156,000	$1,138,160	$1,159,280	$ 966,900
and associated control units having minimum data transfer rate of 90 KC, minimum packing density of 800 bpi and 9 channels					
Card Equipment					
Card Reader and Control Unit (Min. speed 800 cpm)	1	77,500	59,000	92,140	65,565
Card Punch and Control Unit (Min. speed 250 cpm)	1				
Line Printer and Control Unit (Min. speed 1000 lpm, 132 print pos.)	1	67,500	60,000	44,200	73,515
Totals		$2,932,000	$3,529,000	$2,732,185	$2,630,440

FIGURE 52 FMS CENTRAL FILE PROCESSOR OF CONFIGURATION C

Component	No. Units Req'd	Purchase Price		
		CDC 3300	PDP 10	SDS Sigma 7
Central Processor	1	$247,000	$99,500	$197,100
(Including the following features:				
Word Size 24 bits or larger Add time less than 3 μs Floating Point Hardware 2 Index Registers Single level indirect addressing Time Sharing features: Multi-level interrupt Interval Timer Paging or swapping)				
Input/Output Controller	1	23,200	*	50,000
(Consisting of a minimum of 2 high speed channels and 8 low speed channels. All configurations considered can accomodate up to 16 high speed data communication lines.)				
Main Memory	1	362,000	288,000	388,000
(Consisting of 65K words having a maximum memory cycle time of 2.0 μs)				

* Included in price of CPU

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FIGURE 52 (CONTINUED)

Component	No. Units Req'd	CDC 3300	Purchase Price PDP 10	SDS Sigma 7
Peripheral Equipment				
Disk File	1	$140,000	$727,000	$150,000
With control unit and having a minimum capacity of 10 million words and an average access time of 100 ms				
Drum Storage	1	188,000	**	68,000
With control unit and having a minimum capacity of 1 million words and an average access time of 25 ms.				
Magnetic Tape Controller	4	100,000	72,000	80,000
Magnetic Tape Drive	20	980,000	312,000	840,000
For 9 channel tape and a 90 KC transfer rate				
Card Reader	1	35,500	15,000	24,000
With controller and a minimum speed of 800 cpm				

**The PDP 10 does not have a drum auxiliary storage device so the disk which has an average access time of 16.7 ms would be used for program swapping.

FIGURE 52 (CONTINUED)

Component	No. Units Req'd	CDC 3300	Purchase Price PDP 10	SDS Sigma 7
Peripheral Equipment (Con't)				
Card Punch	1	$ 42,000	$ 30,000	$ 32,000
With controller and a minimum speed of 100 cpm				
Line Printer	1	67,500	35,000	40,000
With controller and a minimum speed of 600 lpm				
Totals		$2,185,200	$1,578,500	$1,869,100

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FIGURE 53   FMS DISPLAY PROCESSOR OF CONFIGURATION C

Component	No. Units Req'd	CDC 3300	Purchase Price PDP 10	SDS Sigma 7
Central Processor	1	$247,000	$99,500	$197,100
(Including the following features:				
Word size 24 bits or larger Add time less than 3 μs Floating Point Hardware 2 Index Registers Single level indirect addressing Time Sharing Features: Multi-level interrupt Interval Timer Paging or swapping)				
Input/Output Controller	1	32,100	*	50,000
(Consisting of a minimum of 2 high speed channels and 6 low speed channels)				
Main Memory	1	362,000	288,000	388,000
(Consisting of 65K words having a maximum memory cycle time of 2.0 μs)				

* Included in price of CPU

FIGURE 53 (CONTINUED)

Component	No. Units Req'd	Purchase Price		
		CDC 3300	PDP 10	SDS Sigma 7
Peripheral Equipment				
Disk File	1	$140,000	$727,000	$150,000
With control unit and having a minimum capacity of 10 million words and an average access time of 100 ms				
Drum Storage	1	188,000	**	68,000
With control unit and having a minimum capacity of 1 million words and an average access time of 25 ms				
Magnetic Tape Controller	2	50,000	36,000	40,000
Magnetic Tape Drives	10	490,000	156,000	420,000
For 9 channel tape and a 90 KC transfer rate				
Card Reader	1	35,500	15,000	24,000
With controller and a minimum speed of 800 cpm				
Card Punch	1	42,000	30,000	32,000
With controller and a minimum speed of 100 cpm				

**The PDP 10 does not have a drum auxiliary storage device, so the disk which has an average access time of 16.7 ms would be used for program swapping.

FIGURE 53 (CONTINUED

Component	No. Units Req'd	Purchase Price		
		CDC 3300	PDP 10	SDS Sigma 7
Peripheral Equipment (Cont)				
Line Printer	1	$ 67,500	$ 35,000	$ 40,000
With controller and a minimum speed of 600 lpm				
Totals		$1,654,100	$1,386,500	$1,409,100
Graphic Display Console	1-3			
(Including data channel, control unit, color CRT with graphics capability, vector generator, character generator, and pointing device for input)				
Display Buffer Memory	1-3			
Includes 4K of 16 bit words for each display console attached to a CPU				
Total Price Range		$1,553,500 -- $2,155,100		

The above costs are for a local system having three display consoles. If it is desired to locate such a system remotely from the central FMS file retrieval system, then the additional cost of data communications equipment and transmission costs must be added to the above figures. The cost for adding communications I/O channels are given in Figure 54. The costs shown are only for the communications controller and line adapters and do not reflect the cost of the data sets and transmission charges required for each line. It is estimated that one such high speed data line (2000 bps) would be required for each display console included in the remote display processor configuration.

The costs of the configuration given in Figure 52 for the FMS Central File Processor would be for supporting only local FMS display processing configurations. The additional cost for communications terminals to support remote display processing systems are given in Figure 54. There would be one communication terminal required for each display console attached to each remote display processor.

The range of costs for Configuration C, assuming the same manufacturer would be chosen for both of the FMS functions, is $6,066,440 to $7,839,300 which includes the DMS processor, the FMS file processor, and a single local FMS display processor with three on-line consoles. For configurations with a larger number of consoles, refer to Figure 53 for the additional costs. If a remote system is contemplated, then the communications cost can be obtained from Figures 54, 42, and 43.

FIGURE 54   COMMUNICATIONS TERMINAL COSTS FOR THE MEDIUM SIZE CPU CONFIGURATIONS

(Excluding the cost of communications carrier data sets and communications channels)

No. Terminals	Manufacturer and Model		
	CDC 3300	PDP 10	SDS SIGMA 7
1	18,700	14,000	11,000
2	24,400	14,000	18,000
3	30,100	14,000	25,000
4	35,800	14,000	32,000
5	41,500	14,000	39,000
6	47,200	14,000	46,000
7	52,900	14,000	53,000
8	58,600	14,000	60,000
9	77,300	26,000	71,000
10	83,000	26,000	78,000
11	88,700	26,000	85,000
12	94,400	26,000	92,000
13	100,100	26,000	99,000
14	105,800	26,000	106,000
15	111,500	26,000	113,000
16	117,200	26,000	120,000

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5.3 CONFIGURATION SELECTION TRADE-OFF GUIDELINES

In this section the three configurations of Section 5.2 are compared against the system requirements discussed in Section 5.1. The advantages and disadvantages with respect to the system requirements are listed for each configuration.

In some cases the specific requirements listed either apply to all configurations or cannot be compared on a general configuration basis. However, after a particular configuration has been selected these specific requirements can be used to compare the various manufacturer's equipment (i. e. , graphics software availability, hardware expansion features, etc.) and will be of use in making the final hardware selection.

When reading this section, one should keep in mind that the advantages and disadvantages listed do not necessarily carry equal significance. The significance of these factors will become apparent as the detailed system design requirements and developmental constraints are established.

5.3.1 Configuration A Compared Against the System Requirements

Configuration A consisting of a large time shared central processing system with on-line graphical display consoles is compared with the system requirements discussed in Section 5.1. Both the advantages and disadvantages of this configuration are presented.

Reference Para. No.	Requirements	Advantages	Disadvantages
5.1.1	Data Management System	Accommodating the DMS function in the same processing environment with the FMS minimizes I/O operations to transfer data between the systems.	
		Quick look and real-time processing will be expedited in this configuration in that processed experiment data is readily available for analysis by the FMS without intermediate tape handling.	
		The nature of the DMS/FMS computing requirements (i.e., DMS is a data processing job and the FMS is an on-line conversational job) are complementary for efficient use of the multi-processor configuration.	

CONFIGURATION A

Reference Para. No.	Requirements	Advantages	Disadvantages
5.1.2	File Management Subsystem		All individual user actions from each console must be processed as real-time inputs.
5.1.2	User/System Conversation		The system response to the user input must be generated and displayed. In other words a very large processor is tied up doing the trivial but important tasks of servicing the individual consoles.
5.1.2	On-Line Sensor Data Analysis	The execution time of the compiler or interpreter will be facilitated by a large, fast central processing system.	
5.1.2	Graphical Display Manipulation	By using main CPU memory for refreshing the display image more efficient use of memory resources is obtained since the same memory can be utilized by different users at different times.	The display data structure manipulation must be done by the central CPU (i.e., data display rotation, translation, etc.) The display file, for refreshing the display image, must be kept in main core which sacrifices storage capacity and memory cycles.

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CONFIGURATION   A

Reference Para No.	Requirements	Advantages	Disadvantages
5.1.2	Lengthy Data Analysis Batch Type Problems	The response time to the user will be minimized by the use of a fast central processor system.	
5.1.2	File Retrieval and Updating	The centralization of processing for all FMS users facilitates the exchange of information between experimenters.	
5.1.3	Console Equipment (The console equipment is the same for all configurations)	The console is designed to meet experimenter requirements. The use of the data tablet device reduces the processing load that would have been imposed by a light pen.	The special console design will be more expensive from both hardware and software aspects than a console supplied by the computer manufacturer.
5.1.4	User Location		This configuration will not support a remote data analysis terminal for all system capabilities discussed in Section 4 of this report (i. e., data scanning)

CONFIGURATION   A

Reference Para. No.	Requirements	Advantages	Disadvantages
5.1.5	System Usage	The entire processing configuration is available for other uses when not being used to support the on-line users.	Response time for user/system conversation will increase with the number of on-line users and processing demands.
5.1.6, 5.1.7, 5.1.8	System Operation and Development Considerations	The FMS/DMS processing can be accomplished in the same processing configuration. The system programming would all be done on the same processor system.	Only a limited number of on-line display consoles can be supported by this configuration (approx. 5 without adding another large CPU).

5.3.2 Configuration B Compared Against the System Requirements

Configuration B consisting of a large time-shared central processing system with both local and remote small satellite processors each supporting an on-line graphical display console is compared with the system requirements in Section 5. 1 . Both the advantages and disadvantages of this configuration are presented.

Reference Para. No.	Requirements	Advantages	Disadvantages
5.1.1	Data Management Subsystem	Accommodating the DMS function in the same processing environment with a major portion of the FMS minimizes I/O operations to transfer data between the systems.	
		Quick-look and real-time processing will be expedited in this configuration in that processed experiment data is readily available for analysis by the FMS without intermediate tape handling.	
		The nature of the DMS/FMS computing requirements (i.e., DMS is a data processing job and the FMS is an on-line conversational job) are complementary for efficient use of the multi-processor configuration.	
5.1.2	File Management Subsystem		
5.1.2	User/System Conversation	The real-time processing of user inputs can be accomplished by the small CPU causing less interruption of the central CPU	

Reference Para. No.	Requirements	Advantages	Disadvantages
		system. The display of system responses to user inputs can be generated by the small CPU which will reduce the response time to the user.	
5.1.2	On-Line Sensor Data Analysis	The execution time of the compiler or interpreter will be facilitated by a large, fast, central processing system.	
5.1.2	Graphical Display Manipulation	The display data structure manipulation would be done by the small CPU (i.e., data display rotation, translation, etc.)	
		Using the small CPU memory for storing the display file for refreshing the display would avoid the loss of memory cycles by the large system.	
5.1.2	Lengthy Data Analysis Batch Type Problems	The response time to the user will be minimized by the use of a fast central processor system.	
5.1.2	File Retrieval and Updating	The file maintenance functions of the FMS would be accomplished in the central CPU system	

Reference Para. No.	Requirements	Advantages	Disadvantages
		which would facilitate the exchange of information between experimenters.	
5.1.3	Console Equipment (The console equipment is the same for all configurations.)	The console is designed to meet the experimenter's requirements. The use of the data tablet device reduces the processing load that would have been imposed by a light pen.	The special console design will be more expensive from both hardware and software aspects than a console supplied by the computer manufacturer.
5.1.4	User Location	This configuration will support a remote data analysis terminal with the only sacrifice being in slightly longer response time for some functions.	
5.1.5	System Usage	Response time for user/system conversation is not affected by the number of system users or processing demands on the central processor.	The small CPU's are not utilized unless their associated consoles are active.

Reference Para. No.	Requirements	Advantages	Disadvantages
5.1.6, 5.1.7, 5.1.8	System Operation and Development Considerations	Assignment of FMS functions unique to an individual user which do not require a powerful central processor should improve DMS throughput and/or provide more excess capacity.

A large number of on-line display consoles can be supported in this configuration (approx. 20-30).

The FMS/DMS processing can be accomplished in the same processing configuration. | The FMS program development must be accomplished on two different machines. |

5..3. 3 Configuration C Compared Against the System Requirements

Configuration C consists of a large simplex DMS processor, a medium size processor for FMS file processing and both local and remote medium size time-shared processors each supporting three on-line graphical display consoles. This configuration is compared with the system requirements discussed in Section 5.1 giving both the advantages and disadvantages.

CONFIGURATION   C

Reference Para. No.	Requirements	Advantages	Disadvantages
5.1.1	Data Management Subsystem		The FMS/DMS functions would have to be accomplished in separate processing systems. Since the DMS and FMS would not be implemented on the same processing system, the quick look and real-time processing functions might require certain manual procedures such as the mounting of tapes or switching of tape drives.
5.1.2	File Management Subsystem		
5.1.2	User/System Conversation	The limited number of display consoles attached to each medium size processor will provide for a faster system response to user actions than in configuration A . However, this response time will be longer than for configuration B .	All individual user actions from each console must be processed as real-time inputs to the time-shared medium size display processor.
5.1.2	On-Line Sensor Data Analysis		The execution time of the compiler or interpreter will be longer in this configuration than

CONFIGURATION · C·

Reference Para. No.	Requirements	Advantages	Disadvantages
			in Configuration A or B due to reduced processor performance characteristics.
5.1.2	Graphical Display Manipulation		The display data structure manipulation must be done by the central CPU (i. e., data display rotation, translation, etc.)· The display file for refreshing the display image would have to be stored in a special core memory for this purpose to avoid overloading the central processor system.
5.1.2	Lengthy Data Analysis Batch Type Problems		The response time to the user will be longer for these type problems than in Configuration A and B due to the reduced processor capabilities.
5.1.2	File Retrieval and Updating		The retrieving and updating of experimenter's data and program files would be less efficient in this configuration as each medium sized CPU would have to interface with a central

CONFIGURATION   C

Reference Para. No.	Requirements	Advantages	Disadvantages
			data bank. This would be necessary to enable experimenters to easily exchange data and programs and not be restricted to . a single console/CPU system.
5. 1. 3	Console Equipment (The console equipment is the same for all configurations)	The console is designed to meet experimenter requirements. The use of the data tablet device reduces the processing load that would have been imposed by a light pen.	The special console design will be more expensive from both hardware and software aspects than a console supplied by the computer manufacturer.
5. 1. 4	User Location	If there were a number of users at a single remote location then an entire configuration could be placed at that site with a communications link back to the central FMS data and program bank.	The two alternatives in this configuration for locating a console at a remote site are: a) to place a complete configuration C at a remote site with from 1 to 3 consoles; or b) to use a small processor as proposed in Configuration B . The disadvantage to approach a) is the cost that would be incurred to provide support for a single experimenter. The disadvantage

Reference Para. No.	Requirements	Advantages	Disadvantages
			to approach b) is that a portion of the FMS would have to be reprogrammed for the small computer, and the software system in the medium size processor would also have to be modified.
5.1.5	System Usage		The processing load can not be shared between processors. Response time for user/system conversation will increase with the number of on-line users and processing demands.
5.1.6, 5.1.7, 5.1.8	System Operation and Development Considerations	The majority of the FMS program development would all be done on the same processor.	The FMS/DMS processing must be divided between two processing configurations. Only a limited number (3) of on-line display consoles can be supported by each of the medium size processor configurations.

5.4   SUMMARY AND CONCLUSIONS

A set of basic system capabilities and requirements is postulated for a future on-line space data analysis system.   Three equipment configurations that are capable of meeting the system requirements are described in detail (including cost based on manufacturer's current prices.   Finally, the configurations are compared with the system requirements and the advantages and disadvantages of each are discussed.

A system consisting of several data analysis consoles tied directly to a large central processor (Configuration A) is desirable from a cost viewpoint if only a limited number of consoles are to be included in the system (i.e., 5 or less).   This system would be the easiest to implement with fewer hardware and software interfaces to contend with.   However, if the number of user consoles is expected to increase, then the cost of this approach makes it unattractive.   From the user's viewpoint, response times will not be as good in this configuration as in the other configurations considered due to the central processor performing all console servicing functions.

The system consisting of several consoles, each with a small processor which is interfaced with a large central processor (Configuration B) has many attractive features for implementing an online data analysis system.   For a system which includes more than 5 consoles, it can be seen from Figure 55 that this approach is the most economical.   The response time for the user will be optimized by a small dedicated processor providing real-time processing of user inputs as well as display manipulations such as rotation and translation. The small processor will utilize the large processor in a time-shared fashion for operations requiring greater storage capacity or speed.   In order to minimize the hardware and software interfacing problems, consideration should be given to the compatibility between the large and small processors.

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The third system, consisting of a medium-size processor servicing up to three data analysis consoles with a central medium size processor for providing data and program files (Configuration C), appears to be the least attractive of the configurations considered. Response time for servicing user inputs will be better than Configuration A but not as good as Configuration B. The software and hardware interfaces will be more complex and the over-all system costs are higher than for either of the other configurations.

In conclusion, the most desirable equipment configuration for implementing the experimenter's on-line data analysis system is a small processor for each display console to accomplish the real-time servicing of user inputs and some manipulation of the graphical displays, and a large time-shared processor for computational support (Configuration B).

The FMS and DMS processing requirements are complementary for operation in a time-shared environment: combining these functions simplifies information transfer problems. However, design of this type of complex time-shared system consisting of on-line users requiring fast response and the transfer of relatively large amounts of data should include the use of computer simulation techniques. It has been demonstrated in a previously-referenced report,[47] that optimum system parameters for time-shared systems cannot be determined from the analytical techniques similar to those that have been used in the past for batch processing systems.

FIGURE 55   COMPARISON OF AVERAGE SYSTEM
COSTS FOR CONFIGURATIONS A, B, AND C

6. SUMMARY

The interactive or on-line use of computers with information display equipment is a means for enhancing the ability to rapidly process and interpret large volumes of measurement data. In this section conclusions and recommendations related to the selection and use of equipment for this application are summarized, with cross references given by section or appendix number.

6.1 THE CONSOLE

Processed measurement data in a form which is ready for interpretation is frequently multi-dimensional, in that several items of descriptive information may be associated with each item of data. Information coding power such as provided by color, intensity, focus, or flicker modulation of a displayed image, is necessary for efficient display of multi-dimensional data (3.1). The coding power of full-color is approximately twenty times that of intensity (I; 3.1.1) or flicker (II; III; 3.1.2), forty times that of focus (3.1.2), and three and one-half times that of intensity, flicker, and focus combined (3.1.2). Also, the cost of full color equipment is estimated to be the same or slightly less than that of the focus-intensity-flicker equipment (IV). Therefore, full-color capability is recommended for multi-dimensional data display.

Depth coding of an additional information dimension is feasible using projection and optical illusion techniques in a standard two-dimensional display (VII; 3.1.3), but equipment for true three-dimensional display of computer-generated images has not advanced beyond the research state (V).

For the full-color capability in an individual display console the tri-color shadow mask type of cathode-ray tube is recommended in preference to other designs such as the Chromatron (VI; 3.1.4). The shadow mask design offers a number of advantages and has several relative disadvantages. One shortcoming in regards to luminance

may be overcome in the near future with the development of more efficient phosphors (IX). The resolution of the shadow mask is more limited than in other designs (3.1.5) but the resolution requirement in displays for processed data interpretation would not seem as great as, e.g., that of design graphics, provided a scaling capability is present.

In order to maintain a flicker-free image, display commands to a shadow mask tube must be repeated at a rate of 30 hertz or better (II). At a given refresh interval, image capacity may be limited by electron beam deflection speed (3.1.6) or the digital to analog conversion rate for display commands: at any refresh interval the storage capacity for display commands (3.3.1) might be the limiting factor. Techniques for increasing image capacity beyond that of existing equipment (VII) are within the state-of-the-art (VIII; 3.1.6) and should be employed for applications involving large volumes of data.

Finally, the specification of the display device for the user's console should include human factors considerations, particularly in regards to the control of eye strain inducing factors and soft X-ray radiation (3.1.7).

The specification of an input device for the user's console begins with the consideration of human factors (3.2) since this device provides the means for the user to "talk to" the computer and must be engineered for ease of use and acceptance by the user. The device recommended for the present application is the phase tablet (3.2.2) with which the user may simply use his finger (3.2.3) for the pointing, drawing, and text input functions.

Decisions as to which display and input support functions should be implemented in the form of console peripheral devices may be made using as criteria the degree of confidence with which a function may be pre-defined (since the definition will be "frozen" once the function is implemented in hardware) and anticipated frequency of use. Based primarily upon these criteria it is recommended that a small computer's memory serve for general display memory purposes in

the console design (3.3.1); that at least one console in a multiple user system be capable of time multiplexing between this display memory and a high data rate, high capacity drum (3.3.1); that circuits be provided for displaying a "capture-area" sized cursor symbol slaved to phase tablet generated input position signals, and for detecting coincidence of electron beam position and input position at a variable reduced level of precision (3.3.2); and that a programmable short segment stroke or Lissajous Figure generator be used for character, vector, and curve generation (3.3.3). With the exception of the hardware function of permanently recording data display images it is recommended that all other console support be provided by computer programs (3.3.4). The hardcopy function should receive relatively infrequent use, some of which may be concerned with dynamic data displays. Therefore, a single off-line device with color capability should suffice for this purpose, provided it is properly modified and backed up with computer programs for the generation of motion pictures (XIII).

For the specified user console with its single display and single input device, pilot tests (VII) substantiate the desirability of techniques such as a light symbol (X; 3.2.1) and probability typewriter (XI) for efficiency of console use.

6.2 SOFTWARE

The design of the software is centered about a proposed set of user primitive and control operators (4.1). This set of operators provides the space data analyst with a hierarchial system for specifying procedures as exemplified by the work of Culler[36] in the development of an on-line numerical analysis system. An example of the use of these primitive operators is presented (XII). With this approach the user is able to develop complex data analysis and display strategies by using a set of basic system primitive operators. The application of the strategies to data sets is a simple and straightforward operation of telling the system to apply strategy A to data set B similar to the approach developed by Goodenough[40] (4.1.10).

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The software to support the user primitive and control operators is a configuration independent, file oriented, interpretive system (4.5). The interpretive processor receives as input a symbol string representing a strategy which identifies computational sequences and display representations consisting of combinations of primitive operators. The processor then accesses the appropriate data and system files to execute the desired operations and updates the display data base so the user can view the result. This approach is a framework for implementing the File Management Subsystem (FMS) portion of an on-line data analysis system. The main elements of this system are shown in Figure 39 (4.5).

6.3   HARDWARE

A set of basic system capabilities and requirements is postulated for a future on-line space data analysis system (5.1). Three equipment configurations that are capable of meeting the system requirements are described in detail (including cost based on manufacturer's current prices (5.2)). Finally, the configurations are compared with the system requirements and the advantages and disadvantages of each are discussed (5.3).

A system consisting of several data analysis consoles tied directly to a large central processor (Configuration A, 5.2.1) is desirable from a cost viewpoint if only a limited number of consoles are to be included in the system (i.e., 5 or less). This system would be the easiest to implement with fewer hardware and software interfaces to contend with. However, if the number of user consoles is expected to increase, then the cost of this approach makes it unattractive. From the user's viewpoint, response times will not be as good in this configuration as in the other configurations considered due to the central processor performing all console servicing functions.

The system consisting of several consoles, each with a small processor which is interfaced with a large central processor

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(Configuration B, 5.2.2) has many attractive features for implementing an on-line data analysis system. For a system which includes more than 5 consoles, it can be seen from Figure 55 (5.4) that this approach is the most economical. The response time for the user will be optimized by a small dedicated processor providing real-time processing of user inputs as well as display manipulations such as rotation and translation. The small processor will utilize the large processor in a time-shared fashion for operations requiring greater storage capacity or speed. In order to minimize the hardware and software interfacing problems, consideration should be given to the compatibility between the large and small processors.

The third system, consisting of a medium-size processor servicing up to three data analysis consoles with a central medium size processor for providing data and program files (Configuration C, 5.2.3), appears to be the least attractive of the configurations considered. Response time for servicing user inputs will be better than Configuration A but not as good as Configuration B. The software and hardware interfaces will be more complex and the over-all system costs are higher than for either of the other configurations.

In conclusion, the most desirable equipment configuration for implementing the experimenter's on-line data analysis system is a small processor for each display console to accomplish the real-time servicing of user inputs and some manipulation of the graphical displays, and a large time-shared processor for computational support (Configuration B).

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system parameters for time-shared systems cannot be determined from the analytical techniques similar to those that have been used in the past for batch processing systems.

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APPENDIX I
COLOR VALUE DISCRIMINATION MEASUREMENTS

A. Purpose

The work described here was undertaken for two purposes. The first was to establish a basis for comparing color with the black and white intensity-flicker-focus combination as media for information transfer in computer generated displays. The second purpose was to develop preliminary color and intensity scales for information coding purposes in later phases of the effort.

B. Conditions

Observations were made using the Experimental Dynamic Processor, DX-1, at AFCRL. The available equipment included a three-color, shadow mask type cathode-ray tube driven at a 30 c.p.s. refresh rate by a drum buffer. The tube, with its choice of phosphors, was a 1961 vintage standard R.C.A. product. The intensity of each of the three primary colors was programmable in 16 levels and beam spot position was programmable on a 512 point square raster. An existing computer program was used to generate color "swatch" rectangles such as shown in Figure I.1.
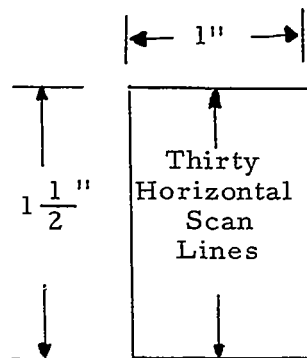
FIGURE I.1 UNIFORM COLOR RECTANGLE

Columns were constructed by displaying rectangles one above the other with no separating space between rectangles. Before the observations were made, it was noted that the display intensity at the right and left column edges was greater than at the center, indicating non-linearity in the electron beam deflection velocity. Strips of masking tape were placed on the face of the tube to obscure these higher intensity edges. This reduced the observable column width to 1/2 inch, <u>but improved the uniformity of color within each rectangle.</u>

C. Approach

Two observers worked together in adjusting the color values, working upwards in one column at a time. The color value of each rectangle was adjusted so that it appeared to both observers to be distinctly but barely different from that of the rectangle below it. Following this plan, the intensity values of each primary color taken alone were varied. Then the secondary values were explored by setting a primary at full intensity and stepping through another primary, for all combinations. Finally a primary at a time was varied with the remaining two set at full intensity. These paths correspond to the edges of a cube (Figure I.2) in which all 3-intensity color mixtures may be mapped.

D. Observations

Each intensity adjustment which produced a discernable change in color value is represented by an "x" in the Figure I.3 table. In addition to following the color solid edges, the diagonal from black to white was explored. In doing so, it was found necessary to reduce the intensity of the blue primary to one step less than the red and green settings in order to obtain satisfactory grays. Upon completion, several control observations were made. The earliest observations were replicated in order to be sure that the observers' discrimination judgement had not drifted. No drift had occurred. Then the second-from-last values along the three edges leading to white were displayed together and were found to be discriminable.

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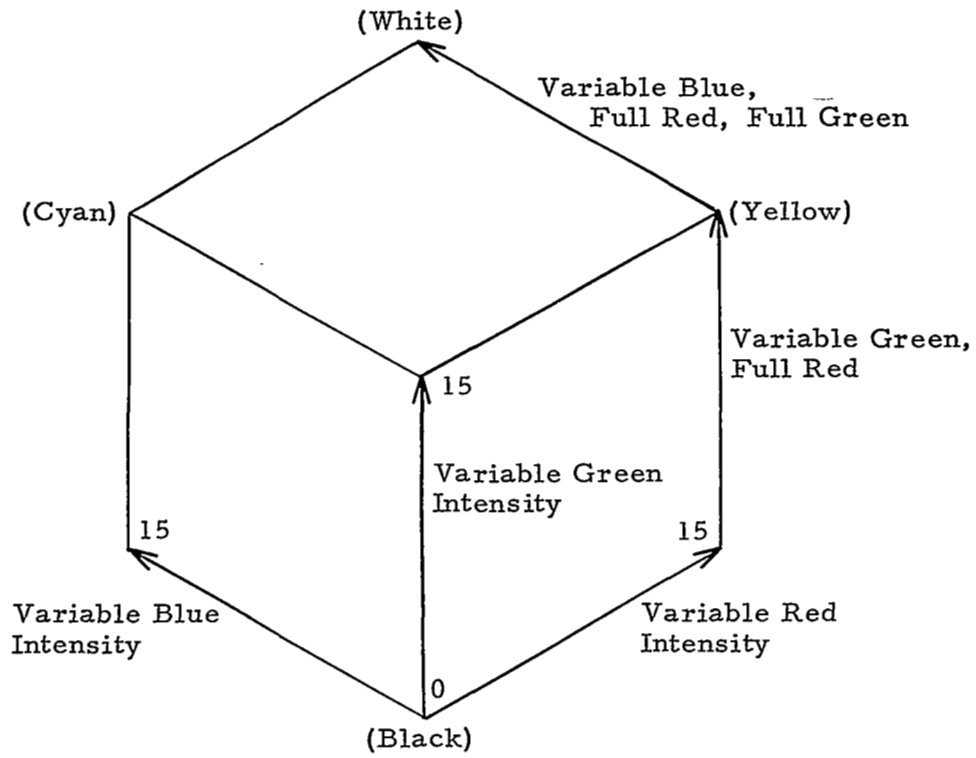
FIGURE I.2   ADDITIVE COLOR MIXTURE SOLID

Cube Edge (Color Vector)	Variable Additive	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Black - Green	Green	x				x	x	x	x	x	x			x			x
Red - Yellow	"	x					x	x	x	x	x	x	x		x		x
Blue - Cyan	"	x						x		x		x			x		x
Magenta - White	"	x							x		x		x		x		x
Black - Red	Red	x				x	x	x	x		x		x		x		x
Blue - Magenta	"	x						x			x		x		x		x
Green - Yellow	"	x									x				x·		x
Cyan - White	"	x										x			x		x
Black - Blue	Blue	x					x		x		x			x			x
Red - Magenta	"	x						x		x		x			x		x
Green - Cyan	"	x							x				x				x
Yellow - White	"	x							x				x				x
Black - White	All 3*	x				x	x	x	x	x	x	x	x		x		x

* With Blue at one intensity level less than indicated, except at zero.

FIGURE I. 3   COLOR MIXTURE DISCRIMINABILITY OBSERVATIONS

E.   Discussion

One way in which the observations may be summarized is by counting the number of discrimination intervals on each side of the color cube and along the black to white diagonal, as in Figure I. 4. The first row in this table provides a relative basis for comparing the information coding power offered by color with the power of black and white intensity.

Color Additives

Base Color	Green	Red	Blue	White
Black	8	8	5	10
Red	9	x	5	x
Blue	5	5	x	x
Green	x	3	3	x
2 Primaries	5	3	3	x

FIGURE I. 4   COLOR AND INTENSITY CODING POWER

It is interesting to note that the red-yellow vector contained more usable coding levels (nine) than does the black-green vector (eight). This singular instance of more coding power in the secondary mixture than in the primary hue may be due to the fact that visual response to color peaks in the yellow-green region of the spectrum or it may be due to the adjustment of the equipment. The truest yellow observed was on this red-yellow edge, at R 15, G 11, B 0 (rather than at the R 15, G 15, B 0 corner, which appeared to be a yellow-green).

A color coding scale of 39 discriminable steps may be constructed by following the edges from black (1), to red (8), to yellow (9), to green (3), to cyan (3), to blue (5), to magenta (5), to white (5). This number of steps is probably a maximum for the edges involved. As the size of the color "swatches" decreases (or as the distance separating them increases), it is expected that the number of discriminable steps will decrease: color discriminability in "point" displays is discussed in Appendix VII.

Since performing this study the color equipment of the DX-1 has been modified in order to obtain more linear response to the 16

intensity settings of the three primaries. Although this affected the balance of response as shown in Figures I.3 and I.4, the total color coding power was not appreciably affected.

APPENDIX II

ON THE USE OF FLICKER AS
A MEDIUM FOR INFORMATION TRANSFER

The number of ways in which a graphical display can represent information is determined by the available set of coding modalities. In present day on-line computer displays, this set commonly includes number, size, shape, position, orientation, line length line structure, and sometimes motion, intensity, and line width. Experiments with the use of color and depth are being conducted in the laboratories. Very little attention has been given to focus or flicker, although it would seem that flicker, in particular, has definite potential as a medium for information transfer.

A.   Definitions

Flicker is the visual effect produced by alternating light and darkness. As the frequency of alternation increases from zero hertz the effect is at first coarse, then progressively finer, until it disappears at what is called the flicker-free threshold, or critical fusion frequency. A classic example of flicker is provided in the technology of motion picture projection. As a means of preventing vertical image movement when film advances from frame to frame, projection is interrupted between frames. The resulting alternation of light and darkness on the projection screen creates an objectionable flicker at 24 frames per second (16 in the case of home movies), the rate of film advance. The usual solution is to double the alternation frequency by projecting each frame twice. Even at a projection rate of 48 hertz the projected luminance must be limited to less than 20 foot-lamberts in order to assure fusion of flicker in the image perceived.

The flicker sometimes observed in sustained cathode-ray tube displays is generally not pure flicker. A scanning effect is also present, which is produced by motion of the electron beam spot

during the generation of an image on the phosphor surface. While this effect varies with the time required to generate an image, a means for its control lies in the fact that the eye can be fooled. Consider the case of commercial television, broadcast at 30 frames per second. A frame is generated by scanning the beam first through the odd raster lines, then through the even lines: this image interlacing technique doubles the vertical rate of beam movement, rendering the scanning effect less noticeable. Image interlacing, not to be confused with computer program interlacing, has also been used with success in computer display programming. In an instance described by Ivan Sutherland[2] it is reported that "the flicker of the display is reduced greatly by not displaying each spot successively". However, the flicker in this instance (scanning effect) is transformed to a crawling or twinkling effect, depending on the interlace method, and in the case of twinkle fine detail may not be readable.

While it is true that scanning and flicker are both produced by the cyclic energizing of phosphor at a common regeneration frequency, it is erroneous to conclude that two names have been given to a single effect. A blinking point display exhibits flicker but not scanning. A single oscilloscope trace exhibits scanning but not flicker. In the general case the extent to which the causes of these effects may vary independently is indicated by the expression

$$T_r = t_s + t_d \; ,$$

where T_r is the display regeneration interval,

t_s is image scanning time, and

t_d is a time delay between scans. A delay may be imposed by the manufacturer to prevent phosphor damage. In a computer program driven display, delays will occur as housekeeping or non-display program functions are performed. In a constant frequency buffer driven display the amount of data in the display file determines

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the ratio of t_s/t_d. Nevertheless, it is customary in the literature, and adequate for many purposes, to consider flicker and scanning as a single cyclic effect. Except where a distinction is specifically made, the term "flicker" will be used in the single effect sense for the remainder of this discussion

B.   The Critical Fusion Frequency

If flicker is to be controlled it would be useful to know the value of the critical fusion frequency at which flicker disappears. A search through the literature of computer display work, which is a rich source of advice on the value of the critical fusion frequency, reveals little agreement and leads to the inference that a wide variation is possible. Figure II. 1 summarizes the results of a recent search. There are several known factors which affect flicker fusion. Most of these can be controlled.

Regeneration Frequency (hertz)	Remarks from the literature
4	A text display flickers and is quite disturbing. These remarks are not applied to a similar display replenished at about 12 paints/sec.
17	Exceeds the upper limit of the flicker region.
30	The lower limit for flicker-free display, according to several sources. This rate is compatible with a standard 1800 RPM drum or disc buffer.
40+	Required to avoid flicker under normal lighting conditions.
50 - 60	Desirable in a high performance, on-line, alpha-numeric and graphic display console.

FIGURE II. 1   INDICATIONS OF VARIATION IN THE CRITICAL
FUSION FREQUENCY VALUE

C.   Factors Affecting Fusion

Image persistence reduces flicker. A P33 phosphor, the spectral distribution of which peaks near 5900 $\overset{o}{A}$ (orange) has long persistence and is a good choice for flicker reduction in stationary displays. A P7 phosphor with blue and yellow components is generally specified in display console design for long life, medium image persistence, and convenience of light pen engineering. The blue component which fluoresces during phosphor activation, and to which the light pen is sensitive, may be masked with a yellow filter in order to reduce flicker. A low persistence phosphor such as P16 which peaks around 3800 $\overset{o}{A}$ (violet) is sometimes specified for photographic applications or dynamic displays in which persistence "ghosts" would be objectionable.

Display luminance is a primary factor determining the critical fusion frequency. The effect of luminance can be demonstrated on a console with intensity control: decreasing the intensity reduces flicker.

In a recent display demonstration, this author observed a case of flicker elimination by room darkening. The image displayed was a small, high line density raster regenerated at approximately 30 hertz on a P7 phosphor. The flicker under room lights appeared as a rapid scanning effect. The causative factor associated with ambient lighting was not determined, but visual field contrast and stroboscopic interference from the overhead fluorescents might be suspected. Display contrast may be increased with a filter of circularly polarized cellulose acetate, such as Polaroid Corp. stock no. HNCP37 x .030". This does not interfere with light pen sensing.

Finally, human factors may affect the perception of flicker. Unfortunately, little is known about the physiological mechanism which produces flicker fusion. The age of the observer has been found to be one factor.[14]

Phosphor type, display luminance and ambient lighting are controllable factors. Obviously luminance and flicker would interact if used in conjunction as coding modalities, but this would be an unlikely combination. Some ambient lighting is necessary when written material is used at the display console, and is probably necessary to prevent eye-strain. Human factors are not controllable: if they have sufficient effect on the fusion value then "tunability" might be a requirement in any system offering flicker control.

D.   Methods for Flicker Control

Flicker elimination is well within the state of the art: several models of buffered display consoles operating at 60 hertz are commercially available. A somewhat more challenging proposition is the control of flicker as a display technique. The difficulty is increased by the desirability in many cases of having parts of the display image flicker while the rest stays flicker-free. However, given a value of scanning time t_s which is small enough to eliminate the scanning effect, and a fixed set of the factors which affect fusion, then flicker control reduces to control of the delay time t_d in the regeneration interval T_r for an image part, while maintaining a constant value of T_r for other parts of the image.

With present day equipment the most direct form of delay time control would appear to be the enabling of display for an image part only on every n^{th} scan, where n is a non-zero positive integer. Flicker control would be limited: in a system operating at 60 hertz, for example, image part regeneration frequencies would be limited to 60, 30, 20, 15, 12, 10,...hertz. Although the apparent linearity (and therefore the usefulness) of such a progression is subject to question, a reasonable degree of usefulness is suspected. This suspicion is based on the logarithmic nature of human response to sound frequency: in music the octave interval represents a frequency change with a factor of two.

This display masking form of delay time control might be implemented for experimental purposes by programming the alternate storing and erasing of display information. A more efficient method could be realized with special circuitry which would, in effect, compare scan count (modulo n) against 0 for an image part in order to enable display. In a recirculating buffer driven display system the display information and associated n values, which would be input to this circuitry, might be stored in parallel tracks or delay lines.

In a computer memory driven system the display address counter (which ordinarily is incremented by a unit count after a break cycle) or a display skip command might be altered to permit conditional skipping over image parts. Unless compensatory delays were introduced, however, this would decrease T_r for the entire image. A different approach might be more appropriate for this type of system. The development of more flexible methods for flicker control remains to be justified by demonstrated usefulness of flicker as a coding modality.

E.   Applications

A simple application of flicker is the blinking of image parts at 1 to 3 hertz as an attention getting device. Blinking control is available in many display systems and dates back at least to the SAGE system. A more sophisticated application would be the use of flicker for quantitative information transfer. A limit for this application is reflected in the estimate that no more than two coding levels of flicker can be identified.

Pushing the state of the art a bit, more ambitious applications in the realm of man–computer symbiosis are suggested by the observation that in man, discrimination (the ability to perceive changes) is much more acute than the ability to identify coding levels in isolation. This suggests that qualitative information might be conveyed by full spectrum flicker coding of appropriate information. The

usefulness of qualitative impressions in symbiosis can be illustrated
by a number of examples. Consider computer aided design of a bridge
section with structural members flicker coded to indicate the forces
in them, rather than labeled with corresponding numerical values.
The eye is led more quickly to problem areas and the display is less
cluttered with detail. Light pen interrogation might be used to evoke
a numerical value of interest. The bells, memory address neons and
accumulator loudspeakers sometimes used for monitoring and debug-
ging operations in early generation computers might be replaced by a
displayed flow chart model of the program, in which flicker indicated
frequencies of program path and loop use during program operation.
In real-time data monitoring, measurements of data quality might be
flicker coded. For data analysis, the flicker coding of statistical con-
fidence might be appropriate. The irritating effects of flicker which
have been reported (phychological in the 8 to 15 hertz range, physio-
logical in the 4 to 7 hertz range) reinforce the natural analogy of
flicker and quality.

APPENDIX III
FLICKER DISCRIMINATION INVESTIGATIONS

A.   Purpose

   This study sought to determine the information coding power of image flicker for a computer generated display, based on the number of discriminable frequency levels.

B.   Conditions

   Equipment used was the Whirlwind computer, located at the corporate headquarters of Wolf Research and Development Corporation in Concord, Mass. Throughout the study a single sixteen inch direct view cathode-ray tube was used, at a constant intensity setting. The phosphor type was P7. Artificial ambient lighting was constant, but some variation of natural ambient lighting was unavoidable.

C.   Method

   A computer program was prepared which facilitated variation of image repetition (flicker) rates in several display images. A 60 cps internal clock was used to obtain 60, 30, 20,...,60/n hertz repetition rates. Also, the execution time of a simple program loop was used for the same purpose when repetition rates not given by 60/n were desired. The calculated time periods established using the program loop were tested using a program designed to count repetitions over a ten second interval (as established with the 60 cps clock and verified by stopwatch). Since the number of repetitions was an integer count, this measurement was subject to an error of $\pm .999$ repetitions in the ten second period (Figure III. 1) or $\pm .099...$ hertz. This error is of course most meaningful at the low end of the flicker frequency range.

Measured Count = 1
(-.99.. Error)

Measured Count = 2
(+.00.. Error)

Measured Count = 3
(+.99.. Error)
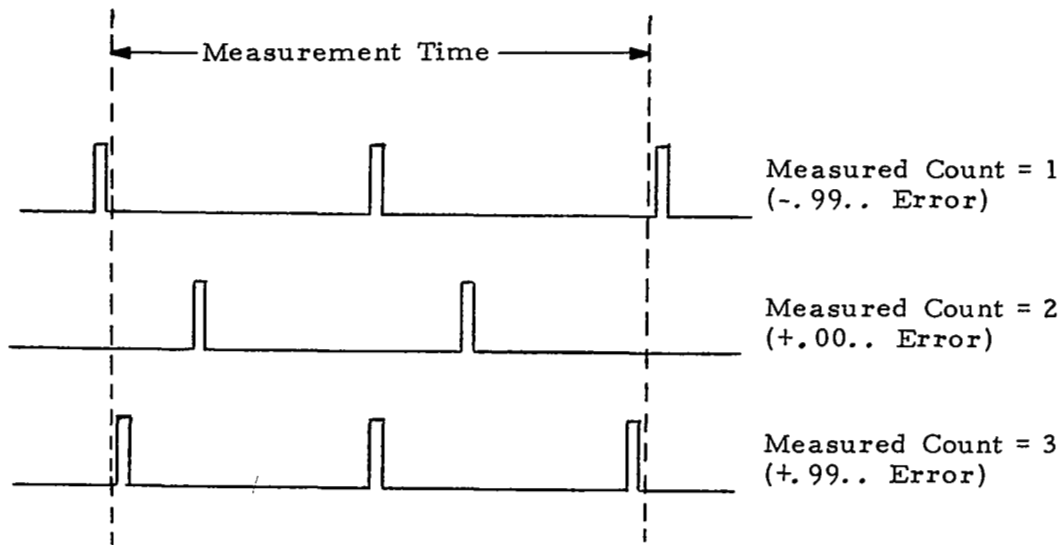
FIGURE III.1 METHODOLOGICAL ERROR IN COUNTING DISPLAY
REPETITION PULSES

Using this program, a series of three experiments was
conducted, each aimed at measuring or verifying minimum frequency
scale intervals separating discriminable pairs of flicker frequencies
over the range of the scale. These experiments were conducted in the
following order of increasingly difficult conditions.

D.   Detection of Change Experiment

Two image patterns, each composed of three flickering
figure eights, were used (Figure III. 2). Distances between centers
were 2. 4" and 3. 8"

Six subjects were tested in the following manner. One of
the patterns was displayed with the three figure eights flickering at a
common frequency. The frequency of one figure eight, chosen ran-
domly, was gradually changed until the subject successfully identified
the figure eight that had changed. He was informed whether an increase
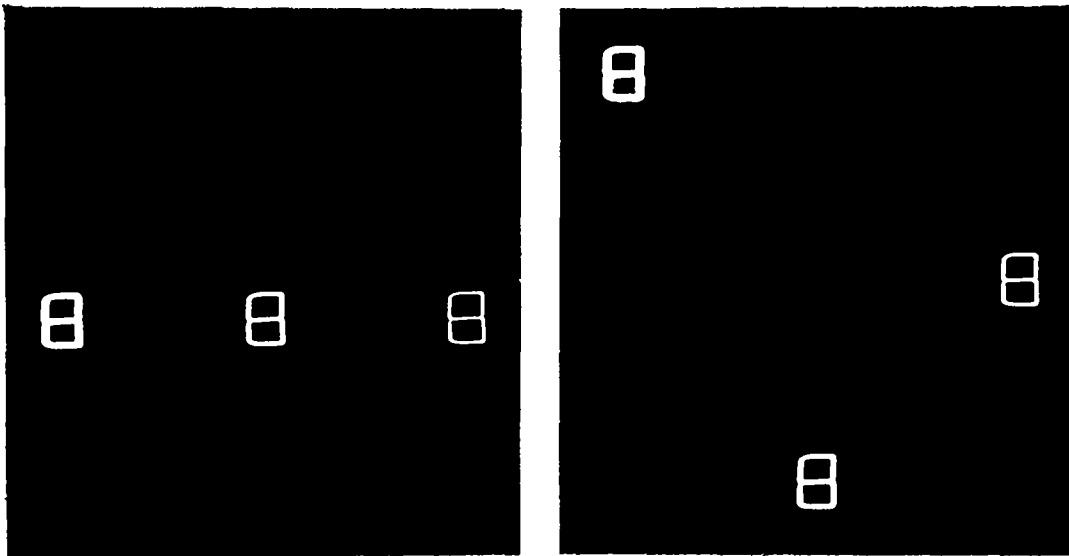
FIGURE III. 2   DETECTION OF CHANGE PATTERNS

or decrease was to be expected, and was asked to be quite sure of his conclusion: he was not informed however of his errors. After successful identification, the frequencies of the three figure eights were set at the new (detected) value.

Thus, the frequency range was stepped through, in increasing and decreasing directions for each subject. In half the cases the sequence was increasing first, decreasing second. The maximum frequency used was 60 hertz, although some subjects reported perception of intensity change at higher frequencies. The minimum frequency used was 1 hertz since it was felt that at lower frequencies the time required to detect a change would be excessive.

The frequencies at which changes were successfully detected were recorded and plotted on log-log paper. These results are shown in Figure III. 3.

Based on these results, three flicker scales were established for further testing. One corresponded to the best performance
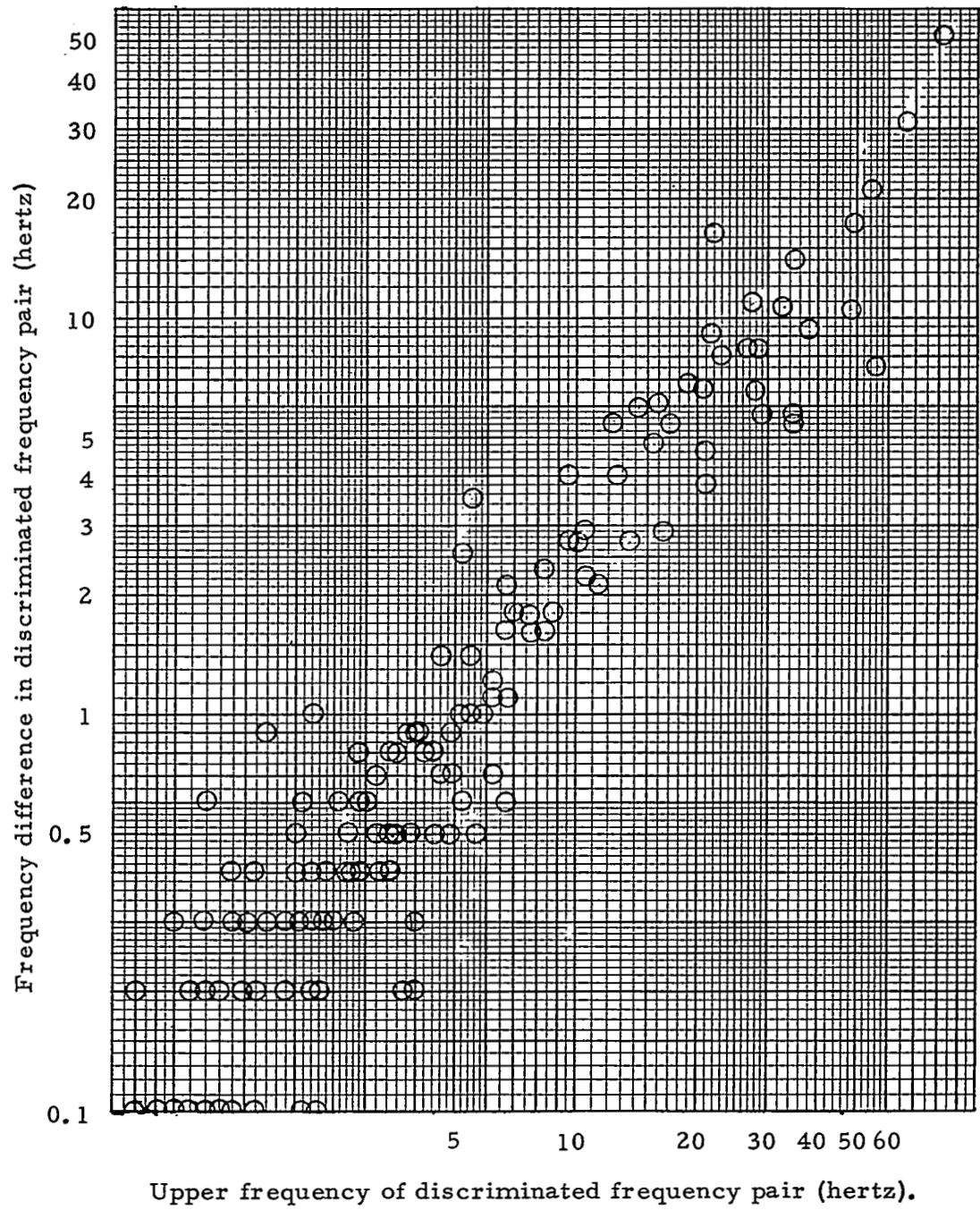
FIGURE III.3   RESULTS FROM CHANGE DETECTION EXPERIMENT

and consisted of sixteen "notes"; another corresponded to worst per-
formance and consisted of eight "notes"; a third consisted of twelve
"notes". The frequencies of the notes in these scales are given in
Figure III. 4.

16 Note Scale	12 Note Scale	8 Note Scale
60	60	60
40	30	20
30	20	10
20	15	4. 61
15	10	2. 72
10	6. 66	1. 76
8. 57	4. 61	1. 20
6. 66	3. 32	1. 00
5. 00	2. 40	
4. 00	1. 82	
3. 16	1. 40	
2. 50	1. 11	
2. 00		
1. 62		
1. 33		
1. 11		

FIGURE III. 4   FREQUENCIES OF
FLICKER TEST SCALES

E.   Relationship Identification Experiment

In this experiment discriminability among three fre-
quencies at a time was tested. Triplets of adjacent notes were selec-
ted from the frequency scales, at random, and were used in setting
three flicker rates in the figure eight display patterns. For each such
triplet the subject was asked which figure eight was flickering fastest,
which slowest. Each time the display was terminated at the end of
five seconds. Each triplet was used a total of three times in the se-
quence for each subject. The results of this experiment are shown in
Figure III. 5
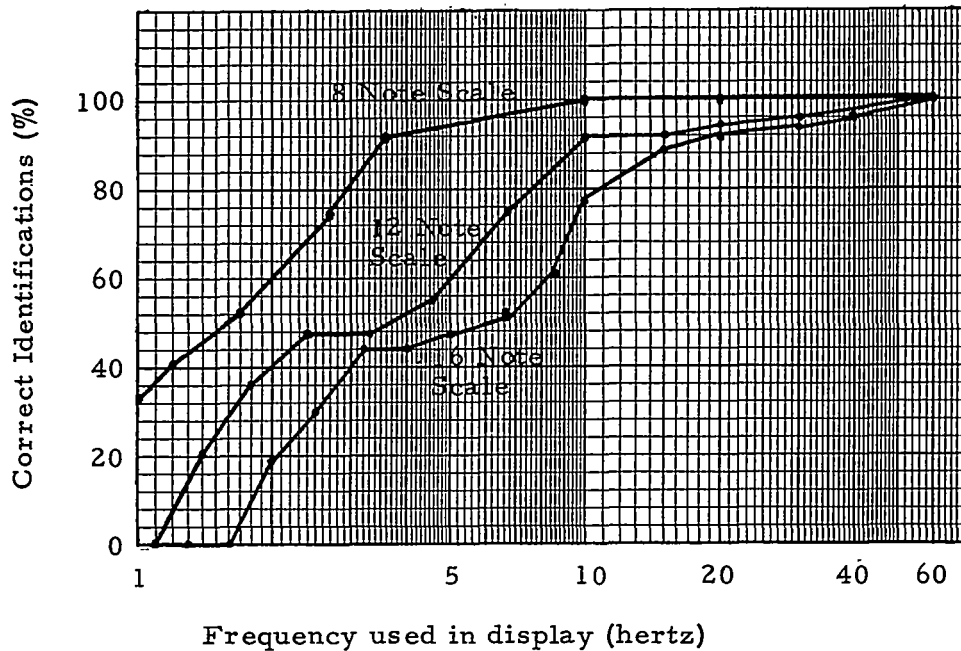
FIGURE III.5 RESULTS OF RELATIONSHIP IDENTI-
FICATION EXPERIMENT

F. Pattern Recognition Experiment

The display image in this experiment consisted of an 8 x 8
grid of equally spaced points, the display of which was flicker modu-
lated with various test patterns. Four to seven flicker rates were
employed in the six patterns shown in Figure III. 6.

Flicker frequencies from the three scales were used in
subjective evaluation of the scales in pattern displays. Rather than
using subjects the experimenter examined each pattern in all fre-
quency sets in order to evaluate the obviousness of the pattern, and
high and low frequency points or lines. In these displays points of
common frequency were generated almost simultaneously.

III-6

```
C  B  B  B  B  C  C  D        E  E  D  D  D  D  E  E
C  B  A  A  B  B  C  D        E  D  C  C  C  D  D  E
C  B  A  A  A  B  C  D        E  D  C  B  B  C  D  D
C  B  A  A  A  B  C  C        E  D  C  B  A  B  C  D
C  B  B  B  B  B  C  C        E  E  D  C  B  B  C  D
C  B  C  C  C  B  C  D        E  G  E  D  C  C  C  D
C  B  C  C  C  B  C  D        E  G  G  E  D  D  D  D
C  B  B  C  C  B  C  D        E  G  G  G  E  E  E  E


C  B  B  C  D  E  G  H        C  C  C  C  B  B  B  B
B  C  B  C  D  E  G  H        C  D  D  C  B  A  A  B
A  B  C  C  D  E  G  H        C  D  D  C  B  A  A  B
A  B  C  C  D  E  G  H        C  C  C  C  B  B  B  B
B  C  D  D  C  D  E  G        D  D  D  C  C  C  B  B
C  D  E  E  D  C  D  E        D  E  D  D  D  C  B  A
D  E  G  G  E  D  C  D        D  E  E  E  D  C  B  A
D  E  G  G  E  E  D  C        D  E  G  E  D  C  B  B


B  B  B  C  D  E  E  E        H  H  G  E  D  D  D  D
B  A  B  C  D  E  G  E        H  G  E  D  C  C  C  D
B  B  B  C  D  E  E  E        G  E  D  C  B  B  C  D
C  C  C  C  D  D  D  D        E  D  C  B  A  B  C  D
E  E  E  E  D  D  D  D        D  C  B  A  B  C  D  E
G  G  G  E  D  C  C  C        C  B  A  B  C  D  E  G
G  H  G  E  D  C  B  C        B  A  B  C  D  E  G  H
G  G  G  E  D  C  C  C        A  B  C  D  E  G  H  H
```

FIGURE III.6   PATTERNS FOR RECOGNITION EXPERIMENT

In general the ability to determine the structure or general shape of the contour lines seemed inversely proportional to the flicker frequency. Unfortunately, on the other hand, the ability to distinguish between levels of flicker frequencies is best at the higher frequencies as indicated by the second experiment and confirmed in this experiment. Determining the relative frequencies of adjacent points was possible in the medium to high frequency range for all scales but took more effort in the 12 and 16 note scales than would be desirable. Distinguishing between two extreme highs or lows was very difficult using the 8 note scale and impossible using the 12 and 16 scales.

The experiment indicated that if one is only interested in the highs, lows and "steepness" between them, the 16 level set of frequencies should be useful. If one were interested also in a more detailed description of the structure of the pattern, the 8 level set of frequencies would be required.

A 10 level set using the highest five values of the 16 level set and five lower values of the 8 level set would seem to provide a happy compromise.

In this experiment, programming requirements for the Whirlwind I necessitated displaying of all points with the same flicker frequency simultaneously. If points with the same frequency were allowed to flicker at random times, this visual cue to the pattern would be lost. One the other hand, a more densely packed grid of points might be expected to enhance flicker pattern recognition.

G.   Conclusions and Remarks

This study indicates that the maximum useful number of flicker levels in a computer generated display is approximately twelve. Beyond this conclusion, several observations may be of interest.

III-8

1. As flicker frequencies decrease the time required for discrimination increases. Below about 10 hertz, 5 seconds is sometimes not long enough a time for discriminating among the frequency triplets used in the second experiment.

2. Below about 10 hertz the observer of flicker sometimes loses orientation as to what is "fast flicker" and what is "slow flicker". In this region the subjects were sometimes convinced that an erroneous identification was correct.

3. Phase shifting of two elements flickering at nearly the same frequencies sometimes provides a cue to minute frequency differences. One subject learned quickly to use this cue in the first experiment and performed exceedingly well in regards to discrimination, but exceedingly poorly in regards to time consumed. His performance data were thrown out of the results.

4. Phase shifting sometimes produces a neon-sign effect, i.e., in the first experiment at low frequencies, some subjects perceived a single figure eight moving through the pattern positions, rather than three figure eights flickering independently. When a subject entered this "Mode" his performance usually deteriorated. From a human factors point of view, flickering displays tired the eyes of the subjects, more often than not.

5. The critical fusion frequency for flicker under the test conditions was approximately 32 hertz. Above this level increases in frequency were detectable as increases in intensity.

APPENDIX IV
COST COMPARISON, FOCUS-INTENSITY-FLICKER
VERSUS COLOR

To arrive at a relative cost comparison of a color display and a special black and white display, common components may be eliminated and only the differences considered.

For instance, both color and black and white systems require a computer, display memory, x-y deflection, cabinet, light pen, etc., which are of comparable cost to the two systems. But the cost of the color system's six convergence coils, purity coil, lateral magnet and three gun color tube with shadow mask and phosphor dot screen, all with supportive circuitry, must be estimated and compared with the cost of the features unique to the focus-intensity-repetition rate (FIR) system. In particular, the cost of 14 counters (for varying the repetition rate of display spots), plus the assorted circuitry of intensity and focus control must be compared with unique color components. This is done in Figure IV.1.

Note also that this "difference-cost" analysis indicates that the two systems are about equal in cost, the color system being slightly less than the FIR system. The extra cost of the six convergence coils of the color system is offset by the fourteen counters of the FIR system. An average cost of $100 per counter is assumed even though counters involving n/2 or even powers of 2 are relatively cheaper. Non-powers of 2 require counters costing more than $100. DEC (Digital Equipment Corporation) module prices have been quoted because they appear to be relatively inexpensive compared with certain other vendor's components.

In the accompanying drawings of the FIR (Figure IV.4) and Color (Figure IV.3) systems, components are shown in block diagram form. In both decoding systems, it is assumed that a CRT is driven by signals which are read from a drum rotating at 60 R.P.S. Because

Quantity	Item @ Unit Cost	Subcost
COLOR:		
12	DEC flip flops @ $26.20	$314.40
3	DEC 601 amplifiers @ $60	180.00
3	CDC Hold & Sample (transient shunts) @ $200	600.00
3	DEC A607 analog amplifiers @ $180	540.00
1	lateral magnet, purity coil, and circuitry	100.00
1	Three gun color tube, shadow mask, phosphor dot pattern (over & above b & w)	90.00
3	DEC A704, or Philbrick reference supply @ $184	552.00
		$2,376.40
FIR :		
8	DEC flip flops @ $26.20	209.60
20	AND gates @ $10.00	200.00
4	DEC 601 amplifiers and divider networks @ $60.00	240.00
2	DEC A704 amplifiers @ $184	368.00
2	DEC A201 amplifiers @ $180	360.00
4	DEC Inverters @ $27.20	108.80
2	CDC Hold and Sample @ $200	400.00
14	counters @ $100 average	1400.00
		$3,286.40

FIGURE IV.1   ESTIMATE OF COST DIFFERENCE FOR COLOR VERSUS FOCUS-INTENSITY-REPETITION RATE DISPLAYS

each system uses the same type of data (32 parallel bits, representing x position (10 bits), y position (10 bits), and 3 information coding attributes (4 bits each)), the same drum design may be used in both systems. In addition, each system uses the same x-y deflection system design, and it need not be shown here. The parallel bit patterns read from both drums are shown for comparison in Figure IV.2. It should be noted that the intensity and focus bits are the binary representations of analog levels, whereas the flicker bits are used to determine if the point should be displayed during the present display cycle.

        The flicker control logic is designed to accept a 4 bit code which indicates the repetition rate for current display point. It must then determine if the point should be displayed during the current drum revolution. Since the programmable flicker rates are $60/n$ for $n = 1, 2, \ldots, 15$, let the four bit code represent n_8. If the output of the nth gate of an "n" value decoding network is "and" gated with the output of a modulo n counter, a display qualifying signal will be obtained. Since display commands are read for one point at a time, the output of these "and" gates for all values of "n" may be "or" gated to yield a single signal which qualifies the intensity signal.

Bit No.	FIR	COLOR
0 ↓ 9	x position	x position
10 ↓ 19	y position	y position
20	2^3 focus	2^3 red intensity
21	2^2 "	2^2 "
22	2^1 "	2^1 "
23	2^0 "	2^0 "
24	2^3 intensity	2^3 green intensity
25	2^2 "	2^2 "
26	2^1 "	2^1 "
27	2^0 "	2^0 "
28	2^3 flicker	2^3 blue intensity
29	2^2 "	2^2 "
30	2^1 "	2^1 "
31	2^0 "	2^0 "

FIGURE IV.2   DISPLAY COMMAND COMPARISON
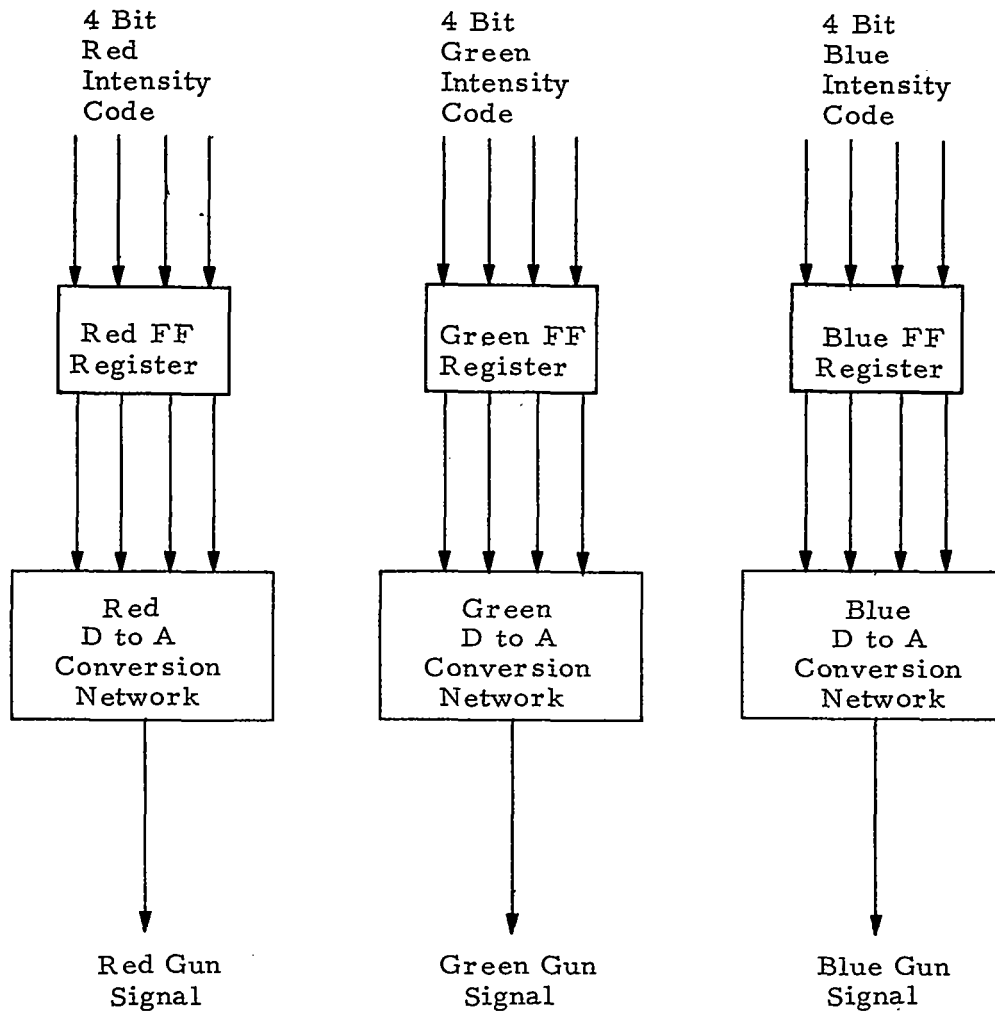
FIGURE IV. 3   COLOR DECODING SYSTEM

4 Bit
Focus
Code

4 Bit
Intensity
Code

4 Bit
Repetition Rate
Code (n_8)

Drum
Revo-
lution
Pulse
(60
Hertz)

Focus FF
Register

Intensity FF
Register

Flicker
Control
Logic

Focus
D to A
Conversion
Network

Intensity
D to A
Conversion
Network

Focus
Coil
Signal

Beam
Intensity
Signal
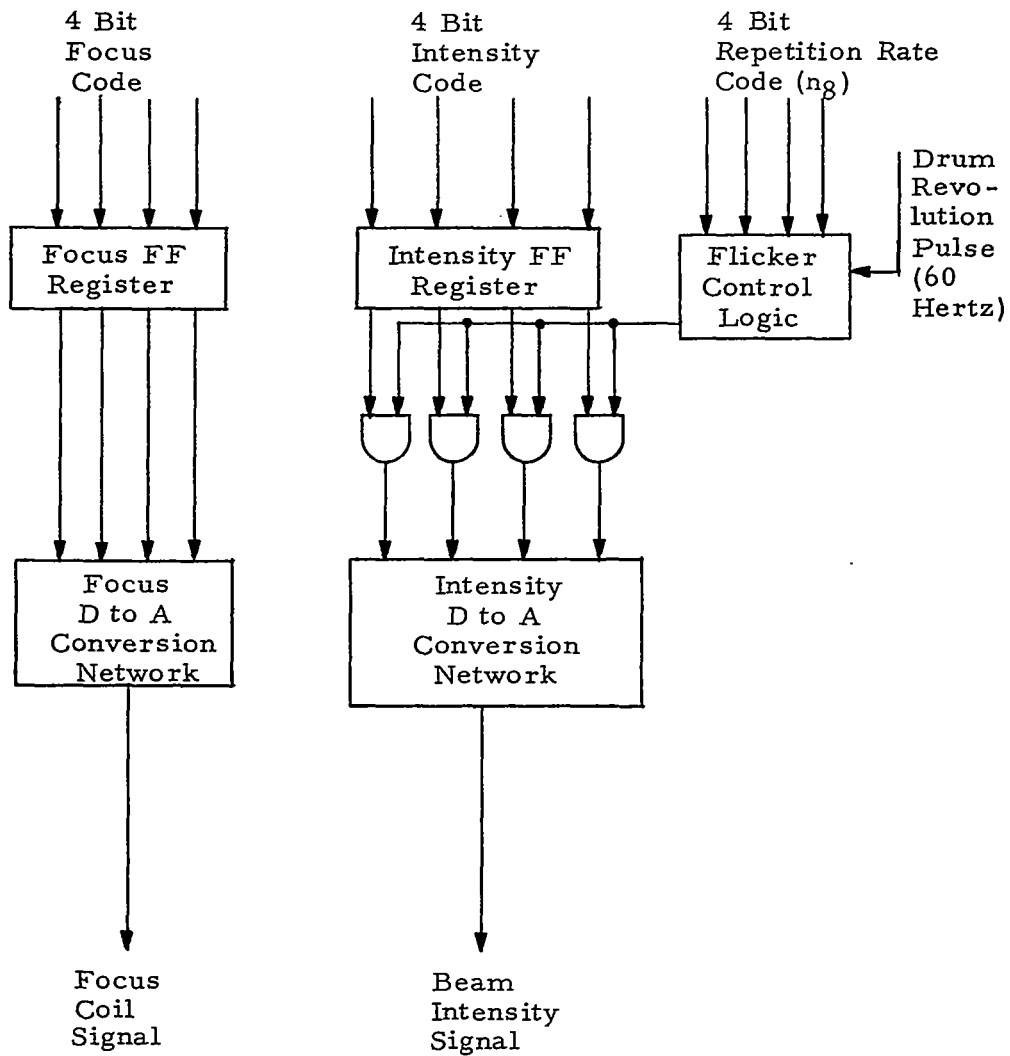
FIGURE IV. 4   FIR DECODING SYSTEM

IV-6

APPENDIX V
THREE-DIMENSIONAL DISPLAY

A sequential three-dimensional (not merely perspective) display has been demonstrated by Dr. A. C. Traub, as indicated in Figure V.1. Traub's technique is based essentially on flicker control. He displays two alternating images on the scope and synchronously vibrates a thin lightweight mirror so as to add a visible z-component to the display (as reflected in the mirror). That is, every time the mirror is "forward", it reflects one image in one x, y plane, and every time the mirror is displaced backward, it reflects the second image in a second x, y plane which is displaced in z from the first. The effect is physically three-dimensional. Traub's mirror consists of aluminumized mylar stretched over a radio loudspeaker, which in turn may be driven by a computer (or other timing device).

Traub has suggested two extensions of this concept. One involves the use of multiple image sources and dichroic mirrors in order to display an image in full color on the vibrating mirror. The dichroic mirror is a form of band pass filter or beam splitter which preferentially transmits specified wavelengths of light while reflecting the balance, and thus may serve as a color filter. The scheme suggested, as shown in Figure V.2, superimposes red, green, and blue images on the vibrating mirror.

The second extension suggested introduces a concave (spherical) mirror between the vibrating mirror and the viewer (Figure V.3) in order to produce a three-dimensional image in space. This display technique would be compatible with the use of Roberts' "Lincoln Wand"[45] for three-dimensional input, since here the image would appear in front of the optical system, rather than behind it.

Another quite different approach to three-dimensional display is suggested in Figure V.4. This approach consists of writing with three CRT's in an ionization chamber. Gaseous flourescence and

phosphorescence both contribute to the display. "Residuals" or un-
wanted line segments pose a problem and unfortunately cannot be
reduced by coincidence techniques. Ideally, certain atoms would be
multi-excitable, i.e., receive energy in tandem from x, y, ż electrons,
and return to ground state by photoemission, the color or intensity
being indicative of the coincident excitation. But no material is known
to possess such properties.

Any truly three-dimensional display is an aid to visualizing
topological surfaces, three-dimensional histograms, vector spaces
($\overrightarrow{\text{curl}}$ E, $\overrightarrow{\text{grad}}$ v), vector functions ($\overrightarrow{\text{curl}}$ E = - $\partial B/\partial t$; $\vec{F}$ = e($\vec{E}$ + $\vec{v}$ X $\vec{B}$)
multipole radiation

$$(d\vec{E} = \frac{1}{(k\mu)^{1/2}} \ d\vec{B} \ X \ \vec{r}) \quad \text{currents } (\text{div} \ \vec{i} = 0), \text{ etc.}$$

Related to the coincident approach of Figure V.4, a neo-
dymium doped glass block might be made to amplify along desired line
segments by coincident writing (stimulation or pumping) techniques.
Switching-scanning of the pumping light can be achieved by known
electro-optical techniques (Pockel crystals and Foster prisms. See
EDN, Jan. '65).
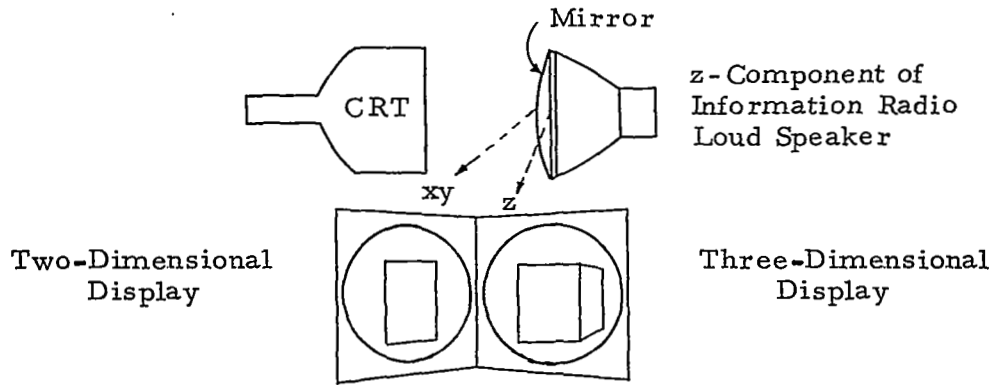
FIGURE V-1   VIBRATING MIRROR THREE-
DIMENSIONAL DISPLAY
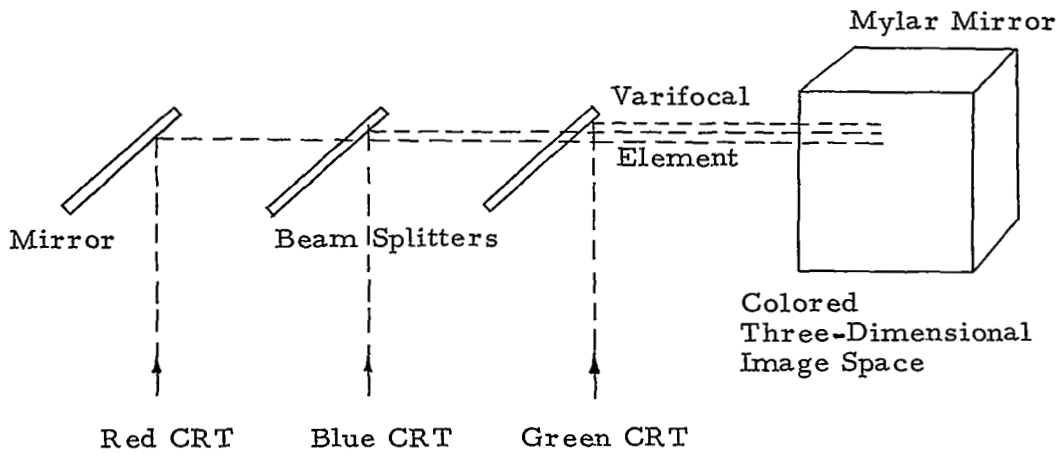
FIGURE V-2   DICHROIC MIRROR AND VIBRATING
MIRROR SYSTEM
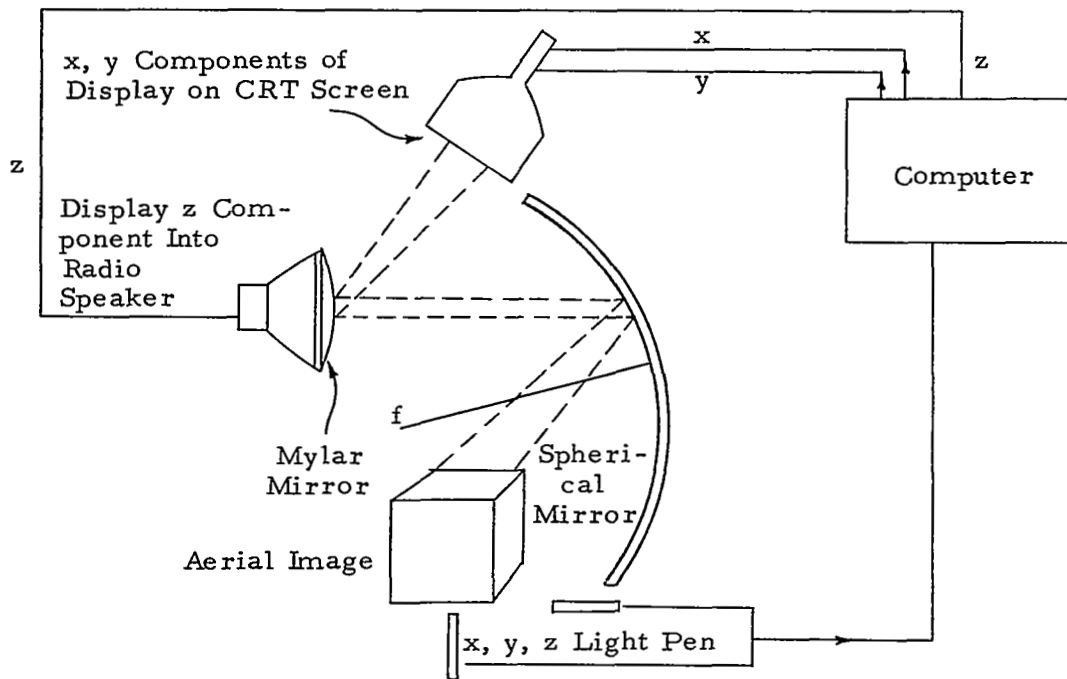
FIGURE V-3   THREE-DIMENSIONAL AERIAL IMAGE

Flourescent-Phosphorescent (Ionization) Vapor

Typical Vapor Trail

Electron Beam

CRT

Vacuum-Ionization-Chamber Studs
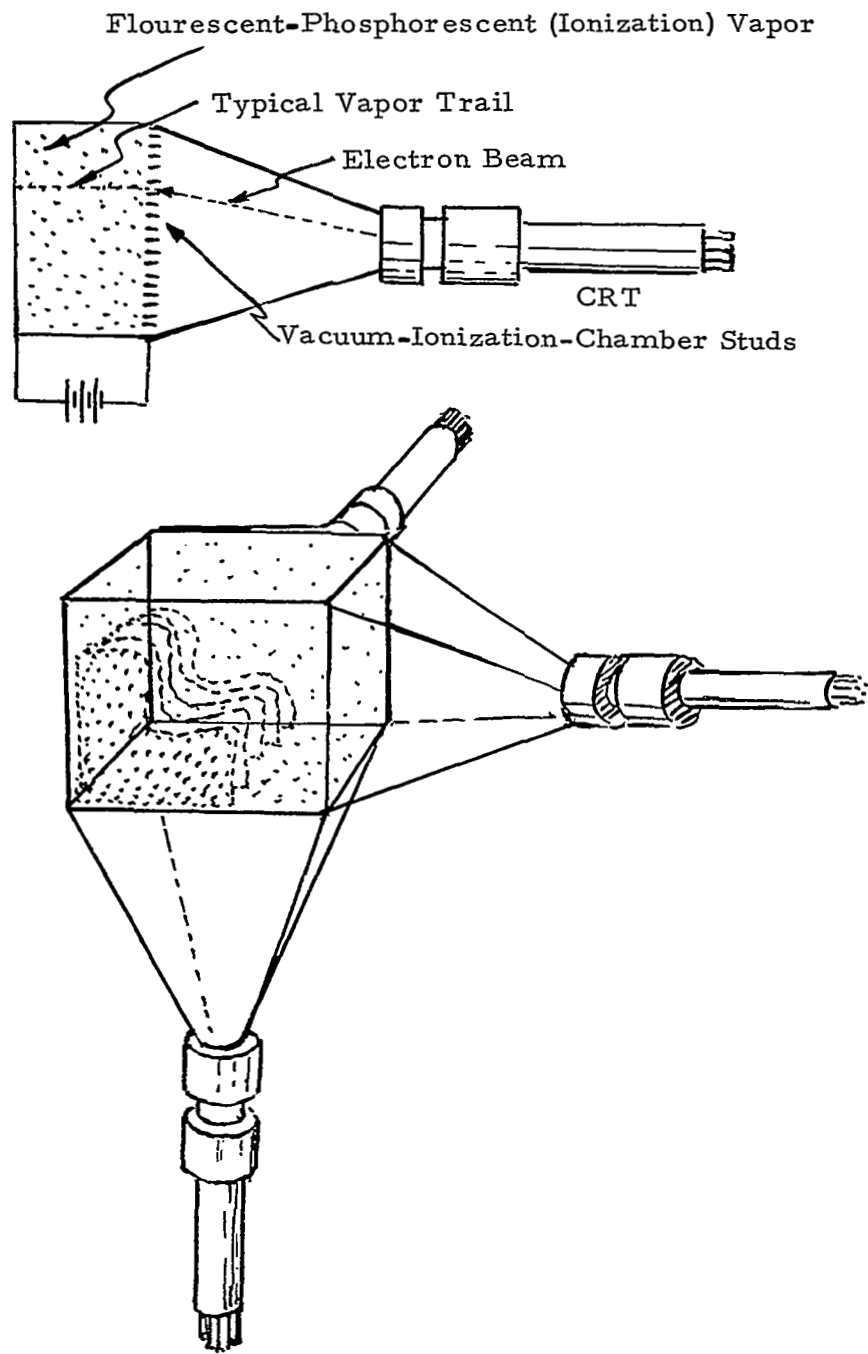
FIGURE V-4   A THREE-DIMENSIONAL DISPLAY

APPENDIX VI

THE LAWRENCE-CHROMATRON GRID DEFLECTION TUBE

The operational basis of a color tube operating on an entirely different principle from the shadow-mask tube is described by Robert Dressler of Chromatic Television Laboratories, Inc. in the article entitled "The PDF Chromatron-a Single or Multi-gun Tri-color Cathode-ray Tube" appearing in the July, 1953, issue of the PROCEEDINGS OF THE IRE. The principal features of the single-gun version of this tube are shown in the accompanying figures. The electron-gun structure mounted in the neck of the tube is of conventional design. The phosphor screen consists of thin strips of primary-color-emitting phosphors deposited on a flat glass plate, as shown in the small detail view. Mounted immediately behind the phosphor screen (with a spacing on the order of 1/3 inch) is a wire grid, so constructed that alternate wires may be brought out to separate electrical connections. In the most common version of the tube, the phosphor strips are of equal width, but there are twice as many green strips as there are of red or blue. The wire grid has only half as many wires as there are phosphor strips, and is so aligned that the wires fall immediately behind the blue and red strips. Note that all the wires adjacent to blue strips are brought out to one electrical connection, and that the wires adjacent to the red strips are also connected electrically. The strong accelerating field between the grid and the phosphor plate forms, in effect, a series of cylindrical lenses which tend to focus the scanning beam into a somewhat smaller spot. When the grid wires are all at the same potential, the focusing action is such that the entire beam tends to land only on the green phosphor strips, as shown by the sketch. The electron-optical efficiency of the focus-mask tube is considerably greater than that of the shadow-mask tube. In the latter, about 85 percent of the incident electrons are blocked by the shadow-mask (which is at the same potential as the phosphor dot plate), while in the focus-mask tube, only about 15 percent of the electrons are intercepted by the color grid.

Color switching may be accomplished in a focus-mask tube by varying the potential difference between the alternate wires in the grid by an amount on the order of ± 450 volts. The electrons then tend to be attracted toward the wires of higher potential, and strike the phosphor strip under the high-potential wires (a more sophisticated interpretation would·be that the cylindrical electron lenses formed by the equipotential surfaces are distorted so as to deflect the electrons toward the desired color). The switching may be performed at any reasonable frequency, provided the signal supplied to the gun of the kinescope is time-gated in synchronism with the switching action. The tube may be mounted so that the phosphor strips are either parallel to the scanning lines or at right angles to them; for use in a compatible receiver, the tube can be used most effectively if the phosphor lines are horizontal.

Step-wave switching may be used for the single-gun focus-mask kinescope for relatively low switching frequencies, as in field-sequential or line-sequential systems. In a compatible system, however, it is desirable to perform the switching at a very rapid rate (the color sub-carrier frequency is commonly used for convenience), and the only way to supply the 900-volt peak-to-peak switching signal usually required with reasonable power and bandwidth is by using the sinusoidal wave-form achieved by resonating the capacitance of the grid structure with an external coil. In a typical version of the tube, providing a picture 12 by 16 inches, the required color switching power at 3.58 mc is of the order of 20 watts when the 1.4 micro farad capacitance of the color grid is resonated with an inductor of about 1.5 microhenrys. If the phosphor strips are parallel to the scanning lines, the electron beam follows a sinusoidal path across the phosphor strips, as shown. It is necessary, of course, to provide some sort of gating action for the video signal so that information corresponding to each primary color is presented only at those instants when the beam is landing on the appropriate phosphor strip.

A serious problem is spurious radiation resulting from the use of a very high-level switching signal at the sub-carrier frequency. Radiation from the grid structure itself is not too serious because the fields from adjacent grid wires tend to cancel each other, but the external circuits must be very carefully shielded.

The focus-mask principle can also be applied to three-gun tubes. In this case, no switching voltage is needed, and the grid wires may all be connected together electrically. The cylindrical lenses formed by the potential difference between the wire grid and the phosphor screen make the screen direction-sensitive, such that beams arriving from three slightly different angles can be made to excite phosphor strips of three different positions.

(a) Over-all view and details
    of phosphor plate

Color
Grid

Phosphor
Plate

Gridwires

Color Phosphor

(b) Color Switching

electron

beam

(c) Path of electron beam when switched with
    a sine wave at sub carrier frequency.

Green
Red
Gr
Blue
Green

3 Samples/sec

6 Samples/sec
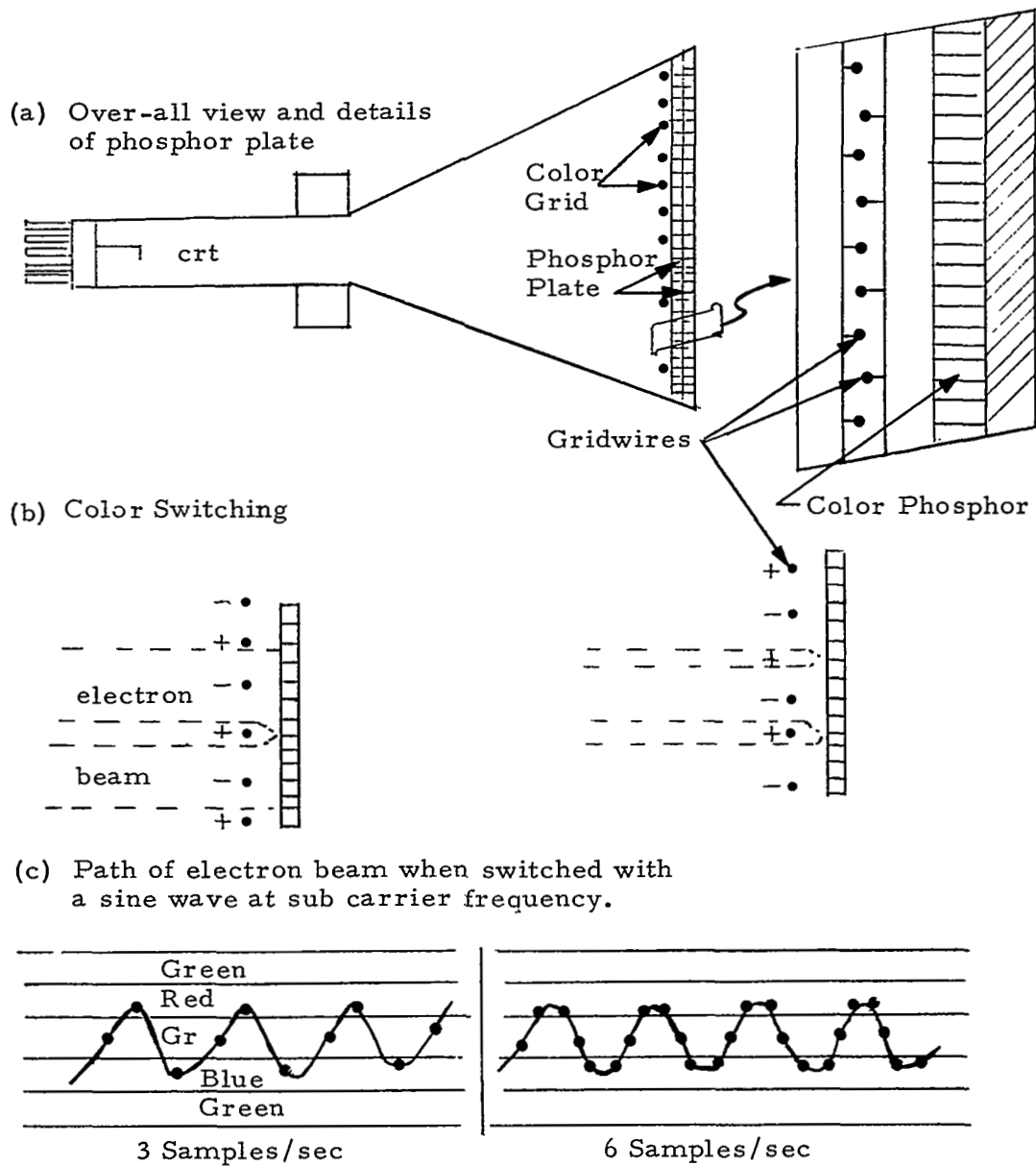
FIGURE VI-1   CHROMATRON TUBE

VI-4

APPENDIX VII
PILOT TESTS OF ON-LINE TECHNIQUES IN COLOR

A demonstration model incorporating on-line techniques for manipulating and displaying large volumes of data has been prepared and tested. The computer programs which constitute this model were coded for operation on the Experimental Dynamic Processor, DX-1, at AFCRL; a rather elaborate experimental sensor data processing system with a unique color oscilloscope capability for man-machine communication. These programs have been made available to AFCRL in return for use of the DX-1. The interactive color displays generated by these programs are demonstrated in a motion picture film prepared by Wolf Research and Development Corporation and submitted to NASA Goddard Space Flight Center. Amplifying information and comments regarding advantages and disadvantages of color equipment are presented in this appendix.

A. The Isotopic Abundance Experiment

The demonstration model consisted of display and manipulation programs operating upon data from Goddard Space Flight Center's Isotopic Abundance Experiment. The data from this experiment requires a minimum of computational processing in obtaining a conceptually meaningful form of the data. Accordingly, this experiment is well suited to pilot testing of display and manipulation techniques.

The spacecraft sensor is a scintillation counter. As shown in the Figure VII.1, the energy losses of a trapped isotope particle are measured by three photomultipliers, A, B, and C. Specifications for the scintillation plates are such that particles of interest will penetrate the first plate and be stopped by the second. The photomultiplier voltages V_A and V_B for a particle of interest represent the loss of energy at the first plate (ΔE) and the remainder of particle energy ($E - \Delta E$). These voltages are converted from pulse height to pulse

FIGURE VII.1 ISOTOPIC ABUNDANCE EXPERIMENT
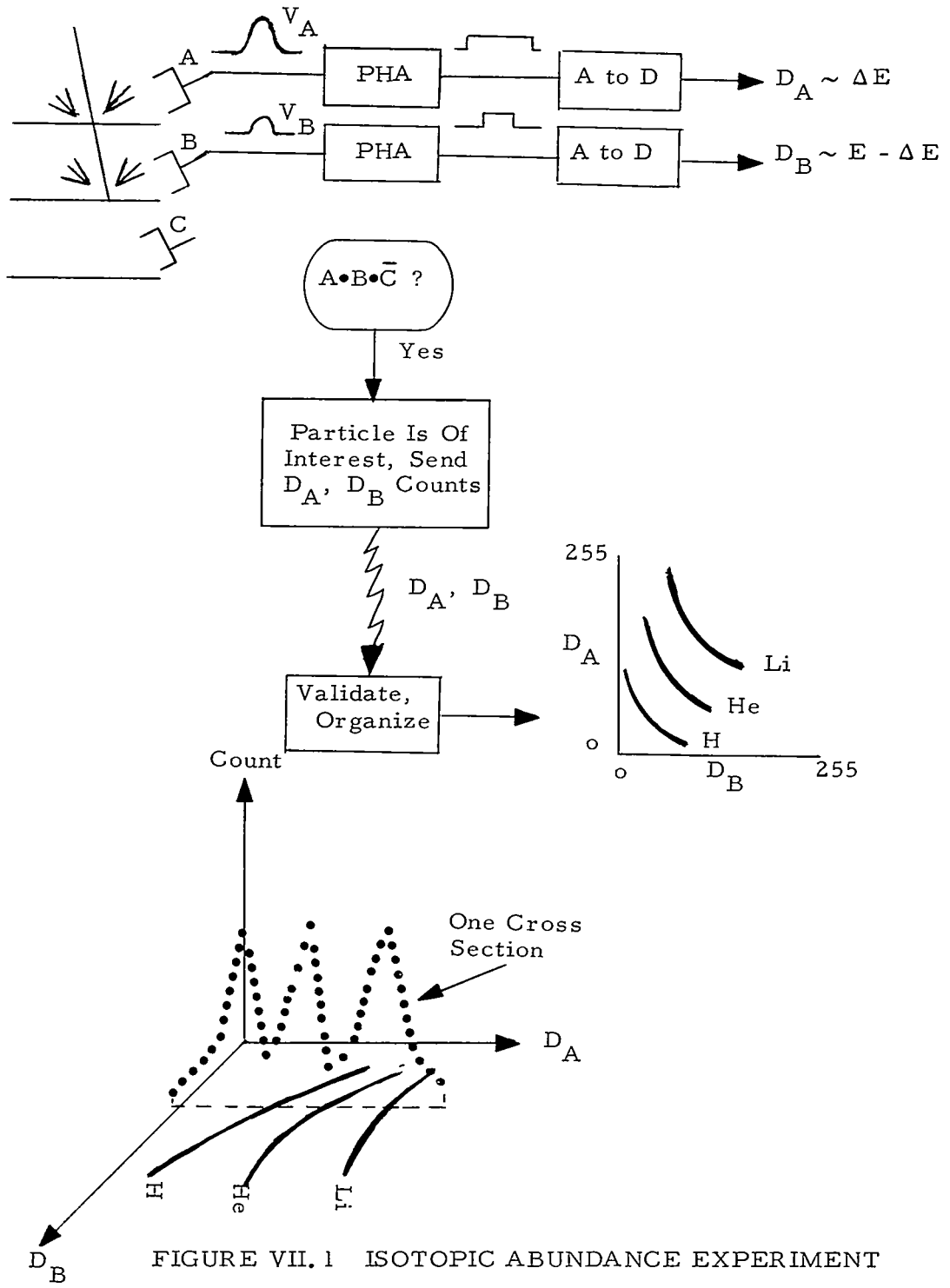
duration to digital form, which is transmitted to a ground station. A plot of data is accumulated over a period of time by adding a unit count at the appropriate coordinate intersection for each data point received. The result is a three-dimensional isotopic mass spectrogram.

Examining an isometric projection of this plot, the experimenter might desire to obtain a good first approximation of a function which fits the data surface. If the data and function surfaces were superimposed in a display, it would be quite difficult to distinguish the points belonging to each. Alternating the images might be useful if differences were few and minor. It appears more practical to display a single surface, modulating each point with color to represent the deviation of the corresponding point on the second surface. With a black and white scope the modulation medium might be focus, intensity, or flicker.

B. <u>Color Representation of a Third Dimension</u>

The experiment data were recorded as particle counts at the various energy coordinate positions of a 256 x 256 array. This matrix was compressed into a scanned sequential format for magnetic tape storage. The low valued 128 x 128 quadrant of data was extracted for use in manipulation and display.

The first display was designed for mass spectrogram data examination only. It consisted of a 128 by 128 matrix of display points, each of which was color coded to represent the third dimension, particle count.

Two color scales were used (Figures VII.2, VII.3). Each ranged from black, through a color spectrum, to white, with "notes" on the color scales corresponding to particle count data values. Since zero count corresponded to black (no display point necessary) on both scales, and since the majority of count values were zero, it was possible to display the 128 x 128 display matrix at a flicker-free 30 hertz in most instances.

| Range (Particle Count) | Color Mixture (0 – 15 Intensity) | | | Apparent Color |
	Red	Green	Blue	
0	0	0	0	Black
1 – 2	4	0	0	
3 – 4	5	0	0	
5 – 6	6	0	0	
7 – 8	7	0	0	
9 – 10	9	0	0	
11 – 12	11	0	0	
13 – 14	13	0	0	
15 – 16	15	0	0	Red
17 – 18	15	5	0	
19 – 20	15	6	0	
21 – 22	15	7	0	
23 – 24	15	8	0	
25 – 26	15	9	0	
27 – 28	15	10	0	
29 – 30	15	11	0	
31 – 32	15	13	0	
33 – 34	15	15	0	Yellow
35 – 36	13	15	0	
37 – 38	9	15	0	
39 – 40	0	15	0	Green
41 – 42	0	15	7	
42 – 44	0	15	11	
45 – 46	0	15	15	Cyan
47 – 48	0	13	15	
49 – 50	0	10	15	
51 – 52	0	8	15	
53 – 54	0	6	15	
55 – 56	0	0	15	Blue
57 – 58	6	0	15	
59 – 60	9	0	15	
61 – 62	11	0	15	
63 – 64	13	0	15	
65 – 66	15	0	15	Magenta
67 – 68	15	7	15	
69 – 70	15	9	15	
71 – 72	15	11	15	
73 – 74	15	13	15	
Over 74	15	15	15	White

FIGURE VII. 2   39-NOTE TONAL DISPLAY COLOR SCALE

Range (Particle Count)	Color Mixture (0 - 15 Intensity)			Apparent Color
	Red	Green	Blue	
0	0	0	0	Black
1	5	0	0	
2	10	0	0	
3	15	0	0	Red
4	15	5	0	
5	15	7	0	
6 - 7	15	10	0	
8 - 9	15	15	0	Yellow
10 - 11	9	15	0	
12 - 13	0	15	0	Green
14 - 15	0	15	15	Cyan
16 - 17	0	10	15	
18 - 19	0	7	15	
20 - 23	0	4	15	
24 - 27	0	0	15	Blue
28 - 31	5	0	15	
32 - 39	8	0	15	
40 - 49	10	0	15	
50 - 74	13	0	15	
75 - 99	15	0	15	Magenta
100 - 174	15	7	15	
175 - 249	15	10	15	
Over 249	15	15	15	White

FIGURE VII. 3   23-NOTE TONAL DISPLAY COLOR SCALE

The displays obtained using these scales are shown in Figure VII.4. Note that more detail appears to be present in the 23-note representation than with 39 notes. This is explained by an examination of the scale values, which reveals greater sensitivity to count value change at low values in the case of the 23-note scale. As it turned out approximately 90% of the data from this experiment had a value of less than ten. This indicates a certain usefulness for non-linear color coding. While the number of notes in a color scale is important, so is the distribution of the notes.

39-Note Coding Scale   23-Note Coding Scale
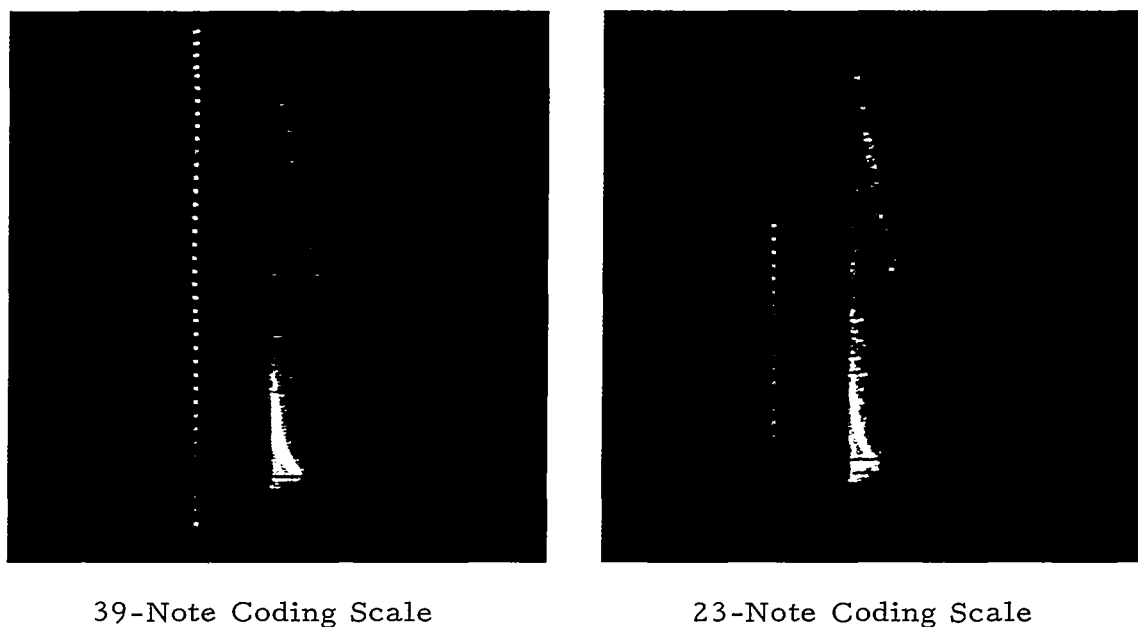
FIGURE VII.4—COLOR REPRESENTATION OF A MASS SPECTROGRAM

The vertical color scale in each photograph shows the colors corresponding to the mixtures listed in Figures VII.2 and VII.3. By positioning the light pen over one of the points in this scale, the user causes that point to be erased (positive visual feedback of a

computer action), and the data is replotted with all points of value less than the point picked displayed in orange-red, all points of equal value displayed in green and all points of higher value displayed in blue (Figure VII.5). In effect, the user passes planes through the data surface at various count value heights.
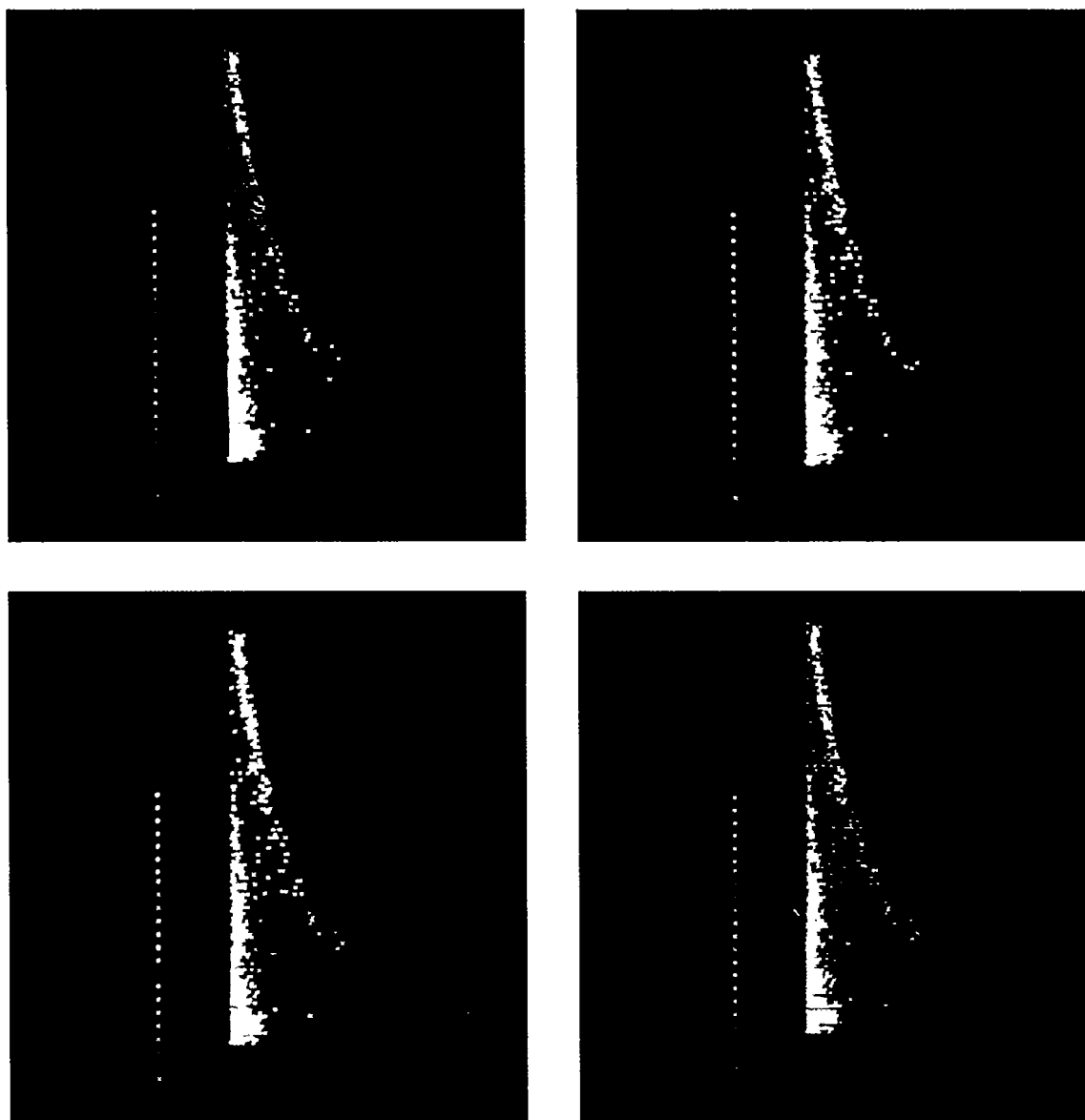
FIGURE VII.5—CONSTANT PARTICLE COUNT CROSS SECTIONS

Several options were given to the user for control of these
data examination displays.   These options were as follows.

1. Reduction of flicker in the display. If the number of
   non-black display points in a data set is too great for
   a 30 hertz frame rate the data is displayed at 15 hertz.
   Flicker is quite apparent at this frame rate. Worse, a
   neon sign effect results from showing part of the data
   during one interval, and the remainder of the data during
   the following interval. This control permits the excess
   of data to be ignored so that the remaining data may be
   displayed at 30 hertz.

2. Replotting of data with a different color scale.

3. Display a summary of several data sets. If the data sets
   summarized were taken sequentially in uninterupted
   time, this summary validly corresponds to an extended
   time period data set.

4. Select another data set for display.

5. Return from constant particle count cross section mode
   to full color scale representation.

C. An Isometric Projection Display Program

An isometric projection display program was prepared in
order to represent the three dimensions of the data on the two-dimen-
sional display without the involvement of color. The following compu-
tational approach was employed.
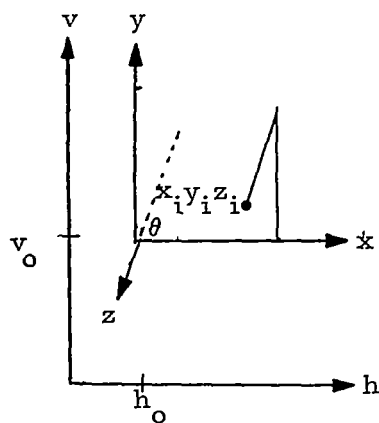
The position of the point $x_i y_i z_i$ on the display plane h, v is given by

$$h_i = h_o + x_i - z_i \cos \Theta$$

$$v_i = v_o + y_i - z_i \sin \Theta$$

where h_o, v_o locates the isometric axes' origin.

FIGURE VII. 6   ISOMETRIC PROJECTION

Since the data is organized in planes parallel to the x, y plane, and these planes are separated by uniform intervals of z, then the computational approach may be simplified, and for data on the mth plane

$$h_i = (h_o - m \Delta X) + x_i$$

$$v_i = (v_o - m \Delta Y) + y_i$$

where the parenthetical terms are constant for the plane, and

$$\Delta X = \Delta Z \cos \Theta, \quad \Delta Y = \Delta Z \sin \Theta, \quad \Delta Z = z_i - z_{i-1}.$$
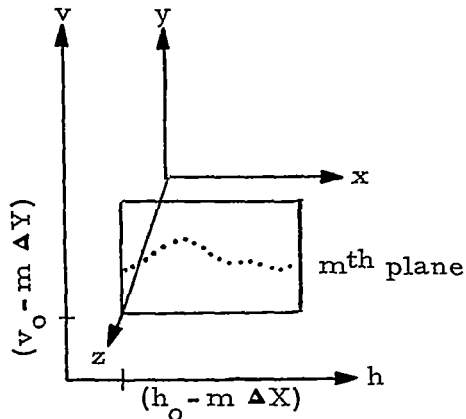
FIGURE VII. 7   MTH PLANE ON ISOMETRIC PROJECTION

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The isotopic abundance experiment plot of ΔE vs. $E - \Delta E$ contains 256 x 256 coordinate values. The DX-1 color display CRT has a raster size of 512 by 512 display point addresses. An isometric projection of the plot exactly fits on the display raster _if_ $\Delta X = \Delta Y =$ one raster interval.
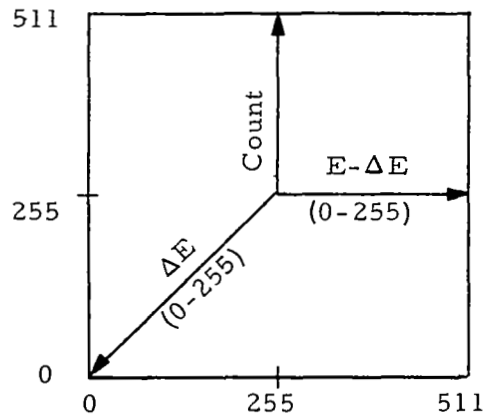
FIGURE VII.8   MAPPING OF DATA PROJECTION ON DISPLAY
                          RASTER

If 256 x 256 displayed points are too difficult to discriminate, it may be desirable to represent 2 x 2, 4 x 4, or 8 x 8 data point sets with a single display point. The averaging effect produced should aid in developing a good first approximation for surface fitting. The user may wish to vary this correspondence parameter.

It may also be useful to permit optional display of constant x, constant y, and constant z contours.

Constant z would consist of a subset of the planes previously described, say, every mth plane.

Constant x would involve the display, say, of every mth point in all constant z planes.

Constant y would involve a more complicated problem of contour fitting employing interpolation techniques where data straddled a contour value. Constant y might not be worth bothering with. In any event, the user may wish to vary m for constant z and x contour generation.

In the program which was prepared the constant z planes in which the data was organized for display corresponded to constant ΔE value. The y or v component of the curves on these planes corresponded to particle count. An option to vary the displayed ΔZ interval (thus spreading or packing the curves representing the data surface) was provided. The constant z option suggested above was also included. The maximum particle count value in each data set was examined by the program and compared with the vertical scale limit. When necessary the count values were scaled down. User control for selecting data sets was included.

D.   A Curve Fitting Program

A simple scheme was employed for fitting a function-generated surface to the actual data surface: since the data surface may be thought of as cross sections on a series of parallel planes, a function to fit the surface may be constructed with a series of curve fitting functions. Of course, this is inelegant and a large number of coefficients must be obtained, but the aim here was the investigation of data manipulation and display techniques rather than mathematical elegance. The curve fitting function first tried was of the following form:

$$y = \frac{a_1 e^{a_4 x}}{a_2 + x^{a_3}} + a_5 .$$

This form did not prove suitable for fitting the E-ΔE vs. count curves. The fifth coefficient performs the relatively useless task

(in this case) of raising or lowering the baseline of the function gener-
ated curve. The function as a whole does not provide the x offset of
the exponential peak which is characteristic of the data.

An interactive technique was used to obtain a more appro-
priate form for the function. On-line with the computer the form of
the function was altered in several ways. After each alteration the
curve it generated was displayed superimposed on an E - ΔE vs. count
data curve, and the coefficient values were varied in order to observe
the effect. After approximately fifteen minutes of this cut-and-try
process a satisfactory function was obtained in the following form:

$$y' = \frac{a_1 e^{a_4 |x - a_5|}}{a_2 + |x - a_5|^{a_3}} \quad , \quad \text{and}$$

$$y = y' \quad \text{when } y' \geq 0,$$

$$y = 0 \quad \text{when } y' < 0.$$

The display image generated by the curve fitting program
appeared as in Figure VII.9. Here, color is used merely for labeling
purposes. Blue is used for the coordinate axis; green for the actual
data cross section; red for the function generated curve.

The five light buttons across the upper left portion of the
display correspond to the five coefficients in the function, in a_1
through a_5 order. The coefficient values are initially zero. When the
user selects one of these light buttons with the light pen, a red dot is
displayed next to it and the value of the corresponding coefficient is
displayed at the bottom of the screen. Once a coefficient is thus sel-
ected it remains selected until another light button is picked with the
light pen.
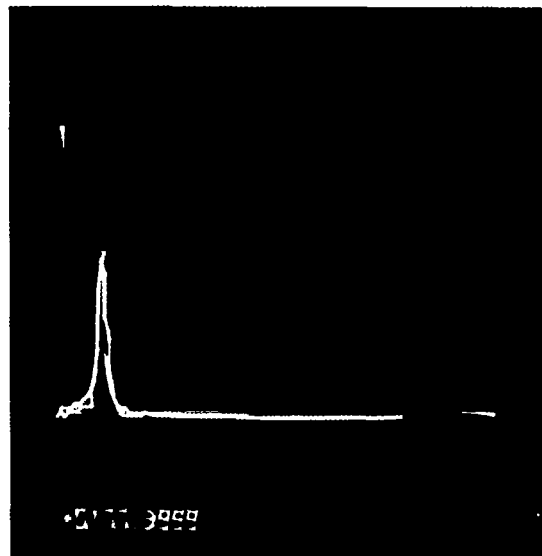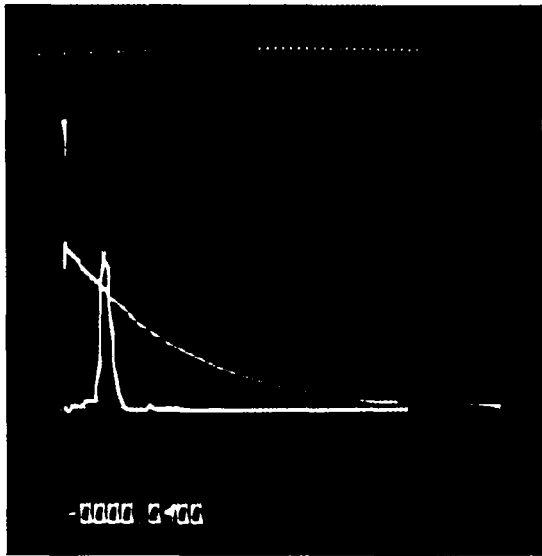
FIGURE VII.9—ON-LINE CURVE FITTING
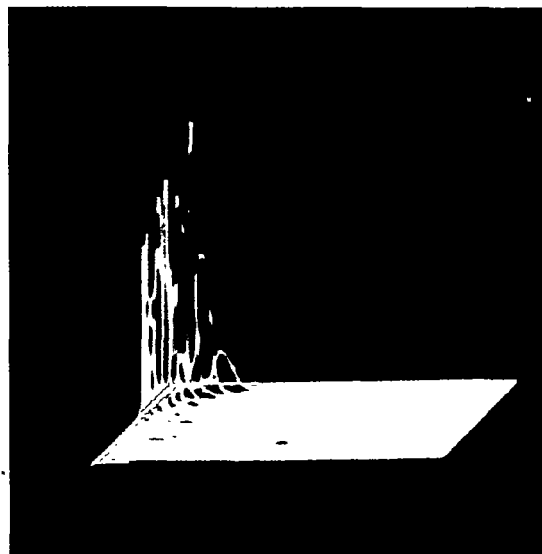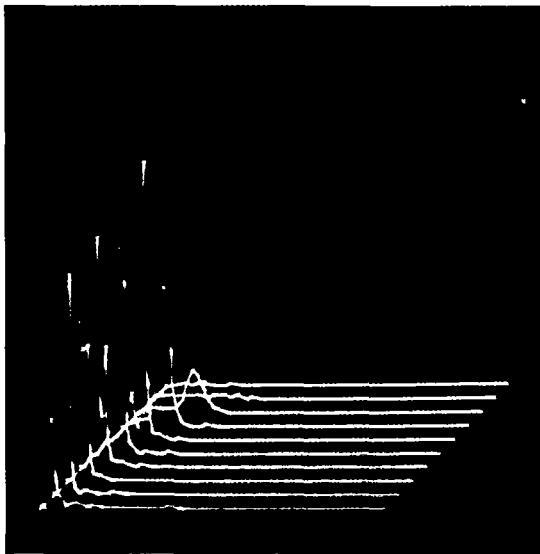
FIGURE VII.10—DATA SURFACES WITH AND WITHOUT
DEVIATION COLOR CODING

The light symbol across the upper right portion of the display facilitates modification of the selected coefficient's value. This is the "gas pedal" light symbol discussed in Section 3.2.1. Light pen pointing at the left side of the red center dot decrements the coefficient, the right side increments: the further from the center, the greater the change. As the coefficient value changes, the shape of the displayed function generated curve changes, and the value displayed at the bottom of the screen changes.

To improve the efficiency of this technique each coefficient is altered at an individual rate corresponding to the sensitivity of the curve to changes in the value of that coefficient. In each case the incrementing value of the ith dot to the right or left of gas pedal center is $\pm (i/10)$ (maximum increment for the coefficient). There are 21 dots in the gas pedal. The sensitivity adjustment in the form of the maximum increment for a coefficient is set using the on-line typewriter, and can be altered with a push button option.

When the user is satisfied with the fit of a curve obtained by changing the values of the coefficients he may terminate curve fitting by pointing the light pen at the light button at the lower right of the display. The curve fitting coefficient values are saved for further use.

E.   Color Representation of a Fourth Dimension for Data Surface Fitting

Computer program linkage was established between the isometric projection program and the curve fitting program so that a user might alternately use one then the other for fitting curves to the data surface in order to obtain a good first approximation fit. In the isometric projection of the data surface some means for examining the deviation of the function generated surface from the data surface was required. If the two surfaces were displayed simultaneously, superimposed, it would be quite difficult to distinguish the points belonging to each. Therefore, color was used to represent this fourth dimension, deviation.

This use of color is shown in Figure VII. 10. Warm colors indicate a function generated value less than the actual particle count data value. At cyan (blue-green) the values are identical. Cooler colors indicate generated values greater than actual values. The color coding scale is given in Figure VII. 11.

After one pass through the data surface the curve fitting user may wish to rework one or more curves in which colors furthest from cyan appear. Exit from the isometric projection program to the curve fitting program is accomplished by light pen selection of the curve the user wishes to work on next.

F.   Comments on Color Programming

Color appears to be a very effective medium for displaying data, especially data which exceeds the capabilities of two-dimensional displays. Differences in tones appear to be easily recognized and extreme differences should be recognizable even to the color blind. However, the ability of a color blind person to recognize color was not investigated in this work.

One limitation in the use of color is the fusing effect that occurs when many points of various colors are displayed together in a small area. The apparent color of all the points tends to be some mixture of the individual colors. This fusing effect is desirable at the limit of shadow-mask resolution where red, green, and blue phosphor spots are energized in various intensities to obtain a programmed color mixture. For the display of color coded data points, however, an empirical spacing of the displayed points is necessary. The fusing effect is severe during display of "adjacent" points since spot size has a diameter of approximately three raster units. Although the display hardware permits resolution to one raster unit, points displayed at a distance of less than three raster units apart will overlap. Thus, for minimum point resolution the effective display area is reduced to a 170 x 170 point area.

Generated Minus Actual Value	Color Mixture			Apparent Color
	Red	Green	Blue	
Less than -15	13	0	0	
-15	15	0	0	
-14	15	5	0	Red
-13	15	6	0	
-12	15	7	0	
-11	15	8	0	
-10	15	9	0	
-9	15	10	0	
-8	15	11	0	
-7	15	13	0	
-6	15	15	0	Yellow
-5	13	15	0	
-4	9	15	0	
-3	0	15	0	Green
-2	0	15	7	
-1	0	15	11	
0	0	15	15	Cyan
1	0	13	15	
2	0	10	15	
3	0	8	15	
4	0	6	15	
5	0	0	15	Blue
6	6	0	15	
7	9	0	15	
8	11	0	15	
9	13	0	15	
10	15	0	15	Magenta
11	15	7	15	
12	15	9	15	
13	15	11	15	
14	15	13	15	
Greater than 14	15	15	15	White

FIGURE VII. 11   ISOMETRIC SURFACE FITTING COLOR SCALE

A related limitation affecting discrimination of "notes" on a color scale is that the smaller a displayed color spot, the less discriminable its color.

Design of the described programs was limited in some respects by the hardware used. The color CRT focused poorly, especially when the beam was moved too quickly. Also, a beam of full intensity red appeared on the screen as reddish-orange. This hampered the mixing of colors somewhat. A more serious limitation was the relatively slow speed of the electron beams, compared to the drum speed. The electron beams travel approximately one-thirteenth of the difference between their actual position and the position indicated by the x-y deflection registers in 1.67 μsecs., the time needed to read and execute one drum byte. Thus the beam never truly reaches the designated position but slowly approaches it. This necessitated the dedication of a large number of drum bytes for waiting between display commands to move the beam, and restricted the amount of data in the display. Although it is possible to use two head groups of the drum for display, objectionable flicker is introduced. For reasonable freedom from flicker, display is restricted to one head group.

The drum used was only addressable by sectors and not by words. Therefore, it was necessary to use a buffer the size of a sector to read and write on the drum. To make changes or additions to the display, it was often necessary to rewrite the drum or leave enough unused drum bytes for all possible changes. Both methods tend to be somewhat inefficient. Character generation proved very inefficient because of the amount of drum storage made necessary by slowness of the beam.

Some changes were made to the beam intensity control circuits in order to obtain more linear visual response to color intensity scale commands. Circuit changes to permit the programmed specification of hue, brightness and saturation rather than intensities of red, blue, and green were considered but not implemented.

It is felt that the problems encountered in the use of the DX-1 system were of minor significance compared to the advantages of this equipment.

G.   The DX-1 System Components

The system components of the DX-1 installation at the Air Force Cambridge Research Laboratories which were used for the development of these color displays included:

1. PDP-1 digital computer,
2. Drum memory and display buffer storage,
3. Display processor and drum/core-driven color CRT,
4. Floating point hardware,
5. Tape drives,
6. On-line typewriter,
7. Light pen and sense switches.

The PDP-1 is a high speed, solid state digital computer with a memory capacity of 12,288 words of 18-bit length.

Drum memory consists of 10 head groups or tracks rotating at 30 revolutions per second. A head group reads 20 sectors, each with a capacity of 1000 6-bit bytes. The color CRT is driven by the second and/or third head groups. Thus, if the display uses only one track, the refresh rate is 30 hertz. For a display using both tracks, the refresh rate is 15 hertz and flicker is introduced. Instructions to the display processor consist of 6-bit bytes which are executed in 1.67 seconds. Drum transfers to and from core memory are made a sector at a time.

The CRT is an RCA color tube with a 10-inch square display area and functions as a 512 x 512 point raster scope. It is capable of 16 levels of intensity color of each of the red, green, or blue color beams in any mixture. The display circuits operate in either

the reset or increment mode. In the reset mode, the origin is located at the extreme lower left of the scope.

H.   Program Flow Charts

The programs described in this appendix are more completely detailed in the following flow charts.

FIGURE- VII. 12 MASS SPECTROGRAM TONAL DISPLAY
FLOW CHART

```
        ( F )                              ( H )
          |                                  |
          v                                  v
      /Display \                         / Color   \
     / Summary  \ ---no--> ( G )        /Scale Point \ ---no--> ( I )
      \   ?    /                         \ Picked ? /
          |                                  |
         yes                               yes
          |                                  |
          v                                  v
     /Rewind  \                      +----------------+
    ( Summa-   )                     |     Set to     |
     \ry Tape /                      |   Eliminate    |
          |                          |   Color Dot    |
          v                          |  from Scale    |
   /----------\                      +----------------+
  /    Get     \                             |
 (   Summary    )                            v
  \    Data     /                   +----------------+
   \----------/                     |     Set to     |
          |                         |   Display in   |
          v                         |  Three Color   |
        ( E )                       |     Mode       |
                                    +----------------+
                                             |
                                             v
                                           ( J )


        ( G )                              ( I )
          |                                  |
          v                                  v
      / Re-    \                        / Change   \
     /display   \ --yes--> ( E )       /Color Scales\ --no--> ( B )
     \using Color/                      \    ?     /
      \ Scale?  /                           |
          |                                yes
         no                                  |
          |                                  v
          v                         +----------------+
        ( H )                       |     Set to     |
                                    |  Use Other     |
                                    |  Color Scale   |
                                    +----------------+
                                             |
                                             v
                                           ( E )
```
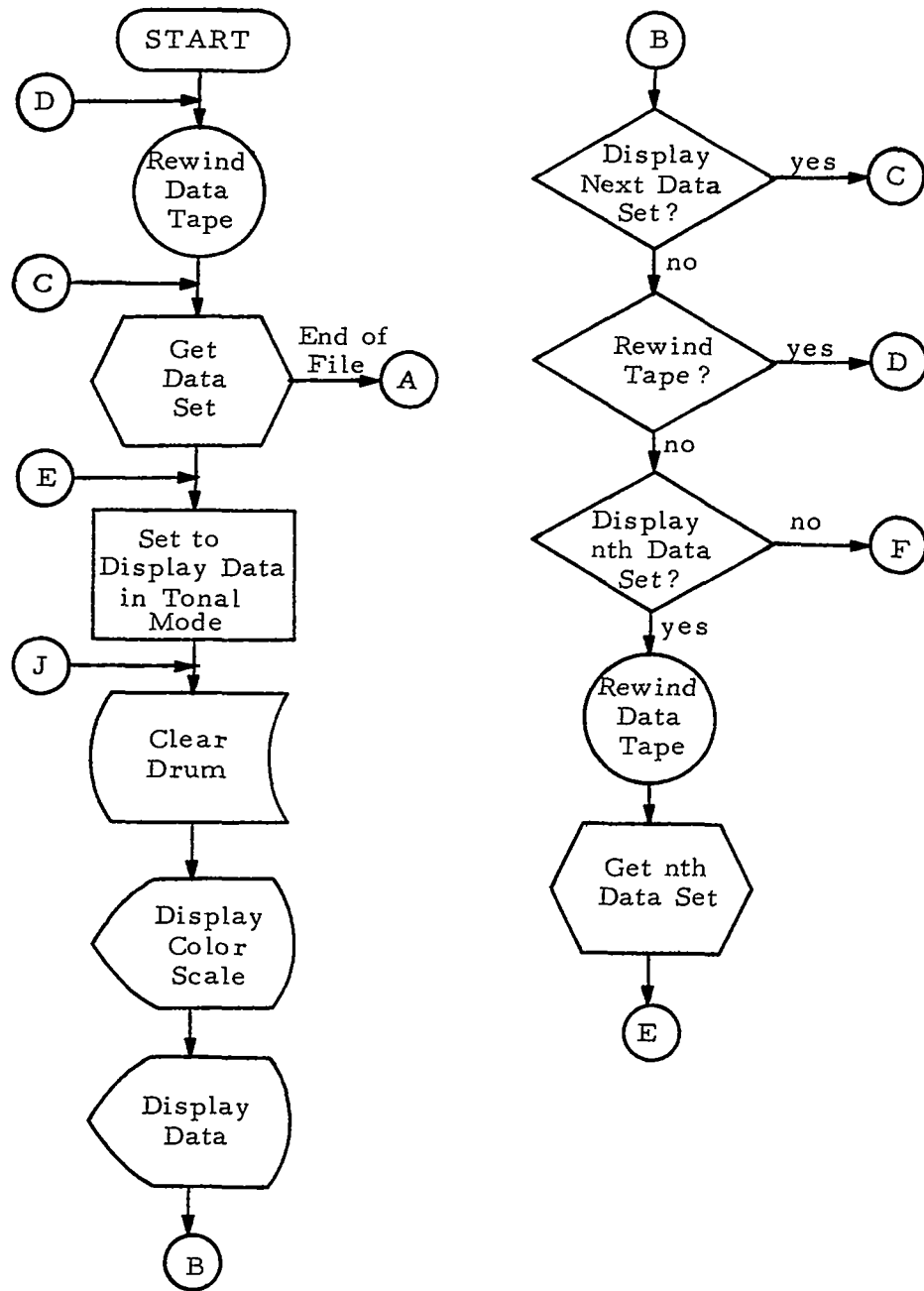
·FIGURE VII. 12   MASS SPECTROGRAM TONAL DISPLAY
  (Con't)   FLOW CHART

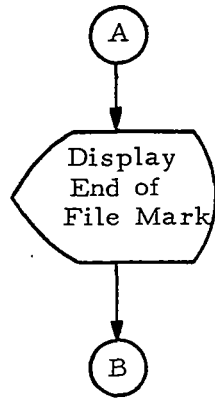VII-21
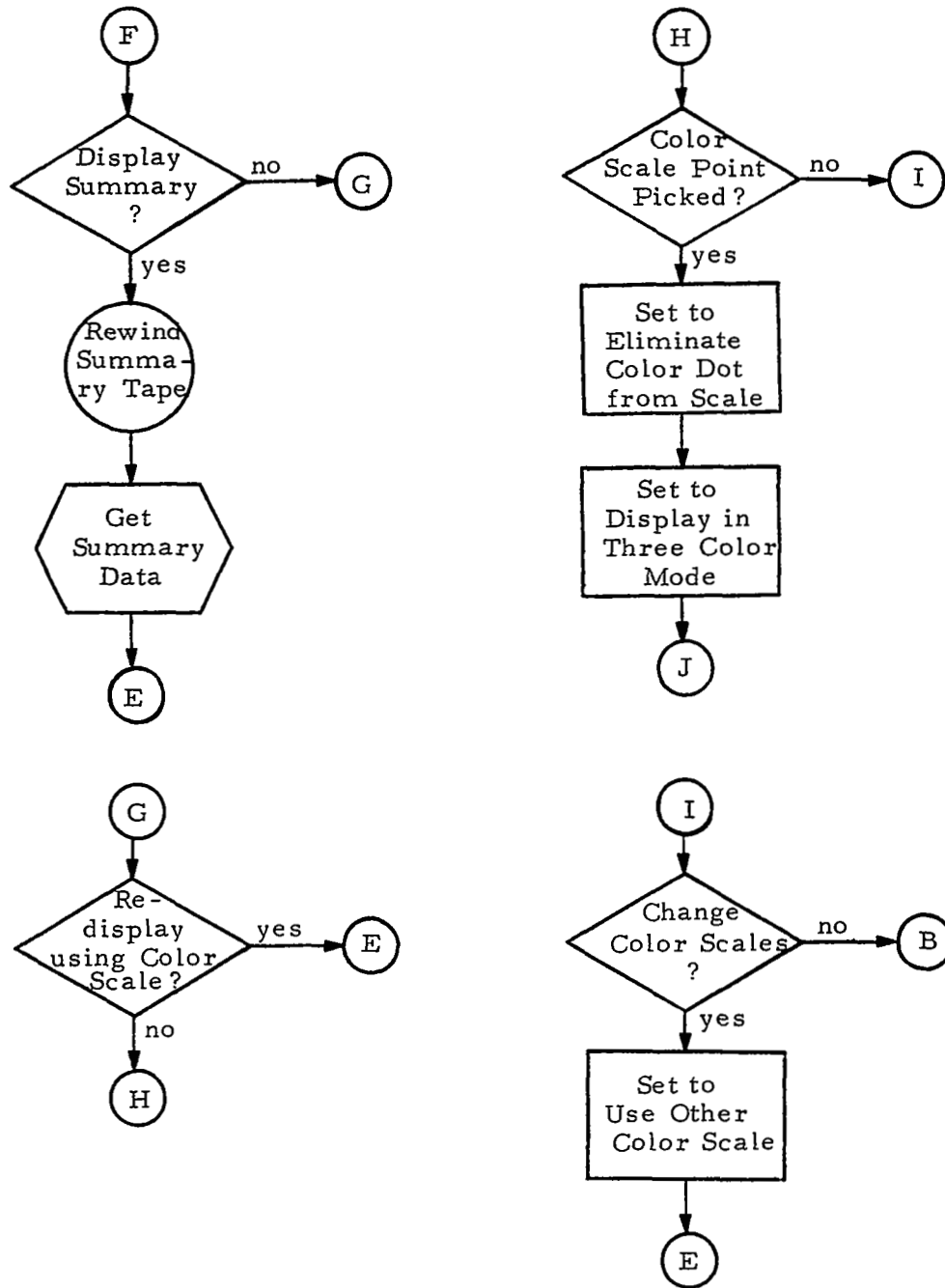
FIGURE VII. 12   MASS SPECTROGRAM TONAL DISPLAY
    (Con't)   FLOW CHART
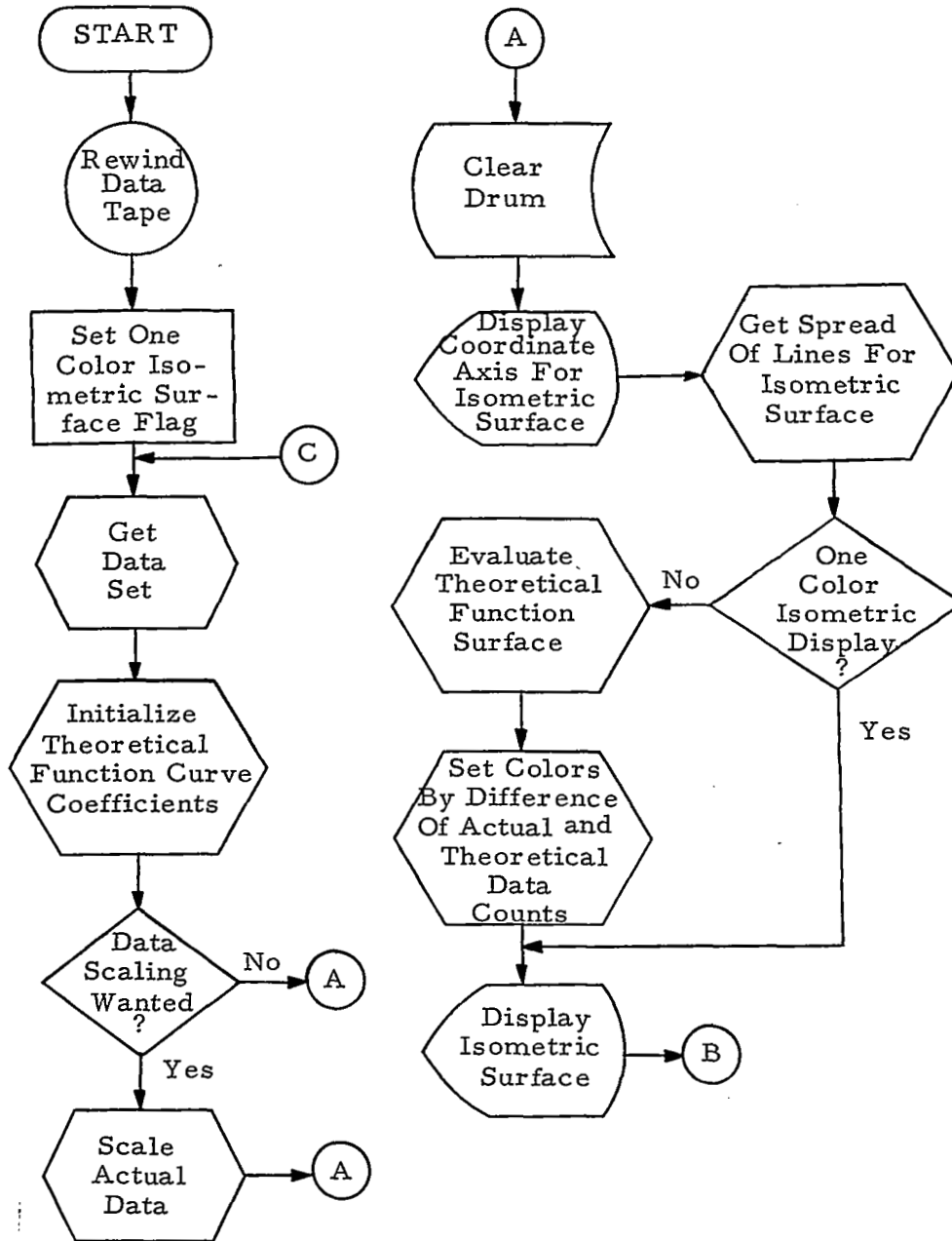
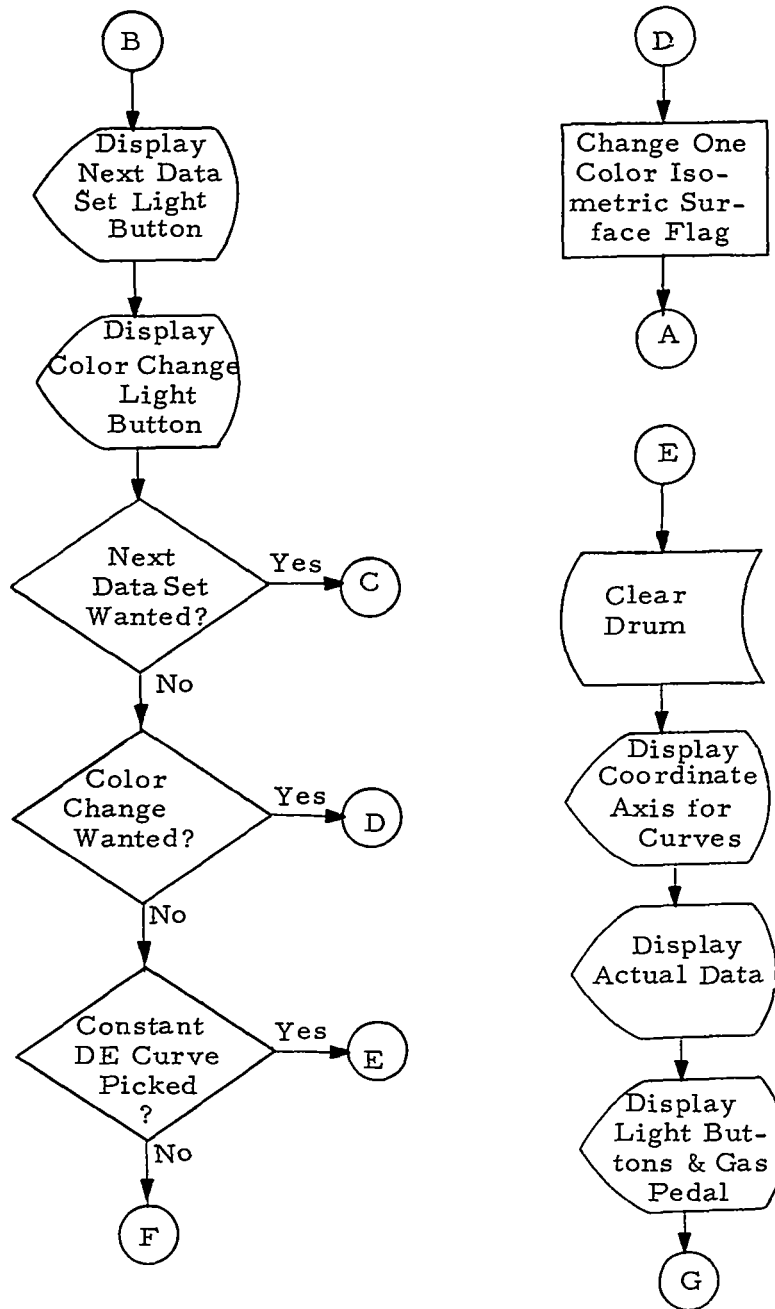FIGURE VII. 13   ISOMETRIC PROJECTION AND CURVE
FITTING FLOW CHARTS

FIGURE VII. 13   ISOMETRIC PROJECTION AND CURVE
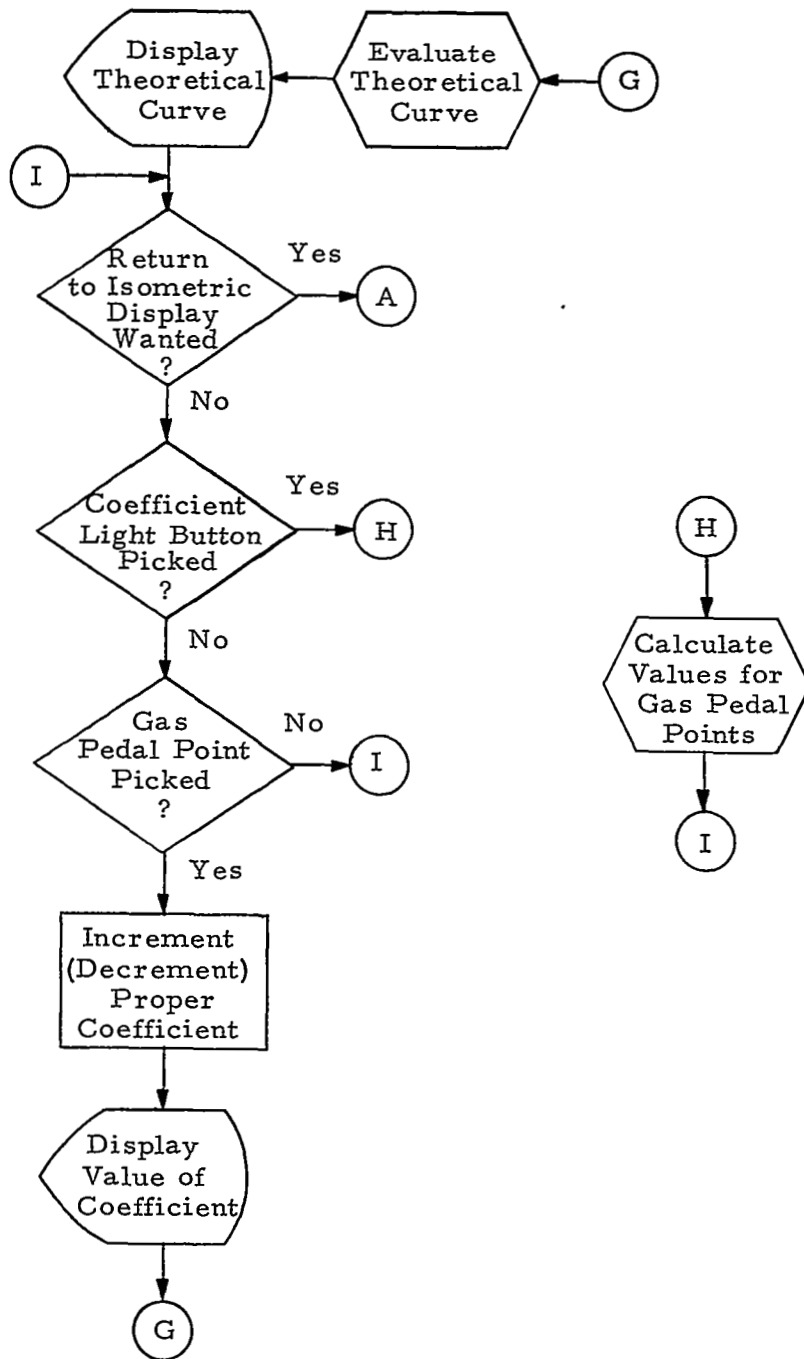(Con't)   FITTING FLOW CHARTS

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FIGURE VII. 13   ISOMETRIC PROJECTION AND CURVE
(Con't)   FITTING FLOW CHARTS

APPENDIX VIII
HIGH CAPACITY TONAL DISPLAY

A limiting factor in the usefulness of computer display con-
soles is the quantity of digital data which can be displayed at a flicker-
free regeneration rate. Typical present day equipment has a maximum
capacity of approximately 5,000 (closely spaced) display points. This
is a severe limitation for the space scientist or others engaged in ex-
amining and interpreting the meaning of large volumes of data.

At the Digigraphic Laboratories of Control Data Corpo-
ration in Burlington, Massachusetts, computer display equipment has
recently been developed with a capacity of approximately 100,000
(closely spaced) points at a flicker-free regeneration rate. Further
efforts are aimed at increasing the capacity to approximately 250,000
points.

Data from the Isotopic Abundance Experiment (described
in Appendix VII) has been reformatted for input to this equipment. When
first displayed, the results were disappointing. As it turned out, the
characteristics of the data surface (high peaks dropping rapidly to flat
plains) were not especially suitable for the 32 level (5 bit) linear scale
employed in the black and white intensity coding of data points. How-
ever, five switches on the front of the console permitted modification
of the digital to analog conversion process. By changing the position
of one of these switches all data bits in the corresponding binary digit
position could be complemented, set at zero, or set at one. By adjust-
ing these switches much more satisfactory displays were obtained, as
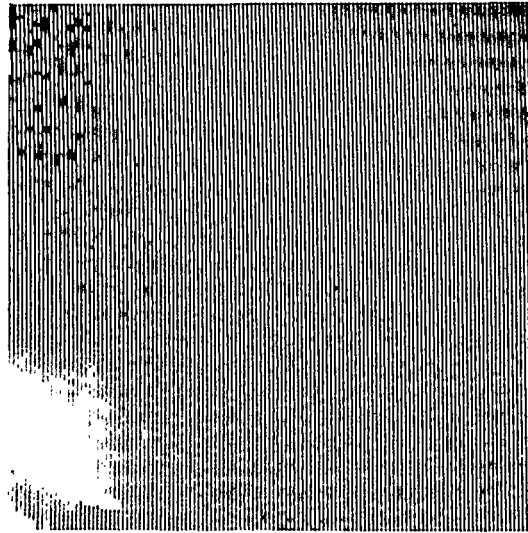shown in the following figures.

FIGURE VIII. 1   MASS SPECTROGRAM (NN11N)

For Figure VIII. 1 the swtich settings were NN11N (where
N indicates normal conversion, 1 indicates bits forced to equal one,
and the left to right order corresponds to decreasing significance).
The effect here enhances contrasts between low valued data and zero
value background
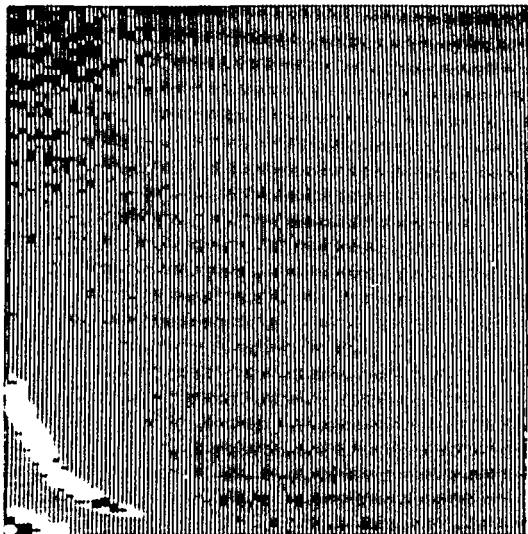
FIGURE VIII. 2   MASS SPECTROGRAM (NINNN)

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In Figure VIII. 2 the switch settings NINNN gave normal low valued data display but inverted (I) some of the relatively high valued data in the lower left corner, making certain points stand out (black). Notice the enhancement of detail in general in that area.
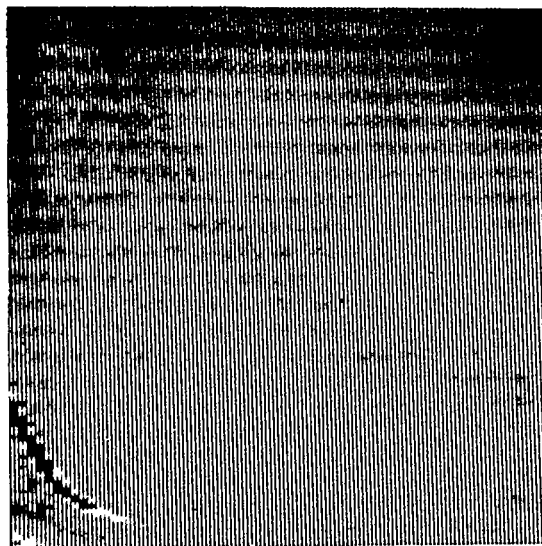
FIGURE VIII. 3   MASS SPECTROGRAM (INNII)

In Figure VIII. 3 the inversion of low order bits produced a photographic negative effect in the low valued data. The inversion of the high order bit made it possible to locate some of the highest valued data (light gray within the black area).

The coarseness of the seam lines in these pictures must be evaluated in light of the fact that approximately 23% of the 100, 000 point display area is shown in each picture. The structure of the scan lines reflects the method of display generation. The electron beam is driven in a scanning mode, a variable length vector at a time. Typically the length is set at   0. 25". Each vector contains 16 spots of various intensities. At 0. 25" vector length, each spot is approximately 15 mils in size.

A magnetic drum is used for buffer storage of display commands. The time required to load commands onto the drum for a 100,000 point display is approximately 8 seconds. The drum, rotating at 1800 r.p.m., generates 20,000 vectors in one revolution, or one vector in 1.67 microseconds. Some of the vectors move the beam to the next scan line with the beam off. Eighty bits of intensity data (16 points x 5 bits) are read in parallel during each 1.67 microsecond interval, along with vector position bits. The analog to digital conversion rate is 9.6 megacycles.

The price quoted for this system (September 26, 1967) is as follows:

273	Console	$ 47,500
3298	Controller	48,000
275	Buffer Drum	87,500.

Q.S.E. modifications to the above items
for tonal display   75,000

Total $258,000

The manufacturer recommends that the console be interfaced to a CDC 3200 or 3300 with peripherals as needed for input, plus an eight million character disk, model 854 (required for the digigraphics computer aided design software) and a 3307 high speed data channel (24 bit parallel transfer).

In spite of the poor match of data and intensity coding scale in this example, the usefulness of the tonal techniques for displaying large volumes of data should be apparent.

It is not apparent that thirty two levels in a black and white intensity scale are discriminable. One reply of Digigraphics Laboratories personnel to this question is that 16 levels are discriminable and that the fifth bit may be likened to the overtone. The overtone is not heard but music is flat without it.

An extension of this display technique for use with <u>color</u> appears rather direct. Rather than interpret the eighty parallel bits of data as sixteen five-level intensity commands, they might be interpreted as six color commands of twelve bits each (four for each of the three color beams). The number of points displayed would of course be reduced to 6/16, i. e. , 37,500 vs. 100,000; or 93,750 vs. 250,000. Conversely, each color point may give twenty times the information coding power of an intensity point (Sections 3. 1..1, 3. 1. 2). The manufacturer has no immediate plans for a high capacity color display.

APPENDIX IX

RECENT COLOR PHOSPHORS AND ADVANCES IN COLOR C. R. T. TECHNOLOGY

One of the problems of color display is that of obtaining bright colors without dangerously high accelerating voltages. Accelerating potentials in the 16 kv region are currently used in certain color tubes. These voltages approach the soft x-ray region and pose threats of radiation to users.

Color tube shadow masks obscure a part of the screen (irrespective of electron divergence). Furthermore, no one color of three primaries can occupy more than a third of the screen area. Thus, color displays tend to lack brightness. Screen darkness may be overcome by

1) high accelerating potentials and consequently energetic electron bombardment of the phosphors,

2) efficient color phosphors.

More efficient phosphors mean lower accelerating potentials and safer consoles. Therefore, considerable effort is underway to find more efficient color phosphors.

Efficiency is defined as the total photon energy per total electron energy. It varies from fractions of 1% to 20 + %. Sulfides generally exhibit efficiencies above 15% while oxides show less than 10% efficiency.

It will be recalled that colors are obtained by adding to basic phosphor certain rare earths, metals, oxides, sulfides or other compounds. It is the spectral emission of these compounds (when bombarded with electrons) that an observer sees as red, blue, green or some other color. Phosphor compounds contain many molecular energy levels hence make possible the photo emission of many different colors.

Some colors are too pale even though efficiently generated, while others are obtainable only by excessively high electron accelerating potentials. Thus, the problem is to find efficient rich color emitting phosphor compounds.

The most recent color phosphor compositions are based on rare earch activated host crystals. Specifically, the europium activated oxides or oxysulphides such as yttrium oxide, yttrium vanadate, gadolinium oxide and yttrium oxysulfide are among the mose efficient yet synthesized. (J. A. Davis). All emit narrow band luminescence in the red region of the visible spectrum.

Blue emission (narrow band) is obtained efficiently from zinc sulfide activated with thulium. Green emission can be obtained efficiently from indium orthoborate activated with terbium.

Some of the newer color phosphors are shown in the following list. Note that they are obtained by compounding rare earths (mostly europium) with phosphor:

Composition	Color	Peak Wavelengths (nm)	Radiant Eff. %
$ZnS: Tm$	Blue	478	-
$InBO_3: Tb$	Yellow	542 550	8
$Y_2O_3: Eu$	Red-Or	611	7
$YVO_4: Eu$	Red-Or	615 619	7
$Y_2O_2S: Eu$	Red-Or	615 630	7
$Gd_2O_3: Eu$	Red-Or	611	8

The efficiencies of these compositions are generally acceptable for color display. $YVO_4: Eu$ is already in use as a source of red in color TV and color display

To avoid excessive flicker some persistence (phosphorescence) is desirable, yet for rapid image movement lengthy phosphorescence cannot be tolerated. Excessively long persistence phosphors such as p-27, 34, 38, 39, 40 must be avoided. Many other phosphors are candidate display materials as far as proper phosphorescence is concerned but fail in efficiency, color richness, or excitation energy requirements.

Currently, color TV uses P-22 B(ZnS: Ag), P-22 G (ZnS: cdS: Ag) and P-22 R(YVO_4: Eu). These have decay times to 10% level of 25 microseconds,' 60 microseconds and 0.9 milliseconds respectively. Furthermore, the initial excitation colors of these phosphors (fluorescence) is the same as their after-excitation colors (phosphorescence). That is, they do not change colors during display.

Certain selected color phosphors and their conversion efficiencies are shown in the table:

Composition	Code No.	Color	Peak Wavelength (nm)	Measured Conversion Eff. %
ZnS: Ag	NBS 1020	Blue	452	21
ZnS: Cu	NBS 1022	Green	525	11
ZnCdS: Ag	NBS 1023	Yellow	570	19
ZnCdS: Ag	NBS 1024	Orange	590	12
Zn_2SiO_4: Mn	NBS 1021	Green	525	8 .
ZnS: Mn		Orange·	591	4
ZnO: Zn	P-15	Blue-Gr	505	7
$CaWO_4$		Blue	430	3
$CdSiO_3$: Mn		Orange	590	5
$Zn_3(PO_4)_2$: Mn	NBS 1025	Red	643	6

Here NBS = National Bureau of Standards. The so-called P-number refers to certain usage; not persistence, nor phosphorescense time. Conversion efficiency is the electron (electrical) energy

put into the system divided into the light energy put out by the phosphor compound.

For ultra fast color display, Dr. W. Lehmann of Westinghouse has developed a bright green compound which decays to 1/10th brightness in less than 10^{-9} seconds. He has added a trace of indium to cadmium sulfide and zinc oxide to accomplish this high speed component.

Prospects for eliminating the shadow-mask and the phosphor dot triad pattern have been given considerable impetus by the following line of reasoning.

If a non-linear phosphor is mixed with a phosphor of a different color and lower conversion efficiency, then a change in color results as the beam current is increased. For instance, a non-linear green phosphor and a linear red phosphor can be mixed and affixed homogenously on the display screen then bombarded by low current densities. The primary emission is then from the red phosphor. As the current is increased, the green phosphor crosses over on the output versus current density curves, then dominates over the red. This results progressively in red, orange, orange yellow, yellow and green yellow. While this prototype (developed by IT &T) lacks blue, hence several hues, it is suggestive of what may come.

Note that this non-linear phosphor approach is different from the penetration approach where one of three primary layers are reached by exciting electrons as a function of acceleration potential. In the penetration approach the underlying phosphors must be penetrated before the electrons can reach the outer phosphor layers. This poses a distributed screening problem reminiscent of shadow-masks and calls for generally high accelerating voltages. To the contrary, a homogenous mixture of linear and non-linear phosphors (current activated) comes nearer to the ideal goal of obtaining any desired color at any desired spot at low voltage.

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Finally, Dr. H. Yilmaz of A. D. Little Company has developed a well known theory of color of which E. Land's two-color phenomenon is seen to be a special case. Since Yilmaz's theory is reported in detail in several publications, it will not be reviewed here. Analogous to Land's generating the color spectrum from two colored pigments display people might someday generate the emissive spectrum from two light sources. Theoretically, one should be able to start with any given color and change its wavelength in either direction, hence generate the various colors of the spectrum.

APPENDIX X

ON THE USE OF LIGHT SYMBOLS
AS A TECHNIQUE FOR USER INPUT REQUESTS

Among the many means for transmitting user requests to a display-oriented software system are the light pen, typewriter keys, function buttons, and various other switches and pedals. In the realm of light pen pointing, usage has generally been restricted to pointing to data points, control dots or "light buttons", and mnemonic codes for various user requests. Light symbols are an extension of the light button concept which seem to offer general ease of usage and flexibility of application, in addition to a relatively small part of the display scope needed to accommodate such symbols.

A. Design

Light symbol design can be handled two ways. They can be pre-programmed or user created. Of course, user-created symbols are more flexible but a certain drawing time and core allocation trade off is indicated. However, both approaches to the specification of light symbols have certain design considerations in common. They may be displayed using hardware features such as point, character, and vector generators or any combination of these. They must also observe certain minimum size and spacing restrictions. Optimization involves keeping symbols and their spacing small enough so that the data being displayed is not encroached upon, but large enough so the symbols are legible, distinguishable from neighboring symbols, and selectable by a light pen. (See Section B).

Multiple-choice symbols have the added design criteria that discrete control points must be separated by some minimum distance in order that the user's intentions be clear to the software. This minimum distance will be found to be equal to the diameter of the field of

view of the light pen. (See Section B). In general, a multiple purpose symbol will therefore be larger than a regular light symbol, since all pairwise combinations of discrete control points must be at least a minimum distance apart. For example, if three contol points of a multiple-choice symbol are co-linear, then the length of the line segment joining them is at least as long as twice the diameter of the field of view.

B. Usage

If the light symbols are used in conjunction with a light pen, some consideration should be given to the light pen's interaction with the scope face. The light pen's field of view is assumed to be circular, because this eliminates all problems of rotational orientation of the light pen. The size of the light pen's field of view is determined by the construction of the light pen. Most pens have a lens mounted in the front end of the pen and the distance of this lens from both the photocell in the pen and the scope face determines the size of the field of view. On many pens the photocell to lens distance is variable, thus providing for variable field of view size. The optimum size is that which provides a cylindrical field of view so that pen to scope distance is not important. Furthermore, the pen should be insensitive to ambient lighting and to the afterglow on the scope. Only the bright initial intensity (fluorescence) of each displayed point or symbol should be sensed. The role of the lens in determining field of view is illustrated in Figure X.1. Figures X.1a and 1c show fields of view which depend on pen to scope distance. Figure X.1a shows the field of view when distance d is less than f, the focal length of the lens. Figure X.1b shows d = f and Figure X.1c shows d > f.

If the light symbols are selected using a pointing device, such as is associated with the Sylvania DT-1 Data Tablet, the spacing between multiple choice symbol control points may be set at a smaller distance than typical light pen field of view diameters.
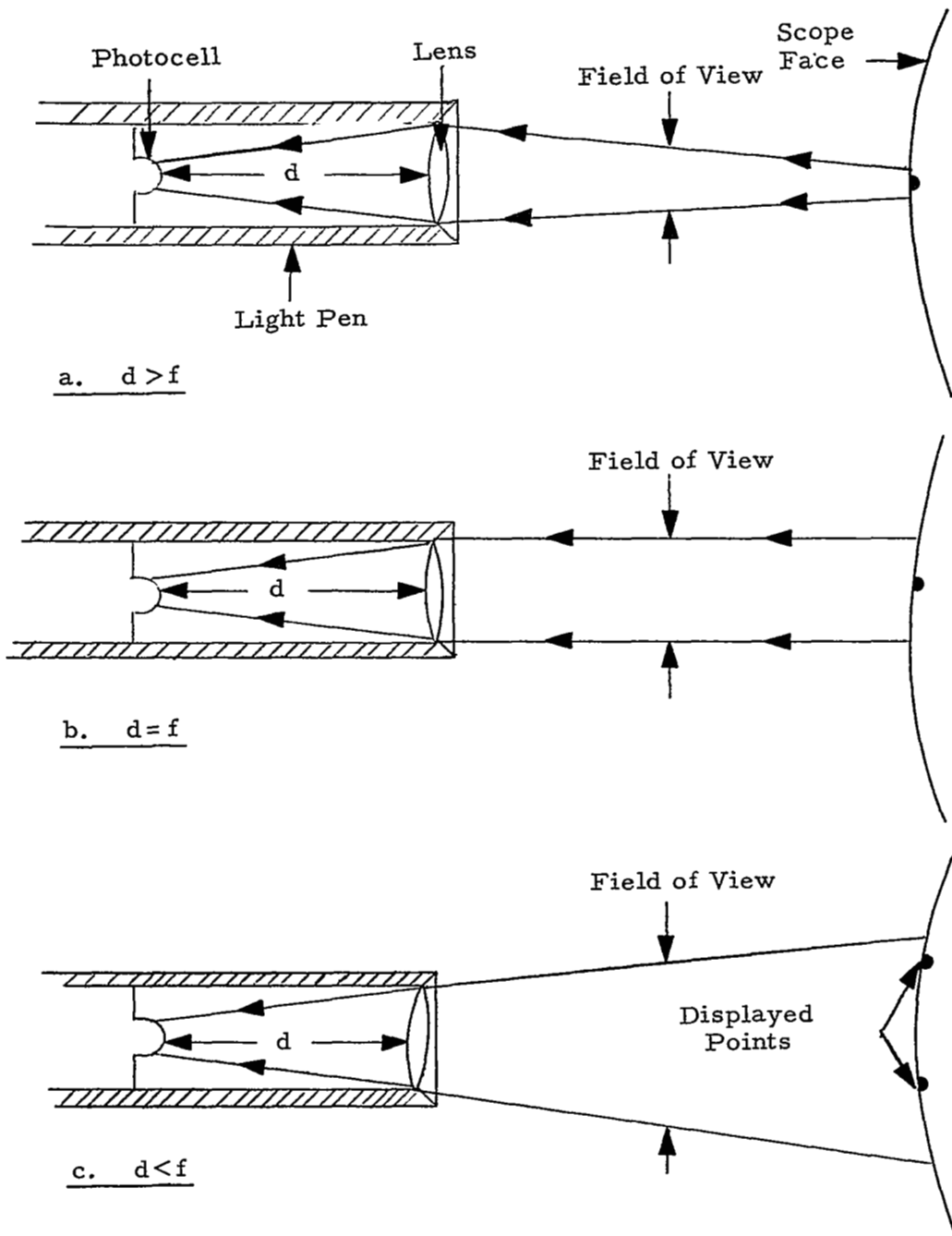
FIGURE X. 1   LIGHT PEN OPTICS

C. Flexibility

The light symbol technique appears to be quite flexible. The symbols can be any size above the minimum and they can be placed anywhere on the screen. They can even be interspersed with display data. The symbols can be either user-created or pre-programmed. They can be single or multiple function symbols. These symbols can also have different meanings when the user is in different "modes".

Light symbols keep the user's attention on the display scope. Light symbols can be used to prompt the user's actions by making available only those symbols which can logically be selected in the present mode. The function associated with a light symbol can be easily transferred to another light symbol. [20]

D. Experimental Use

Trials have been conducted to investigate several aspects of man-machine communication through the use of light symbols "drawn" by the user directly on a CRT display scope. The experimental users were allowed to first draw a set of 8 single function light button shapes for various pre-programmed functions. They then drew a ninth symbol which was to be used as a multi-function sumbol (multi-symbol). The users operated an on-line programming/debugging system, indicating requests through light gun activation of the light symbols just created.

E. Equipment

The experiment was performed on the Whirlwind I computer at WRDC. Whirlwind is a 16-bit, 6144 word, parallel-type computer developed at M. I. T. in 1947. It has 36,864 words of magnetic drum memory and a display system of up to 25 CRT consoles with associated light guns. The displays use P7 phosphor, are core driven, and have no programmable settings for intensity or spot size. The

scope used has a 2048 point square raster in a 10" x 10" viewing area with a point generator, character generator, and vector generator (not used in this experiment).

F. Approach

An existing on-line programming and debugging program was modified so that certain light buttons would be replaced by light symbols created on-line at run time according to the user's choice. The first display presented to the user is shown in Figure X. 2. This display
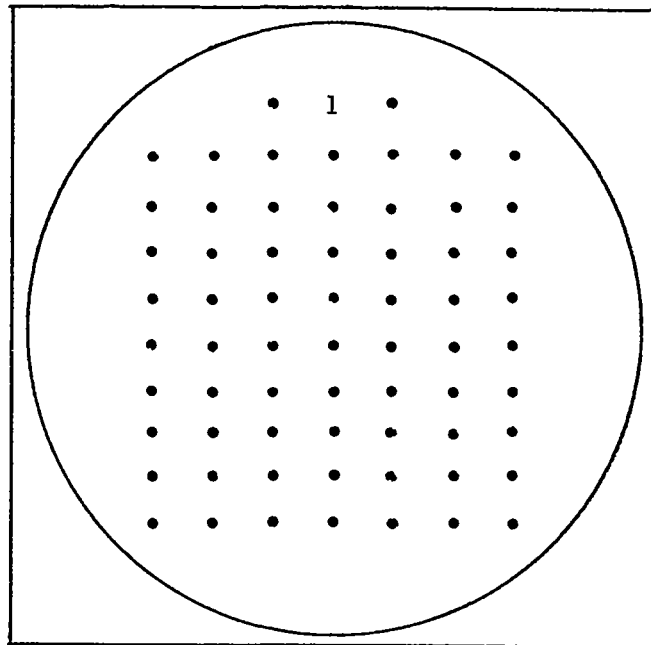
FIGURE X. 2 SYMBOL CREATION RASTER

consisted of a 9 x 7 dot matrix with 2 control buttons above it and a numeric character indicating which of the 9 symbols was currently being designed. As the user selected points of the matrix for his light symbol, the points selected appeared to the right of the matrix, thus indicating the partially built symbol in its ultimate size (see Figure X. 3).
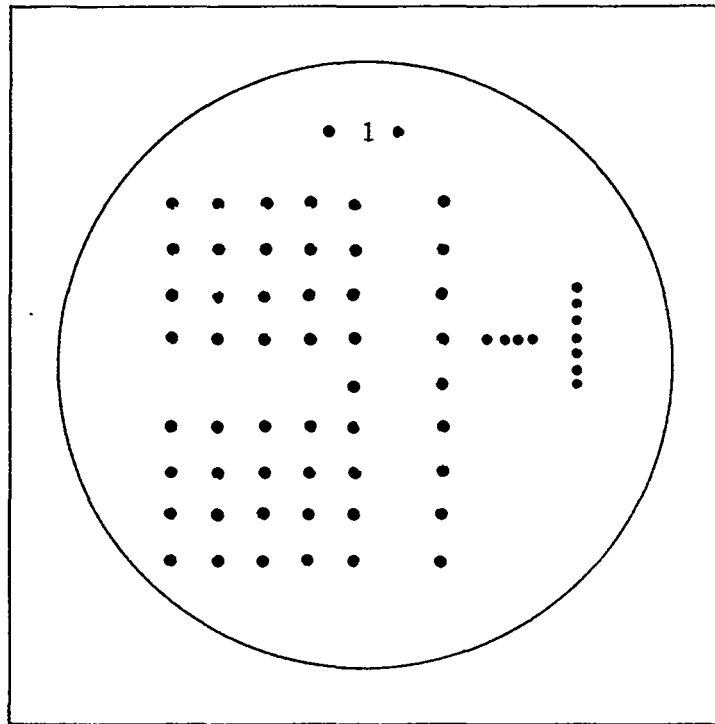
FIGURE X.3   SAMPLE SYMBOL

This procedure has forgiveness built into it, in the form of a reset button just to the left of the sequence number above the large matrix. Activating this button causes the large matrix to be initialized and the partially drawn symbol to be erased from memory. The light button to the right of the number, when activated, stores the user's symbol, advances the sequence number and resets the display to begin construction of the next symbol.

The ninth symbol is a multi-function symbol which has four different functions assigned to its four quadrants. When the user creates the symbol, points picked in a 4 x 3 quadrant will have that quadrant's function assigned to it (see Figure X. 4). For example, if the encircled points in Figure X. 4 were selected as a multisymbol, then the point in the upper left of the symbol has function 5, upper right has function 4, lower right has function 3, and lower left has function 2,

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whereas the center point has no function. The no-function points are
included for continuity of symbols and symmetry of drawing areas.
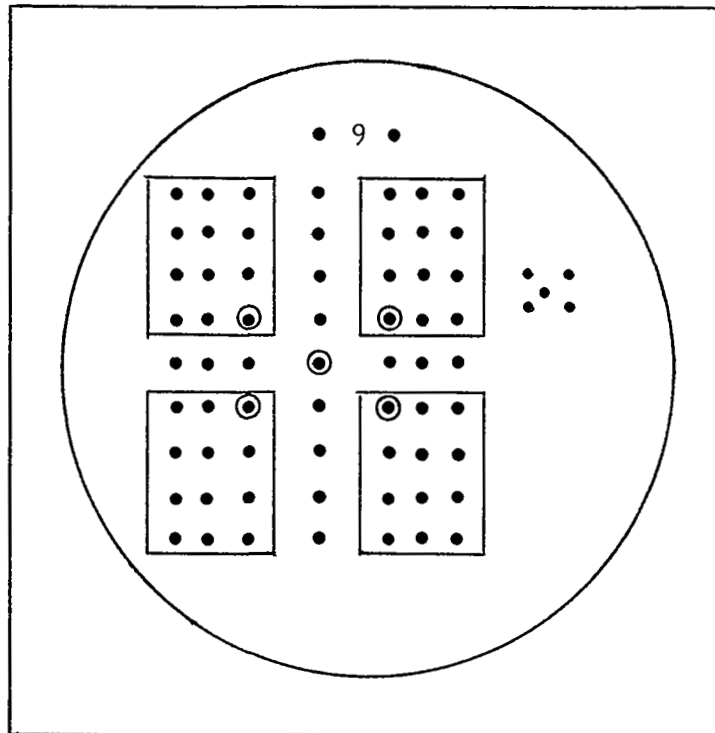
FIGURE X.4   A MULTISYMBOL

        Once the sumbols have been drawn they are used to
initiate requests to the programming/debugging part of the program.
By use of the light gun, the user can examine, modify and correct the
program at will.   The basic display for this phase is indicated in
Figure X.5.   The numbers 0 - 7 represents 3 bits each and are
selected by 'shooting' the light button to their right with the light gun.
The selected numbers then appear as an octal word in the buffer (40 on
the scope).   The numbers 10, 20, 30, 40 represented typical numbers
for the four registers.   The number 40 is the current value of the word
buffer, 30 is the current value of the replacement register, 20 is the
current value of the drum current word register, and 10 is the current
value of the drum address register.
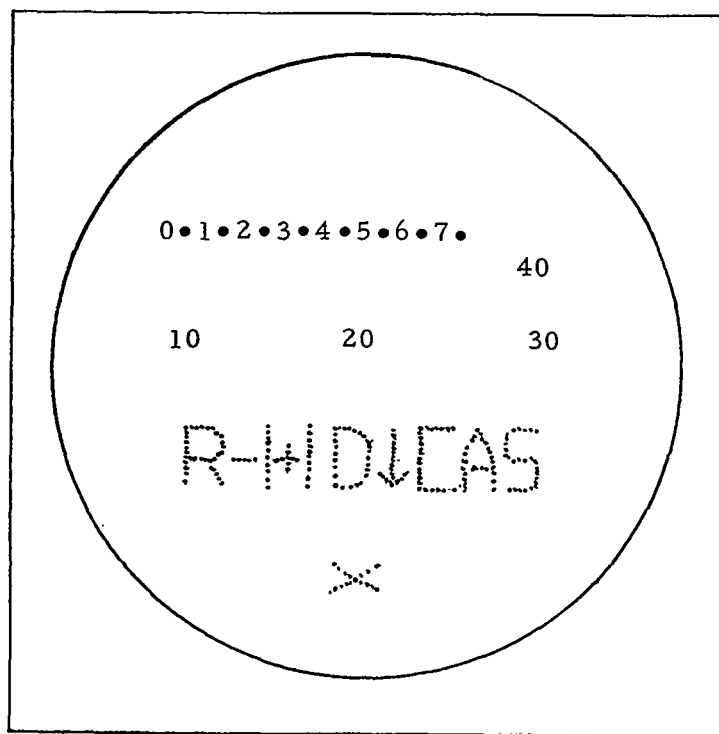
FIGURE X.5   ON-LINE DEBUGGING DISPLAY

Functions of the eight (8) Light Symbols across the bottom of display
are listed below:

Symbol 1 - Activation of this symbol puts the contents of
the replacement word register into the address
on drum as indicated by the drum address
register and then re-examines the address and
places its contents in the current word register.

Symbol 2 - Activation of this symbol causes the address
indicated by the drum address register to be
decremented by 1, then examined, and finally
its contents placed in the current word register.

Symbol 3 - Activation of this symbol indexes the address
counter by 1 and examines that register, placing
its contents in the center box (i. e., current
word register).

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Symbol 4 - Activation of this symbol loads the contents
of the buffer into the drum address register
and then the contents of this drum address
are placed in the current word register.

Symbol 5 - Activation of this symbol loads the contents of
the buffer into the replacement word register.

Symbol 6 - Activation of this symbol clears the buffer to
zero.

Symbol 7 - Activation of this symbol causes the routine to
go into address search mode. It will search from
the address indicated in the address register
upward through the drum, until it finds a word
whose address portion matches the address
portion of the word in the replacement word
register.

Symbol 8 - Activation of this symbol causes the routine to
go into word search mode. It will search from
the address indicated in the address register
upward through the drum, until it finds a word
which matches the entire word in the replacement
word register.

G. Observations

During the drawing and use of symbols by several experi-
menters, it was observed that the use of user-created symbols did
provide an aid in understanding and successfully using the programm-
ing/debugging system. However, there were a number of criticisms
about this experiment including the following.

1) The light gun used had a poor sight and was awkward
to use. The thickness of the protective glass covering the scope face
created parallax problems. The gun could be touching the glass just
above a symbol and when the microswitch trigger was pressed, the
adjacent symbol was observed to have been the one sensed by the photo-
cell in the light gun.

2) The relatively large number of points needed to produce meaningful symbols caused the display time per cycle to be sufficiently large so that the flicker of the display was high enough to be annoying.

3) In this experiment the x and y spacing of the points within a light symbol was variable. The size of the light symbol required to render distinct symbols which are easily selected by light gun, prohibited getting more symbols across the scope. Also, the size of the multisymbol was noted as being too small to easily distinguish parts of it, until the symbols were made over an inch high. The setting used for the x and y spacing at this time was about sixteen raster units. The programming manual recommends no more than six raster units between displayed points for seemingly continuous lines.

4) There was a noticeable lack of flexibility in the choice of symbols possible using only the 63 points in a 9 x 7 array. This could be remedied by allowing more points, but then more display time would be needed, more drawing time needed, and more core locations needed to store the coded points.

5) Lack of the ability to define the functions as well as the symbols was cited. But the complexity of programming this feature and the program being modified put this feature beyond the scope of the present experiment.

5) Criticisms of the multisymbol were many. They included most of the above, and in addition, rejected the quadrant scheme for equating part of a symbol to a function. Each function does not have equal use nor importance. Therefore a symmetrical symbol is not required nor desired in most cases. There are too few points available to give a meaningful multisymbol. Complete freedom of choice of the symbol's orientation as to function was desired. Also the symbol had to be large enough to have ample control over which function would be selected.

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H. Concluding Remarks

It will be noted that the general basis for criticism center-
ed on equipment limitations. Better equipment would probably alleviate
most of the above problems; however, a usefulness for light symbols
is indicated by this study and further study seems warranted in this
area.

APPENDIX XI

ALPHABETIC INPUT VIA PROBABILITY TYPEWRITER

In attempting to work with a design constraint that allows only one input device, which cannot be a keyboard, the graphic system designer is presented with a nontrivial problem to specify a useful technique for high volume alphanumeric input. For many types of on-line input (programming, procedure writing, report generating) this type of input is generally essential. The most natural means of text input for the user is hand printing. Real-time recognition of hand-printed text has been demonstrated by Groner at RAND, and others, and more research in this area is being funded by ARPA and NASA at SDC under Morton I. Bernstein. We have not, however, attempted to include this technique in our present effort, the scope of which does not include specialized areas such as heuristic, adaptive or pattern recognition programs. Instead, we have considered a technique which compared with character recognition should facilitate higher speed input; should require smaller and faster running programs; and should give more favorable response time to the user and allow for efficient management of display areas.

This technique is an extension of the "probability typewriter" as discussed in Research Memorandum-ER-8933, "Human Performance Using A Computer-Generated Alphanumeric 'Keyboard'," Lockheed Georgia Company, May 1967. Although Lockheed's purpose was to compare operator performance using three different configurations of displayed keyboards and a standard typewriter, the notion of probability seems to be applicable to the present purposes.

Efficient management of display areas motivates the system designer to present only a partial alphabet set to the user for character picking. If the partial set consists of the letters which are most likely to follow the last letter selected by the user, then there is a

measurable probability that the letter he wishes to select will be included in the partial set displayed. If the probabilities of all digraph combinations (groups of two letters) are computed for a sample text, a 26 first letter x 26 second letter (English alphabet) probability table may be constructed as a partial set source. An extract from such a table is shown in Figure XI. 1. This table was developed by Lockheed from a sample text.

Each row gives a letter, its percentage of occurrence in the sample text, and a set of five letters in order of their probability of following the first letter in text. Since only five succeeding letter choices are given, a final column provides completeness by giving the percentage of occurrence of any of the remaining 21 letters. Since there seems to be some variation between the probabilities in this table and those given in standard cryptographic texts, caution is indicated in their use. Along the same line it may be noticed that the letter "O" is not given as a succeeding letter to "Z". Further, it is reasonable to expect that digraph frequencies may vary among individual authors. If their variation is sufficient a probability matrix for each user could be in order.

Based on the probabilities given in this table, it may be observed that a partial alphabet set consisting of five characters will, in general, contain the desired letter approximately 72% of the time. More particularly, if the last letter selected by a user was "A", there is a .68 probability that the next letter he will want will be "N", "T", "S", "R", or "L". If the last letter was "Q" the next letter will be "U".

Considering first differences in the cumulative average percentages, it would seem that five letters might be an optimum size for a partial alphabet set display; going to a set of six would probably add only two or three points to the probability of finding the desired letter. This, of course, bears further investigation.

Letter (Col. 1)	Pct of occ.	Most likely 2nd ltr and pct	Second most likely 2nd ltr & pct	Third most likely 2nd ltr & pct.	Fourth most likely 2nd ltr & pct	Fifth most likely 2nd ltr & pct	Pct all other ltrs. follow ltr in Col. 1
A	8%	N 21%	T 17%	S 12%	R 10%	L 8%	32%
B	1.3	E 34	L 17	U 11	O 9	A 7	22
C	2.9	H 19	O 19	E 17	A 13	I 7	25
D	4	E 16	I 14	T 14	A 10	O 8	38
E	13	R 15	D 10	S 9	N 8	A 7	51
F	2.9	T 22	O 21	E 10	I 9	A 7	31
G	1.4	E 14	H 14	O 12	R 10	0	50
H	6	E 50	A 23	I 12	O 7	T 3	5
I	7	N 25	T 13	S 10	O 8	C 7	37
J	0.2	U 35	O 29	A 12	E 12	0	12
K	0.4	E 34	I 21	N 10	A 9	0	26
L	4	E 19	I 15	Y 12	L 12	O 9	33
M	2.6	E 26	A 17	O 12	I 11	P 5	29
N	7	D 12	T 11	G 8	E 6	A 5	58
O	8	N 20	F 14	R 11	U 10	T 6	39
P	2.1	O 17	E 16	A 15	R 15	L 8	29
Q	0.1	U 100	0	0	0	0	0
R	7	E 23	O 12	A 11	T 11	I 10	33
S	6	T 19	E 11	O 10	I 9	S 9	42
T	9	H 39	I 10	O 10	E 8	A 7	26
U	2.8	N 18	S 13	T 13	R 12	L 10	34
V	1.0	E 65	I 14	O 9	A 8	0	4
W	1.5	A 27	H 16	I 16	E 15	O 11	15
X	0.3	P 29	T 19	I 14	A 14	U 10	14
Y	1.5	A 15	O 12	S 12	T 9	W 7	45
Z	0.1	E 43	I 43	W 14	0	0	0
Average		29.1%	16.2%	11.4%	9.4%	5.8%	28.1%
Cum. Average		29.1%	45.3%	56.7%	66.1%	71.9%	100%

FIGURE XI.1   TABLE OF FREQUENCIES

In the three alphabet array configurations examined by Lockheed the full alphabet was displayed in each instance, with the arrangement of letters based on the digraph matrix and the last letter selected. The extension of concept proposed here would be to display only (let's say) five letters at a time followed by special symbols meaning "space", "special characters desired", and "next most probable set of five letters is desired". The obvious feature of this approach would be a savings of display area required.

APPENDIX XII

PRIMITIVE SET TRIALS

The basic set of system primitives and control operators developed in Section 4.of this report have been applied to two data display and analysis problems. A summary of results is presented in this appendix.

A. Problem Discussion

The mathematical equations and data displays were well defined at the beginning of this exercise. The primary goal was to see if one could duplicate these procedures using the proposed set of system primitives. A secondary goal of the experiment was to obtain a feeling for how easy or difficult it would be for the experimenters to use the proposed system.

1) The first problem analyzed was Goddard Space Flight Center's Isotopic Abundance Experiment (c.f. Appendix VII). The data interpretation procedure was considered from experimenter sign-on to sign-off and included the following detailed steps.

    a.   Identification of the spacecraft and specific experiment which serves to identify the experimenter.

    b.   Specification and labeling of data sets over a given time for analysis.

    c.   The development of special symbols to be used in creating strategies for conducting analysis.

    d.   The development of the mathematical computation sequences to reduce the data and compute the information to be displayed.

    e.   The development of graphical display representations for viewing the effect of the computational

sequences. This included the investigation of how to specify color for indicating additional or amplifying information about a given data set.

f.   The combination of the computational sequences and graphical representations into strategies for conducting an analysis of the data sets.

g.   The application of the strategies to the data sets for conducting an analysis session.

h.   The termination of the analysis session where the displays of interest that had been generated were retained for future reference.

The computations and graphical displays were not of a complex nature but the test case did provide an exercise of most of the system functions.

2) The second problem, "A Dynamic Attribute Extraction Procedure Applied to Arbitrary Sensor Data",[37] was chosen to evaluate the system primitives for the development of more complex computational sequences and non-standard or variable graphical representations. This experiment included the development of the computational sequences and graphical representations. The other system functions performed for the experiment discussed in paragraph 1) above were not repeated.

B.   Strategy Development

The approach taken to develop a strategy using the primitive operators is similar to a typical programming effort using a problem-oriented language with the major difference being freedom from the detailed I/O statements or computer configuration considerations. The syntax of the mathematical primitives is designed to closely approximate common mathematical notation. The primitives for constructing graphical representations are specifically oriented towards data analysis functions.

The Isotropic Abundance Experiment required the development of only two computational sequences. The first sequence computes the count of common occurances for the measurements ΔE and $E - \Delta E$ in a 256 X 256 array. The second sequence, for theoretical curve fitting, uses the results from the first sequence as its input and then computes theoretical values for the count along the $E - \Delta E$ axis for constant values of ΔE. The first sequence to sum the common occurances of $E - \Delta E$ and ΔE values as it would appear to the experimenter is shown in Figure XII.1. The array size is determined by the maximum values of ΔE and $E - \Delta E$. By setting $I = \Delta E$ and $J = E - \Delta E$ when the sequence is incorporated into a strategy, the indexing of the array is taken from the data itself and the sum of common occurances is calculated by the equation as shown. The actions required by the experimenter to generate this equation are indicated by the circled numbers ①-⑥ excluding the indication of variables and the sequence name.

An example of a more complex computation from the second experiment is shown in Figure XII.2. This sequence is used to form a basic measurement descriptor δ_{at} at each time (t). The input data, $X_p(t)$, consists of p binary digits at each time (t) of which there are $T + N_O$ sets to be processed in a data set. The values of Δt and N_O are specified by the experimenter as part of the analysis function. T is specified when the data sets are identified for analysis. The experimenter primitive $\oplus$ was developed to provide an "exclusive or" operator.

C.   Results of Trials

As a result of developing strategies for these two experiments, areas for improvement to the primitives and system modes of operation were defined. The improvements made included: a) making the generation of graphical representations more flexible for generating non-standard data displays; b) adding certain conditional operators to the mathematical primitives; c) extending the standard character set for the system to include the Greek alphabet and making the creation of

ABCDEFGHIJKLMN
OPQRSTUVWXYZ
0123456789
- . , : SP

RE
ER
CL ⑥

ANA
CRE
DAT
OFF

SEQUENCE: COMPUTE COUNT

$$C_{IJ} = C_{IJ} + 1.$$

√	+ ⑤	<	SUB ③ ④				DL
Σ	-	>	EXP	[ ]	SN
	/	≤	LOG	( )	IF
	↑	≥	SIN	CY	BY
		=②	COS	SQ ②	CA
	*		CL	SOP	
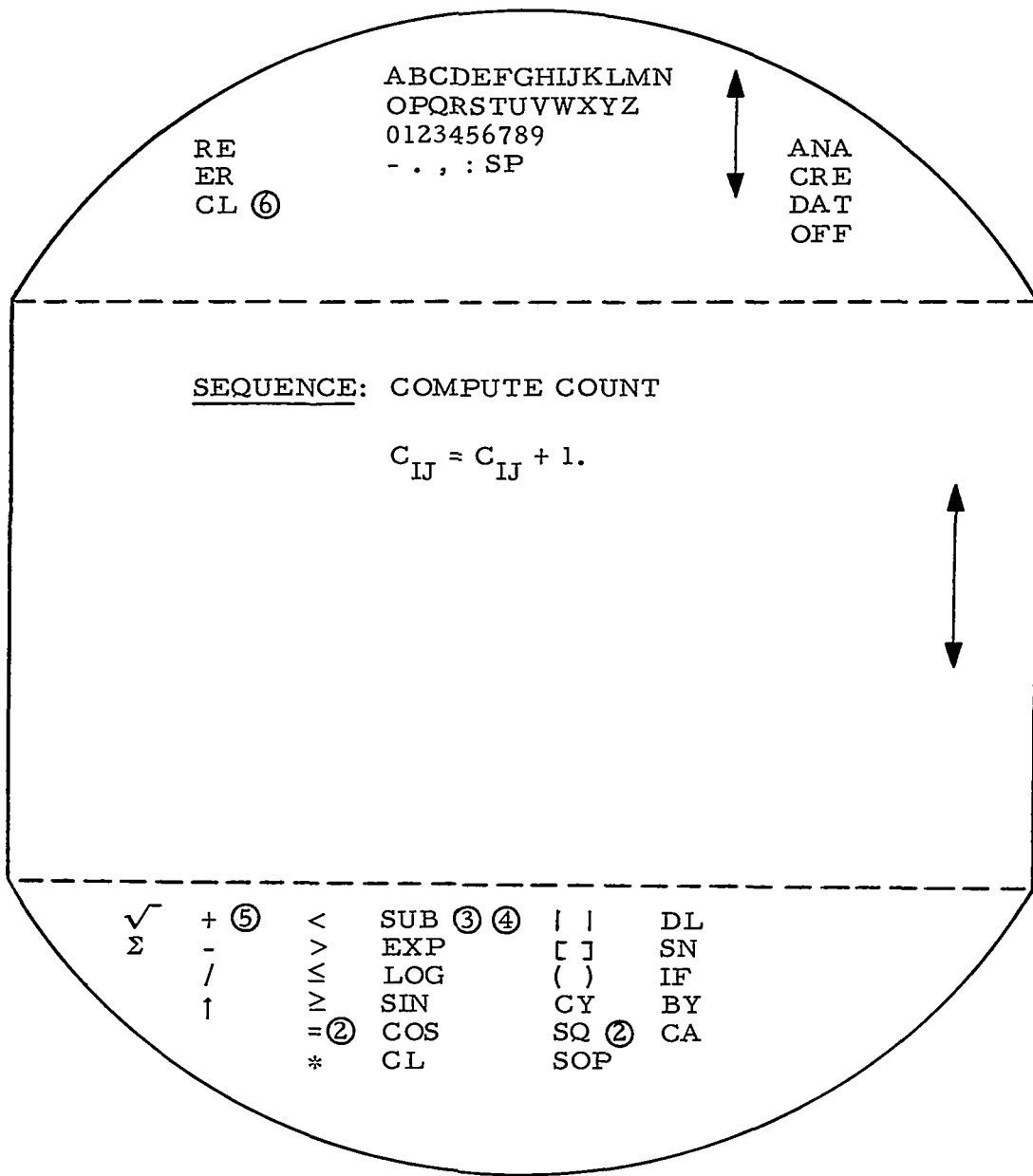
FIGURE XII. 1   SAMPLE MATHEMATICAL COMPUTATION
SEQUENCE FOR THE ISOTOPIC ABUNDANCE
EXPERIMENT

ABCDEFGHIJKLMN
OPQRSTUVWXYZ
0123456789
- . , : SP

RE
ER
CL

ANA
CRE
DAT
OFF

SEQUENCE: $\delta_a(t)$

$$\delta_{at} = \left[(X) \oplus (X_p) * (t + \tau)\right] * C.$$

$$1 \leq N_v \leq N_0 .$$

$$\tau = N_v - 1.$$

$$X = 0, 1.$$

$$C = (N_0 * N_1)^{1/2}.$$

$$a = (X * N_0 * N_1 + \tau * N_1 + P).$$

$$t = t + \Delta t.$$

$$1 \leq t \leq t.$$

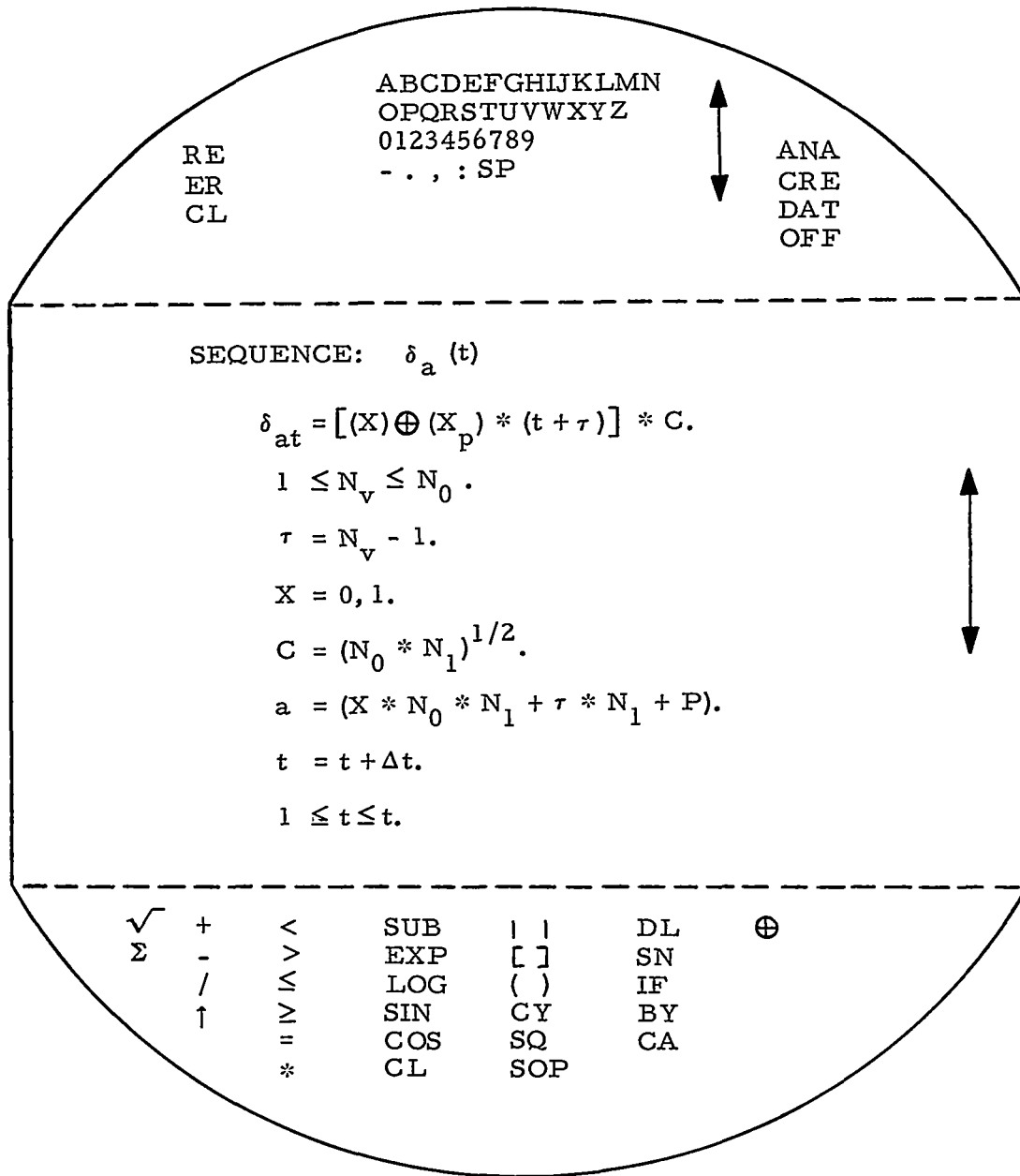| $\sqrt{\ }$ | + | < | SUB | \| \| | DL | $\oplus$ |
Σ	-	>	EXP	[ ]	SN	
	/	$\leq$	LOG	( )	IF	
	$\uparrow$	$\geq$	SIN	CY	BY	
		=	COS	SQ	CA	
		*	CL	SOP		

FIGURE XII.2   SAMPLE MATHEMATICAL COMPUTATION
SEQUENCE FOR THE DYNAMIC ATTRIBUTE
EXTRACTION PROCEDURE

new characters and symbols easier. The approach to user input based on picking characters at random was replaced with the use of lists, where valid choices may be pre-specified, and a fill-in-the-blank type of specification where the list of choices is extensive or unknown.

In summary, the basic set of system primitives appears to be adequate for developing data analysis strategies similar to the ones analyzed and many improvements to the system resulted from this analysis.

APPENDIX XIII

COMPUTER ANIMATION CONFERENCE REPORT

On July 17 and 18, 1967, a conference on computer animation for motion pictures was held in Newton, Massachusetts. This conference was similar to one held two years previously at Bell Telephone Laboratories, and was organized by the Commission on Engineering Education and the Users of Automatic Information Display Equipment (UAIDE). Attendees included those with a need for films (primarily educators); film makers (specialists in composition, timing, use of effects, etc., in motion pictures); and computer display specialists. Since the proceedings of this conference were not published and are probably not available elsewhere, the following summary of the papers, tutorials, and films presented has been included in this report.

Judah Schwartz, M.I.T., on Various Topics in Computer Animation.

Terrible color and texture, and difficulty of instruction were named as disadvantages of the computer as an animation tool. Lower cost was judged a debatable advantage. The recommendation was made that this technique be limited to those things that can only be said by use of a computer. For example, a scaled universe might be created for students of quantum mechanics, astrophysics, or relativity, and they might be shown experiences in that universe in order to develop pedagogical intuition.

A quantum mechanics film was shown, first in black and white, then in blue and white, to illustrate how even a small amount of color can create a more benign learning atmosphere. Technical problems encountered in making this film included the need for a stable camera with pin registration and the need for a computer display fade-out method.

The point was made that in display programming the simplest approach may be the most costly. For example, in the quantum

mechanics film, $y = e^{-x}$ was plotted: it was estimated that the two-instruction approach would have required 20 hours of computer time per minute of film time. The 20 hour figure was reduced to 12 minutes by programming

$$Y_{j+1} = e^{-\epsilon} Y_j , \quad \epsilon = x_j/j$$

which requires that the exponential routine be entered only once. This generation of increments is consistent with random positioning displays but requires care in keeping track of cumulative errors.

A two-dimensional projection of a three-dimensional object is not unique. This is why image tumbling or rotating is useful.

John P. Shannon, Los Alamos Scientific Laboratories, showed a fluid dynamics problem film generated with a CDC 6600 and SC 4020. He reported that particle representation proved less costly than contour representation of fluid flow, quoting 8 seconds of 6600 time per film frame for particle representation. Some Moiré interference patterns appeared in the images as a result of the 4020 mesh size of 1024 x 1024.

A. Michael Noll, Bell Telephone Laboratories, Inc., showed three dimensional movies, viewed with stereoscopic polarized glasses. His conclusion was that 3 D movies can easily be produced using subroutines.

Clarence Kemper, Joseph Kaye & Co., discussed the economic and technical considerations of computer animation. His remarks were based on experience producing a hydrodynamic film under a government grant.

In order to obtain reasonable quality of text a 20 x 30 point matrix had been used for character generation. An image element used extensively in the film was a vector arrow; accordingly a subroutine was developed for arrow construction.

In order to overcome image jitter a professional Bell & Howell stop action camera with locking pin registration was obtained and jury rigged to a SC 4020.

The maximum line segment that can be programmed for the SC4020 is 64 raster points. Breaks appeared between segments when constructing a longer line than this. Therefore each line was retraced, backwards, in order to cover up these interruptions.

Exposure settings were obtained by measuring the light output of the 4020 and adjustments were made manually.

The price of the first film produced was approximately $2,500.00 per film minute. The price for another film on a similar subject (allowing the same subroutines to be used) would be quoted at approximately $600.00 per film minute. These figures compare with $1,000 to $2,000 for hand animation.

Computer execution time was tape limited by the IBM 6450 at 65,000 to 80,000 lines per computer minute, or 65 to 80 lines per penny. Six tenths of a second per frame (1 - 2¢) was required to advance the film.

The primary factor in the high first-time cost was computer program debugging. With the use of subroutine packages this "could be reduced to less than one fourth of production cost". Another technique for reducing this cost element is to produce only every tenth frame on a debug run.

Economic pitfalls cited were numerical analysis problems; poorly detailed storyboard; and last minute changes to the storyboard. Kaye's initial experience was 50% of film cost for programming, but this is now down to about 30% because old routines are being put to use. Hopes are to get the figure down to under 20%.

Donald D. Weiner, Syracuse University, spoke on Self-Explanatory Visualization, a teaching technique based on pure pictures (no titles,

no text) which provides a medium for the teacher remarks-to-student understanding expansion analogous to the FORTRAN-to-machine language expansion.

Also reported was the development of a movie making language for computer animated line drawing and perspectives. The work of Huggins and Knowlton in animation languages was acknowledged.

Woody Anderson, Syracuse University, stressed the importance of selective movement in a picture, achievable by grouping image items in stacks. For the reduction of animation costs it was recommended that a mechanical plotter be used during debugging, rather than the microfilm recorder.

George Michaels, Lawrence Radiation Laboratory, spoke on techniques for producing color movies. These included the Sylvania two-color tube; a white phosphor CRT; (e.g. P4) with a filter; 3 CRT's and dichroic mirrors; a shadow-mask color CRT; and as practiced at LRL, the generation of sequenced images for each color on black and white film, followed by the electro-optical conversion (using sequenced filters) to color film. A savings of 50% was quoted using the DD-80 rather than a SC 4020. The DD-80 operations take from 1/8 to 1/3 the 4020's time.

Kevin Smith, Education Development Center, gave a tutorial on film making. At 24 frames per second, 2-frame animation (same picture twice) is satisfactory for certain types of motion and reduces preparation cost. The quality of 3-frame animation is not considered acceptable under any circumstances. Distinctions were made between raw footage and finished film, and between animation and live action. The use of storyboards was described, as was the use of clapsticks to synchronize soundtrack and film. Work with a moviola editor was described as 98% bookkeeping, 2% art.

The Bell and Howell camera with pin registration allows backing up for double exposures on the SC 4020, with good results.

The Bell and Howell standard movement is used in animation cameras. A less expensive camera with similar features, which like the 4020 camera is designed for animation, is the 18-frame per second $3,695 Giannini.

E. E. Zajac, Bell Telephone Laboratories, Inc., spoke on "How to Get Started". Reference was made by John Carr to the fact that movies were made on the Whirlwind in 1951. Today a typical configuration consists of the following equipment:

| CPU | - - - | Digital Processor | D to A Converter | Camera CRT |
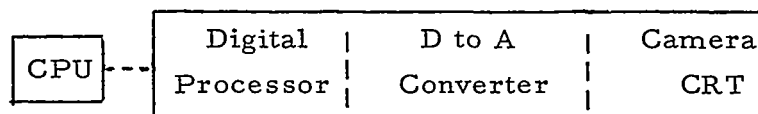
Graphical Computer

Cost: About $ 150 K

An alternate approach is found in the Japanese Hitachi system which uses analog information. Available equipment costs are approximately as follows:

Equipment	Monthly $	Purchase $	Remarks
DEC 338		60K + camera	Designed for Direct Viewing
IBM 2250	1500-2000 + camera		Designed for Direct Viewing
SC 4020	800	130,000*	With automax camera
CDC 280**	5800	170,000	With Giannini camera
B.L. 120	4500	160,000	With automax camera
Calcomp 835CRT		80,000 off-line 60,000 on-line	Incremental Plotter

* Educational Discount Price
** Old DD-80

An alternative to buying the equipment is to take one's magnetic tape to someone else's machine. But at $0.60 per frame, or $864. per film minute (6 minutes of 4020 time) one would pay for a 4020 purchase in one day. The following are sources of 4020 time rental:

Area	Source	Rate	Cameras
Boston	AVCO	$.50/f to .05/f over 10Kf	35 mm 4020 camera
New York	Brooklyn Poly.	$200/hr + $1.44 per min. of film for processing	35 mm B & H 16 mm non registering
Boston	J. Kaye	$135/hr + $30 setup	35 mm B & H
El Segundo	Alpha Graphics	$100 - 150/hr	35 mm 4020
Phila	GE Va. Forge	$0.60/f	35 mm 4020
Boston	Lincoln Lab	?	
Wash	DTMB	?	

The 4020 FORTRAN SCORS package is available for a number of machines from the UAIDE librarian at S. C. , San Diego. The 4020's come in two sizes; 1024 or 4026 character buffer. SCORS was not designed for animation, but the New Brooklyn Polytech Package is available from Zajac. This NBPP will include vector algebra, save-routines for backgrounds, line drawing routines, automatic windowing. Also BEFLIX is available from Knowlton at Murray Hill, but the Bell O. S. is required to run BEFLIX. In order to debug before running on the 4020, IBM has a simulation program, written for the 7094-1401 which produces sample frames on a 1403 printer.

Comparing the DD-80 with the SC 4020, the DD-80 is faster (approximately 20% of the 4020's time).

Robert Davis, Lincoln Laboratory, offered comments on professional quality considerations. At Lincoln Lab he has used an old slap action camera mounted on a tilted forward 4020 CRT.

A RackOver mechanism or Acadamy Frame is used to collimate the camera.

For proper exposure photocell sensors are used and CRT intensity control is adjusted as required by film response. Beam size must be right for use with the extruded beam character stencil. A diagnostic tape with 50 images is used in test runs.

Derek Lamb, Harvard University, discussed non-computer animation, in particular experimental techniques.

In classical hand animation a series of figures are drawn and photographed. Grumbacher celluloid is frequently used for backgrounds, separate drawing of head and feet, etc. This art is on its last legs.

Photo-animation involves zooming in and around a static photograph.

Experimental techniques include scratching, sand papering, perforating film, painting cellulose ink (Pellican T-type) on film.

Other approaches include the use of puppets and clay figures. "Cheapie" hand animation can now be done for $1/foot. (?)

Stromberg-Carlson replied to Michaels' comparison of SC4020 and DD-80. The SC 4060 will have a 3 x 4 frame for movie making; 12 dot sizes for facsimile style tone pictures; and two or more line weights.

Character sizes will be expandable to 64 raster points on the 3072 x 4096 (3 x 4) array. This is four times that of the 4020 so that characters should show up OK on film.

Continuous lines will be available rather than segments. Line drawing speeds will be 1 msec corner to corner for light lines, 4 msec heavy lines.

The 4060 will be adaptable to economic on-line use, with a buffer. An optional pin registered camera will be available at $8K (compare with $4K Giannini).

Frank Sinden, Bell Telephone Laboratories, Inc. cited the five instructions ADVANCE FRAME, SCALE, POINT, LINE, CURVE as an adequate set for line drawing, therefor for animation.

The concept of treating each picture element as a subroutine was described. In five FORTRAN instructions the following steps can be accomplished.

1. calculate picture coordinate data

2. scale data

3. reduce coordinate to 4020 instructions

4. draw

K. C. Knowlton, Bell Telephone Laboratories, Inc., described BEFLIX a software package with which a picture area mosaic matrix of 252 columns and 184 rows can be painted by programmable bugs.

Each computer word contains 3 bits of gray scale information for 12 tiles on the mosaic. Using BUG language the programmer talks to 26 bugs, each a group of 8 registers containing;

1. The pointer to the tile the bug sits on,
2. Width of the surface in machine words,
3. X(bug)
4. Y(bug)
5. Indexing origin address

XIII-8

6. X max.

7. Location of bug

8. Y max

The reason given for the redundancy is to have information immediately available, without calculation time.

W. R. Sutherland, Lincoln Laboratory, spoke on data structures. In a FORTRAN example, record forms (data structures) are single variables or arrays. A picture, however, usually maps more conveniently onto a chain. If a chain is used, means for filling blanks with data or pointers, and means for following chains are needed.

The kinds of things represented in a program, or in a data structure which is later interpreted by a program, are:

1. structure and connections

2. non-displayed supplementary information.

This non-procedural specification allows conflicts of conditions. Core size may be insufficient. A pointer may take control to a cell in slow access auxiliary memory. Recommends consideration of L6 for use in building higher level languages.

APPENDIX XIV

MOTION PICTURE CAMERA CALIBRATION

A motion picture film of displays programmed in the efforts described in Appendices VII and X, and techniques described in Section 3. 2. 3 and Appendix VIII of this report has been prepared and submitted to NASA Goddard Space Flight Center as part of the work performed under the present contract. The production of this film involved a number of activities, as suggested by Appendix XIII. One of these activities, the calibration of the motion picture camera is described here.

A. Purpose

A series of tests was performed on a 16mm Bell & Howell movie camera to determine whether the camera was suitable for making reasonably high quality motion pictures of computer generated displays and related subjects, and if suitable, to obtain calibration data.

B. Tests

The following tests were made:

1. Accuracy of viewfinder at distances of 10, 6, 4, 3, 2, 1, 5 and 1 ft.

2. Depth of field at 6 ft.

3. Constancy of camera speed at a setting of 16 frames per second.

1. Accuracy of view finder was checked with two strips of paper marked off in inches as in Figure XIV. 1.
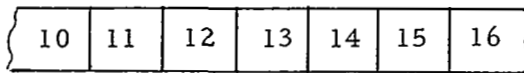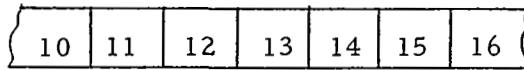
FIGURE XIV. 1 CALIBRATION STRIPS

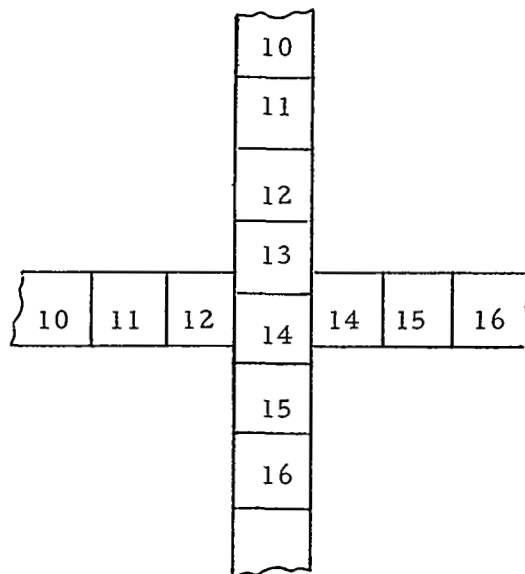They were attached to a wall vertically and horizontally as in Figure XIV. 2.

FIGURE XIV. 2 ARRANGEMENT OF STRIPS

The camera was placed 10, 6, 4, 3, 2, 1.5 and 1 ft. from the strips. At each distance the camera was aimed at the intersection.

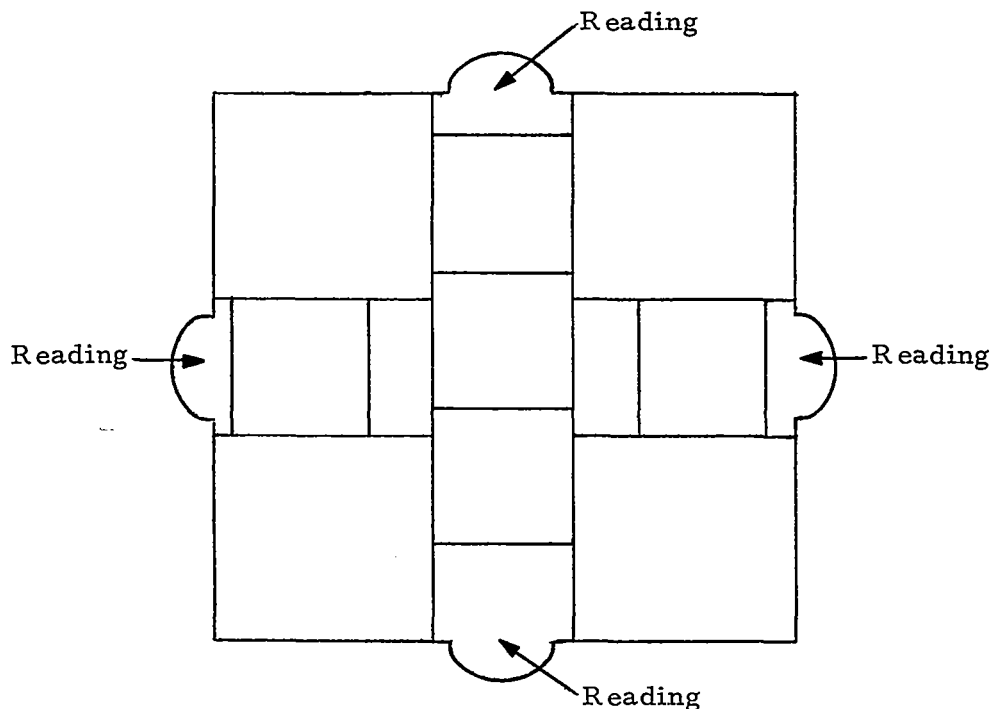of the two tapes and the numbers appearing at the four edges of the finder were recorded. (Figure XIV. 3)

Reading

Reading

Reading

Reading

FIGURE XIV. 3   CAMERA ALIGNMENT

A short section of movie film was taken at each distance. The numbers appearing at the four edges of the film frame were recorded and compared with what the viewfinder indicated at the same distance.

A table of results was prepared. Calibration data indicated both vertical and horizontal offsets at distance from 1 to 6 feet.

2. To determine the depth of field at 6 ft. a newspaper was attached to a wall 6 ft. distant and at an angle of 45° to the camera's film plane (Figure XIV. 4). The camera was aimed at a vertical line drawn through the 6 ft. points. A short segment of movie was then run.
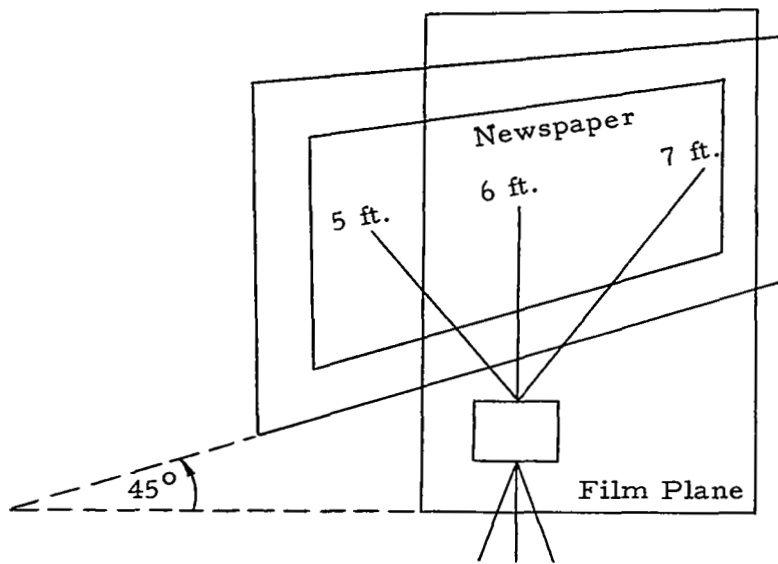
FIGURE XIV.4   DEPTH OF FIELD TEST

The results were that the line focused upon was in focus and the newspaper was in focus between 5 and 7 feet. The depth of field was therefore at least 2 feet. This might indicate that the camera focuses slightly closer than set since more should be in focus in back of the 6 ft. line than in front.

3. To determine the camera's speed uniformity a uniformly incrementing binary counter was photographed for ten seconds with the camera starting fully wound, and also till the spring ran down.

The counter was the set of lights corresponding to the value of the IO register on the PDP-1 computer console. The register was incremented by 1 every 915 microseconds and was left on between increments. The low order 7 bits flashed too fast to be meaningful. They were therefore ignored and the binary point was taken to be between the 7th and 8th bits from the low order end.

With the camera fully wound, the counter (with the shifted binary point) counted to 17 in 15 frames. In a half wound state (after about 32 seconds of running or about 14 feet of film) the camera operated at 94% initial speed. At the end of the wind, the camera slowed to 79% initial speed. The initial speed at 16 frames/sec. setting was determined to be approximately 14.8 frames/sec.

C. Evaluation

With the calibration data obtained, this spring wound continuous motion camera was used for photographing computer displays, with generally satisfactory results.

Unsatisfactory results were obtained when the display repetition rate was less than 15 hertz. The best results were obtained at 30 hertz and above.

APPENDIX XV

FUNCTION GENERATED DISPLAYS

A little over ten years ago when the x, y plotter was made available as a computer accessory, its use was frequently demonstrated using simple mathematical functions to generate intricate plots. Display devices connected to computers may be put to similar use with the added dimension of plot variation in time, or animation. This use of displays may be trivial if the purpose is merely demonstration, or worthwhile as an aid to understanding the nature of a particular function.

As an example of the power of this technique, a spiral generating function was coded in 16 instructions of the Whirlwind I machine language CS-II. The resulting display is documented in the motion picture film submitted under the present contract.

An octal listing of the program is contained in Figure XV. 1 Note that registers 2, 3, 5, 7, 24 can be externally modified during execution time and initally they contain pseudo-random numbers which depend on the effect desired.

Each point displayed is based on the previous point (X_{i-1}, Y_{i-1}). Register usage besides the accumulator (acc) includes:

2	X_i
3	Y_i
5	B_i
7	C
24	A

One complete cycle of the program relates point P_i to P_{i-1} by these recursion relations:

$$Y_i = Y_{i-1} - X_{i-1} * A - A^2 * Y_{i-1}$$

$$X_i = X_{i-1} + B_{i-1} * A * Y_{i-1}$$

$$B_i = B_{i-1} + C$$

The different recurring patterns are obtained by putting different initial values into the external registers 2, 3, 5, 7, 24. These are entered into toggle switches where one switch represents one bit.

Octal Location	Instruction	Explanation
40	cs 3	Clear acc and get complement of Y_{i-1}
41	mr 24	Multiply acc by A
42	sa 2	Add X_{i-1} to acc
43	ts 2	Save acc in X temporarily
44	mr 24	Multiply acc by A
45	sa 3	Add Y_{i-1} to acc
46	ts 3	Save acc in Y
47	mr 5	Multiply acc by B
50	si 600	Select scope and set Y-position to acc
51	cs 2	Clear acc and get complement of X
52	mr 5	Multiply acc by B
53	rc	Set X-position to acc and display the point
54	ca 5	Load acc with B
55	sa 7	Add C to acc
56	ts 5	Store acc in B
57	sp 40	Branch to 40 (beginning of program)

FIGURE XV. 1 SPIRAL GENERATOR PROGRAM

APPENDIX XVI
ON-LINE PROGRAMMING

In the course of this project an on-line programming technique was employed in connection with certain Whirlwind computer applications. Until this time the technique had been considered proprietary by the Wolf Research and Development Corporation. The details of this technique are described in this appendix.

A. The Programming Problem

Since the advent of the high speed electronic digital computer as an instrument for processing command and control military information, performing missile guidance control, and handling the myriad of other governmental and industrial applications for computers, a primary problem has been that of defining a problem solution in terms which are intelligible to the computer. What this problem entails is the translation of the mathematically stated or logically specified procedure into machine instructions peculiar to the digital computer being programmed.

Early programming systems design efforts resulted in development of assembly programs which accept program instructions written in a specialized alphanumeric language. During an assembly program run on the computer, these instructions are converted to the even more specialized language of the computer. More recent developments have led to the design of compilers such as FORTRAN, ALGOL, and PL/I, which accept an alphanumeric description of the program steps in a language which is more nearly related to the mathematical definition of the problem. Therefore, they are a step further removed from the language of the computer. These compiler programs, with their problem-oriented languages, are not universally applicable to all programmable problems.

The seriousness of the programming problem can be appreciated when one considers that an over-all production average of 10 debugged instructions per programmer man-day is commonly quoted, with the output of some large scale systems being as low as one debugged instruction per programmer man-day. Although a skilled programmer is capable of writing many times this number of instructions per day during the actual coding process, the lower average is the result of the many steps between the detailed specification of the problem and the production of a working computer program.

B.   The Approach

A solution to this problem is the use of the computer as an assistant to the programmer. In the case of a large scale machine, however, it is not feasible to sit the programmer at the operator's console and allow him to test each instruction as he writes it. Nor is it practical to give him this form of access to the system just for program check-out. A technique which is feasible is made possible by computer time and procedure sharing, using several remote communication stations. Thus, we may seat the programmer at a "simulated console" which indeed may prove a more powerful tool than the operator's console.

The approach implemented by Wolf Research and Development Corporation was to simulate the computer console at a display console. Special software used in conjunction with the display console provides the programmer with a much more powerful set of control features than are normally available at the computer console. The programmer is given a complete set of mnemonics and control operators which allow him to write assembly language programs online. As each instruction is entered, it is executed and the results and/or changes to the affected machine registers are shown to the user. This feedback assures him that the instructions are doing what he wants.

Although we have limited our concept of on-line programming to assembly language, the underlying concept may be transferred to higher level languages. For these languages, a full set of debugging controls will certainly be much more of an aid to the programmer than the usual run and dump listing that a programmer gets while working at a batch processing installation.

C. The Technique

The on-line real-time programming system includes only the features essential to demonstrate its feasibility. However, the incorporation of such features as selection of any desired computer operation code, macro instructions, and multiplexed servicing of several programmers is entirely feasible and requires no technological breakthroughs.

The present model of the system operates only with the Whirlwind I order code and services one programmer seated at a display console. The nucleus of the system is the display of the order code and control operators as portrayed in Figure XVI. 1. The program writing process involves the selection, by means of the light gun, of the appropriate sequence of instructions and data words. Figure XVI. 2 shows a programmer using the system. The system displays each instruction as it is coded and, in addition, displays the contents of the Accumululator and B-Register resulting from the execution of all instructions with the exception of input-output and transfer instructions.

In order to enter an instruction, the point displayed to the right of the desired operation code is picked with the light gun. Following this, the address portion of the instruction is entered by picking four octal digits in sequence from the octal digit display. If an error occurs in selecting the operation code, this can be corrected by picking the proper operation code provided that the last octal digit of the address has not been entered. If all digits of the address have been entered

prior to discovery of the error, correction can be made by resetting the location counter as described below. As each new instruction is entered, the previously coded instructions are shifted up one line in window shade fashion and a maximum of ten instructions and/or data words are displayed.

Normally, the location counter is set to 40_8 at the beginning of any routine due to a Whirlwind programming convention. As each instruction or data word is entered, the location counter is incremented by one. It is possible to reset the location counter to a different address at any time, by picking the "LOC" operator and the four octal digits of the desired address. A constant or a data word may be entered by picking "CON" or "DATA" and the six octal digits comprising the constant or data word. The contents of the Accumulator may be changed by picking "ACC" and a six digit octal number. An examine feature is also provided which displays the contents of a memory cell when "DISP" and a four octal digit address are picked.

When a programmer has completed coding his program and is satisfied with the test results displayed during this process, he may obtain a paper tape of his program by picking "END". Activation of this function causes all previous coding to be stored on magnetic tape. Core memory locations reserved for program storage are then cleared and the display of previous coding is erased. Present paper tape output has a format which consists of mnemonic instruction codes and octal addresses and is therefore acceptable for input to the Whirlwind Comprehensive System II Conversion Program. A binary paper tape could be produced at this point as an additional option.

If the programmer desires to run his program, he instructs the computer operator to start at location 40. If he finds errors in the program he can return to the real-time programming system and take corrective action. When satisfied with the program, he may produce

a Flexowriter-coded (alphanumeric) tape by picking "END". Alter-
natively, he may request the computer operator to generate a binary
paper tape.

SI .	AD .	
BI .	SU.	
RD.	CM .	1. 2. 3. 4. 5. 6. 7. 0
BO .	SA .	LOC.
RC .	AO .	
SD .	DM .	ACC.
CF .	MR .	CON.
TS .	MH .	
TD .	DV .	DATA.
TA .	SLR .	DISP.
CK .	SŁH .	
AB .	SRR .	END.
EX .	SRH .	
CP .	SF .	
SP .	CLC .	
CA .	CLH .	
CS .	MD .	

LOC	ACC
0040 CON040000	
0041 CON060000	
0042 CON050000	
0043 DTA006315	
0044 CA 0040	040000
0045 MR 0043	003147
0046 AD 0041	063147
0047 MR 0043	005076
0050 AD 0042	055076
0051 TS 0100	055076 000000

FIGURE XVI. 1   ON-LINE PROGRAMMING OPERATORS

FIGURE XVI. 2   ON-LINE PROGRAMMING