III. APPLICATIONS

Alphanumeric Consoles

Introduction

Applications of alphanumeric consoles are potentially as varied as the number of different texts that can be generated on a page. It can be expected that types of applications will eventually become increasingly diverse because of the universal character of interpreting text messages.

The simplest way of considering an alphanumeric console is the "responsive typewriter" concept described by Calvin Mooers. If limited to straightforward manipulation of data, a computer program can be written to determine which message of a limited set of messages has been entered and take appropriate action. In the future, alphanumeric consoles will probably divide into two classes based on the sophistication of the application and the typing skill of the user. Ultimately, consoles could have all the features of office typewriters, such as margin stops, tab settings, single- and double-space options, and a complete character set, particularly upper- and lower-case letters. Hopefully, manufacturers will try to be compatible with the American Standard Code for Information Interchange (ASCII). Such a unit would also have editing features to facilitate the insertion or deletion of text. Keyboards have appeared for "hunt-and-peck" typing with letters arranged in their normal sequence and decimal digits in a separate grouping, that are ideal for short entries such as price quotations or reservation requests. The choice between an alphanumeric console and a teleprinter unit is determined by three factors: 1) the speed of displaying a typical computer response, 2) the need for a permanent "hard copy" record, and 3) equipment cost and communication line charges. Inquiry and reservation systems are instances where much of the data does not have to be in hard copy form at the time of the transaction. Much of the information changes rapidly, and both inquiries and responses are short.

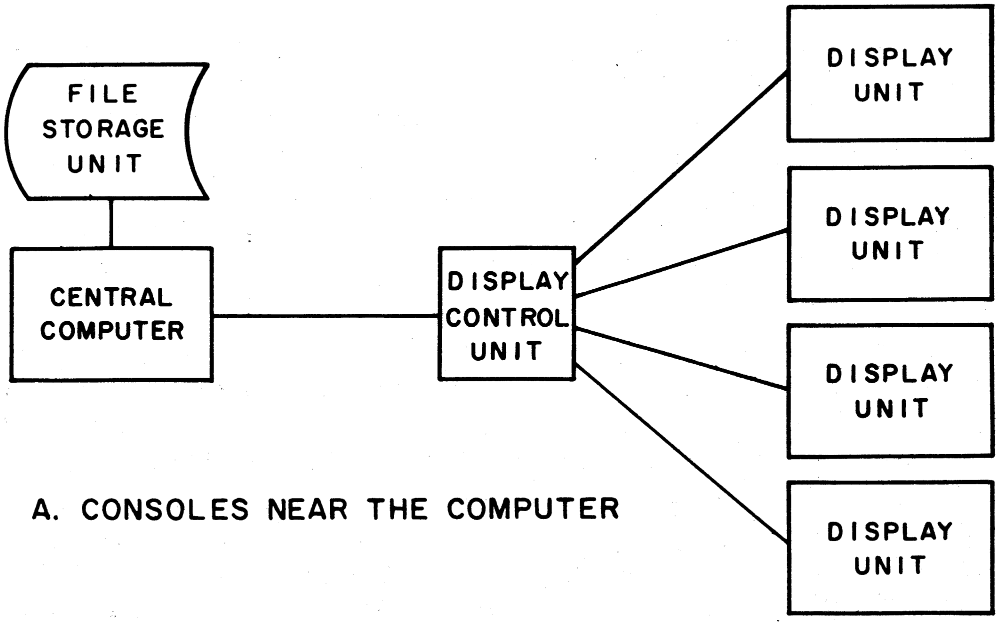
Inquiry Stations

From an equipment standpoint, inquiry systems use consoles at the low end of the available range of 100 to 2,000 characters. Initially, in military and air reservation systems, the pushbuttons used by the operator were custom designed and each button was reserved for a permanent function. Now, however, a typewriter keyboard is the basic input device for the inquiry console, and function switches are reserved only for special controls such as stop printing. This allows any inquiry station to be a standard teleprinter unit. Whether across the room or thousands of miles from the computer, such units can be serviced by the same computer programs. Each inquiry station has access, within milliseconds, to files of data in a mass storage unit. Since many remote stations are simultaneously requesting information or entering new data, software techniques (called multiprogramming) are used to minimize the response time to an inquiry and increase the data flow rate from the mass storage unit. Figure III.1 shows typical equipment configurations for local and remote consoles.

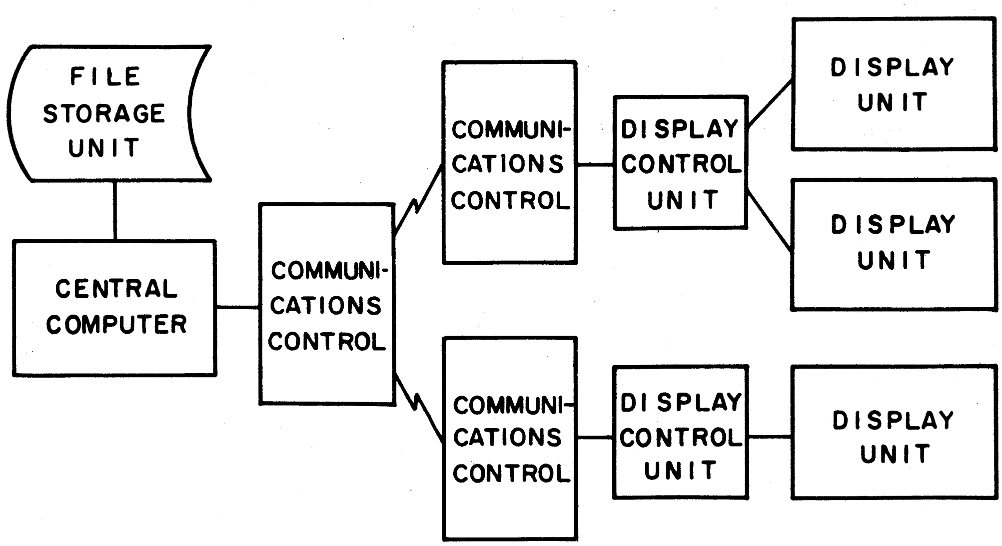
To examine data, a console operator enters a request message, verifies it, then transmits it to the central computer. This message may be entered by 1) depressing one or several special-purpose function switches; 2) depressing function switches and entering an alphanumeric character from the keyboard; or 3) composing a message on the keyboard.

The information entered through the keyboard may be displayed on the unit, for verification by the operator, before transmission. A well-designed system requires the operator to depress a transmit switch or take some other positive action prior to sending the message. The request message is then decoded by the computer, the data retrieved from the mass-storage device, and the output message formatted and sent to the console for display.

A light pen may be used as an alternative to "hunt-and-peck" typing if the data is suitably organized to allow the console operator to make successive selections from a set of tables. The first table or index would show all of the files in the system which the operator could select. The passenger reservation system used by a Canadian airline operates in this manner. The title or name of each file is shown in the index. "Picking" a light spot preceding a file name



A. CONSOLES NEAR THE COMPUTER



B. CONSOLES AND COMPUTER FAR REMOVED

Figure III.1

METHODS OF INTERFACING DISPLAY UNITS AND COMPUTER calls a tabular presentation of that file. Picking spots in this presentation adjusts the inventory of seats on a particular flight in accordance with the ticket agent's transaction. The raster scan used in these units is compatible with commercial television standards and monitors for public viewing and agents' consoles may use many standard television components. The raster scan simplifies the logic required to interpret which selection the agent has made.

Programming languages and files of data have a hierarchical, or tree-like, structure which can be presented on a cathode ray tube console by lines connecting an element at one level with all of its subsidiary elements at the next lower level. Project AESOP, at Mitre Corporation has used such a display to "prompt" a user to compose only acceptable program statements. A picture of the data base structure allows the user to specify the correct terminology so that he retrieves exactly those portions of each record which are of interest to him. An alphanumeric display can show the same information by successively indenting items in a vertical column. All items at the same level in a hierarchy have their left margins aligned, and all items at the next lower level can be shown indented one space to the right and immediately below the higher-level item.

Inquiry consoles are used today in numerous applications, a few of which are briefly described below:

Stock Quotations

Bunker-Ramo Corporation has in operation a stock quotation inquiry system known as Telequote III. The display consoles and control units are located in the offices of stockbrokers or investment firms and connected by low-speed transmission lines to satellite processors in 10 major cities throughout the country. These processors are, in turn, connected to Bunker-Ramo's central computer facility in New York City. The latest stock market information is entered from tickertape into the central computer, sorted and filed. From a remote console, an operator can request specific information on a particular stock by keying the stock exchange code for that stock. The information available includes the number of shares sold, highest and lowest selling prices, earnings per share, and behavior of that stock over a period of time.

Air Reservation Systems

The need for operating airline passenger planes at high capacity places a high premium on the usefulness of an airline reservation system. Airlines have been among the earliest users of on-line inventory systems. Systems currently installed by many airlines use a teleprinter unit, such as the IBM 1050, for input and output. Since the printing rate of such units is approximately 15 characters per second, extended printout could take approximately one minute for each 12 lines of text. A console with a Data Phone terminal can display the same information about 16 times faster. Typically, all flights for the next 30 days are allocated space in the mass storage unit. From his console, a ticket agent can inquire about available seats on flights to a certain destination, sell seat space, or cancel a previous sale. Each customer's name and address are entered for the purpose of notifying passengers of late departures.

Freight Car Schedules

The New York Central Railroad uses alphanumeric consoles to determine the location of its freight cars. The routing of cars is entered into their computer facility by the usual keypunch methods. Connected to the computer are several display stations, each with its own operator. If a customer wants to know when his shipment will arrive, he calls one of these operators on the telephone; the operator queries the computer, then tells the customer where the shipment is and when it will be delivered

Hospital Patient Location Control System

The patient control system at Children's Hospital Medical Center in Boston consists of an input-output terminal in the Admitting Office (see Figure III.2); a computer to store, sort and report patient control information; a Bunker-Ramo input-output terminal at each of 16 nursing stations (see Figure III.3); and "slave" teletype printers in the admitting, accounting, housekeeping, and central reception areas.

When a patient is admitted, a clerk types on the Admitting Office terminal the patient's name, date of birth, sex, medical record number, parents' names, home telephone number, admission num-

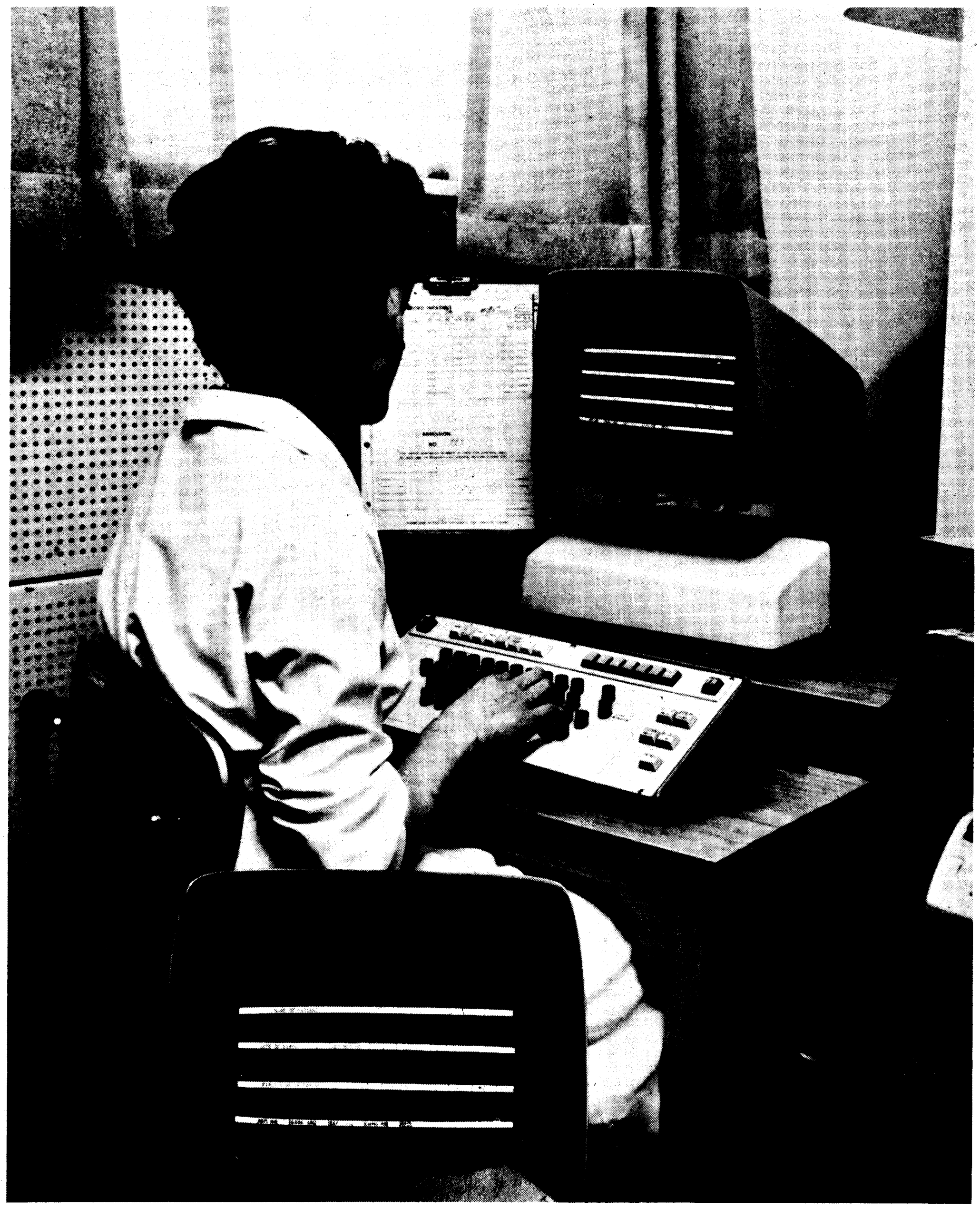


Figure III.2

ADMITTING OFFICE INPUT-OUTPUT TERMINAL
CHILDREN'S HOSPITAL MEDICAL CENTER, BOSTON

Figure III.3

NURSING STATION INPUT-OUTPUT TERMINAL
CHILDREN'S HOSPITAL MEDICAL CENTER, BOSTON

ber, date of admission, and hospital division to which the patient is assigned. After verifying this information as it appears on the cathode ray screen before her, the admitting clerk presses a button to transmit the information to the computer, where it is stored on a random access disc file.

When the patient arrives at the division, a nurse (or clerical assistant) there enters the admission number and "patient admitted" on her terminal. After bed space is assigned, the nurse, by pressing the proper keys on the terminal at her station, can report a patient's condition, transfer to another division, anticipated discharge date, death, actual discharge, and other information. Each time the nurse transmits data through the terminal, she receives visual verification that her message has been correctly transmitted and the proper patient's record noted.

By providing rapid, accurate and current patient information, this system has reduced internal hospital telephone calls, relieved the nursing stations of paper-form preparation and other interruptions, and provided central reception with information for answering inquiries about patients. The system has also eliminated the delay which previously existed in notifying the Admitting Office that a patient has been discharged. The transmission of discharge and transfer notices was previously done by messenger and telephone. It is now known, minute-by-minute, exactly where every in-patient at Children's Hospital is located, and what discharge orders, if any, have been written.

The most important result of this system is that the Admitting Office can maintain a current status of bed spaces occupied, potential beds available, and anticipated discharges for each nursing division. This is particularly helpful to Children's, a 350-bed hospital, where patients range from premature infants to full-grown adolescents of both sexes.

The complete hospital data information system, which will be in operation at Children's late next year, will have terminals not only in all nursing stations but also in clinics and other ancillary and financial service points. Through these terminals, requisitions for ancillary services, drugs, medical and surgical supplies, beds, and clinic inquiring and scheduling will be channeled. Ancillary service requests will be processed, recorded and updated by the computer, which will provide periodic reports for laboratories and data for nursing stations and patients' medical records. In addition, the terminals and computer will be available for input of patient medical profiles and research data for processing, storage and retrieval. Figure III.4 shows the computer configuration and outlines the three-phase implementation of the system.

Teaching Machines

Computer-aided instruction relies upon the fact that some subjects which contain primarily factual information can be taught in small incremental steps, and that learning is reinforced if the student gets a positive response each time he demonstrates comprehension of a new piece of knowledge. Instruction proceeds in a question-and-answer fashion in small repetitive steps on items of factual information.

Until now, programmed instruction has been used principally for teaching the physical sciences and languages, these being subjects in which large amounts of factual data are involved and matters of style or subjective considerations, unlike art or creative writing, play minor roles. Programmed instruction can proceed at a pace that might be tedious for any teacher, and permit repetition that would tax his patience. It also enables students to do remedial work or to make up classes.

In the school environment of the future, teaching carrels have been suggested as the students' primary learning and research location. Classroom teaching materials in programmed instruction would form just a part of the entire reference library of a university. Each student could use his individual terminal to call upon either programmed instruction or conventional texts. Library card catalog information would also be accessible through the student's console; he could specify comprehensive searches of all texts based on such criteria as subject, author's name, date of publication, or a combination of these.

One problem area is providing a console which combines pictorial and textual information. Microfilm immediately comes to mind as a conventional way of converting existing material into a form that can be manipulated by machine. Television scanners could be

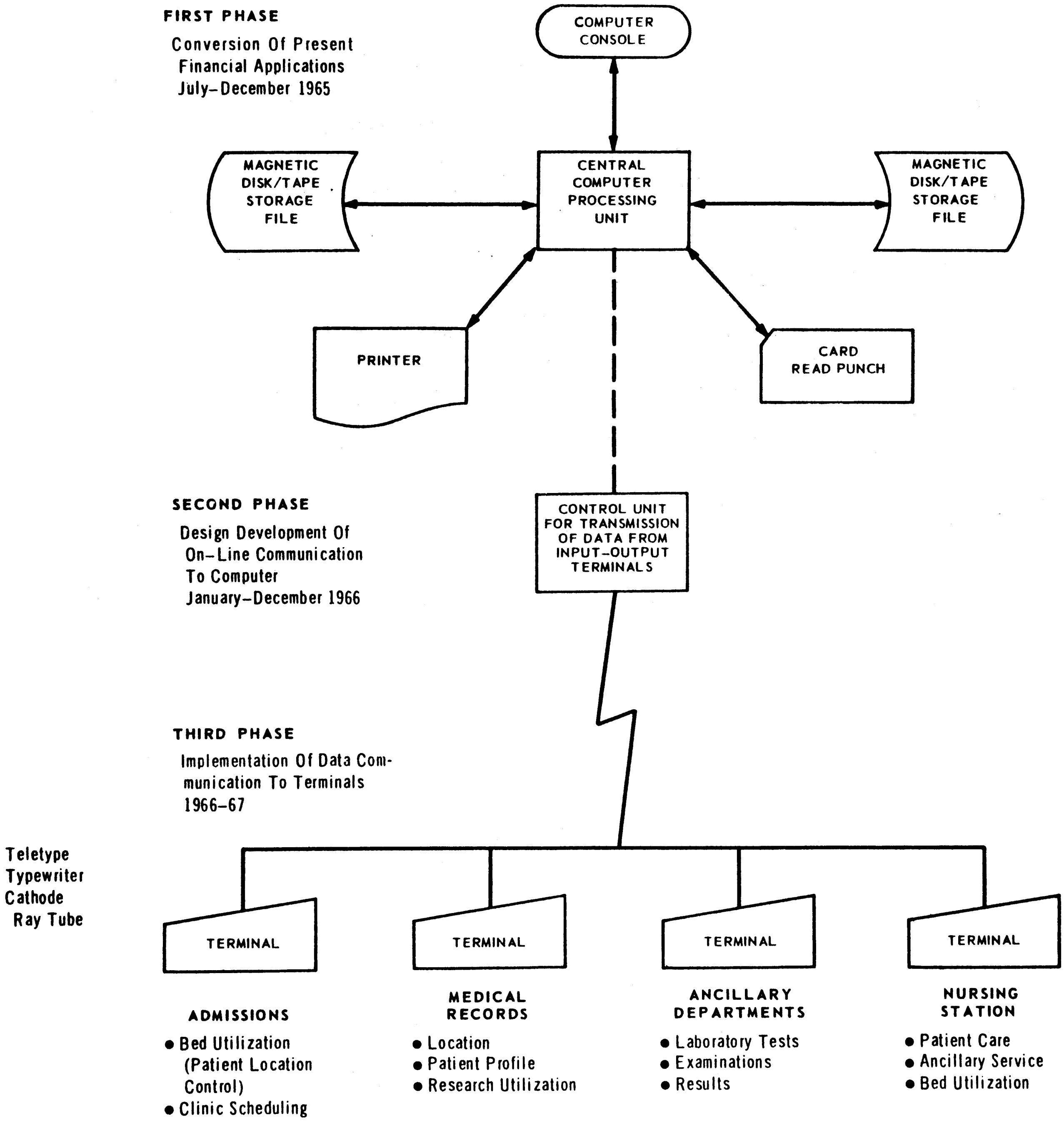


Figure III.4

PATIENT LOCATION CONTROL SYSTEM
CHILDREN'S HOSPITAL MEDICAL CENTER, BOSTON

used to provide pictorial information and digital storage to present textual information to the student. Microfilm cartridges, handled by the student, are widely used in teaching machines because of their economy. Television scanning of microfilm is attractive from a long-term standpoint since it allows the student to be located a distance from the library. The further development of programmed instruction is not limited by hardware costs or techniques in themselves. There have been spirited discussions on the effectiveness of programmed instruction and the best way in which to write programmed text. Cathode ray tube terminals for programmed instruction will come into use as a wide variety of proven programmed texts become available.

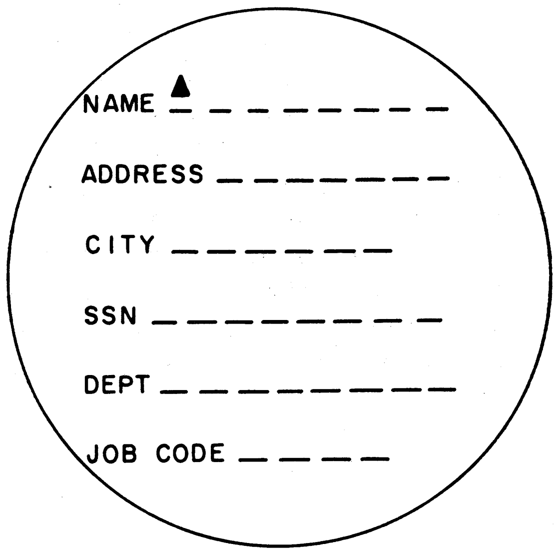
Rocket Checkout

A variation of the concept of programmed instruction is now in use in the checkout of Saturn V rockets. A total of 58 consoles are being acquired by the National Aeronautics and Space Administration (NASA), the number of consoles in a particuler installation varying from two to 20. From his console, each operator can select alphanumeric or vector information from a computer, one of 10 channels from 10 closed-circuit television cameras of 525-line resolution, or a high-resolution television channel linked to a reference bank of 256 slides. Each console has an alphanumeric keyboard, selection switches, and a light pen to allow entry and editing of text messages and vectors. Distribution networks for digital and video information enable information generated at one console position to be made available to all others.

Rocket checkout is a semi-automatic operation; the testing and verification of equipment functioning is automatic, but human monitors must take positive and timely action at critical points and can override the automatic sequence of test and proceed whenever necessary. This approach is also applicable to the construction and testing of complex electronic equipment.

Message Composing

Figure III.5 shows how an alphanumeric console can aid an operator in composing each part of a standard format message with-



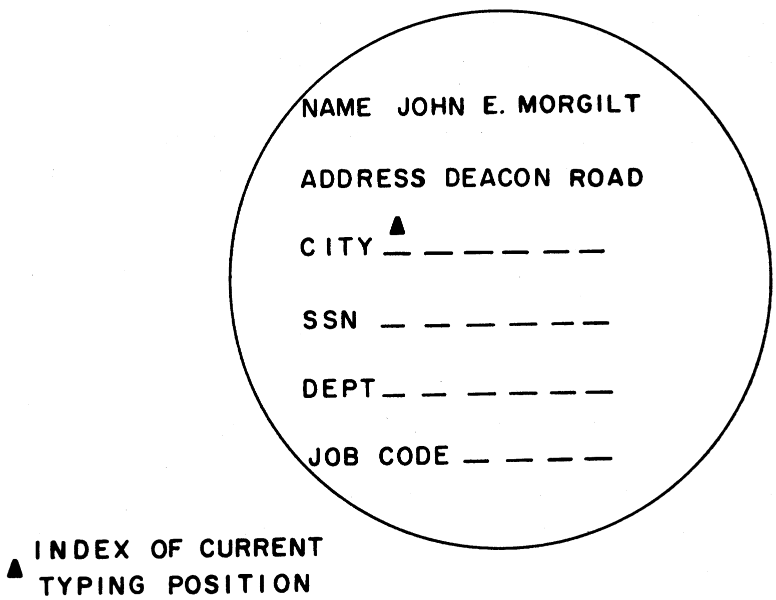


Figure III. 5

FORMATTED DATA INPUT

out having to memorize the constraints on each field. Whenever the operator indicates end-of-field by entering a carriage return or tab, the cursor moves to the first entry in the next data field. The major advantage of a console over a teleprinter unit in this application is the ease with which typing errors can be detected and changed before being sent over a remote line to the computer.

Program Development and Debugging

The three-step sequence of storing, translating and executing statements of a computer program under development may have many possible variations and an ideal system would allow the user a choice of various options. However, the most straightforward grouping of functions is as follows. The programmer enters and has the option of making changes in a single statement prior to entering a carriage return without the statement being processed by the compiler. The carriage return indicates a complete statement to the compiler, which tests for compliance with the grammatical rules of the programming language and diagrams or parses the statement into its operator and parameter parts. A symbol table is developed for all of the different parameters, as is also a macro or function table of all functions for common subroutines called by the program. A grammatical error in the statement is revealed immediately after the carriage return so that the programmer can correct his statement at once. When all statements of the program segment are entered, an "end of segment" indication causes compilation to begin. Machine code is generated which is optimum over the range of the program segment, deleting redundant evaluations and common expressions and removing constants from loops of computations. The advantages and disadvantages of a cathode ray tube console versus a teleprinter unit hinge primarily on the question of: 1) the desirability of a hard-copy record of the program after the debugging session is over, and 2) the ability to browse through different portions of the program during its development.

The executive system for debugging on a cathode ray tube console can implement these features by treating the program as if it were printed on a long scroll which the programmer can roll past his cathode ray tube "window" in either a forward or reverse direction. Similarly, columns of output data originally formatted for print-out on a 120-position line printer may be viewed by shifting the text to the left or right, past the cathode ray tube "window." The ability to call up random pages by number, name or context, such as the name of a "jump" location or a specific occurrence of a common subroutine, is helpful. These facilities have been implemented on experimental systems.

Perhaps the key to program development and debugging on alphanumeric consoles are techniques for minimizing the need for browsing. In scientific computations it is possible, in some instances, to detect program errors based on a graphic plot of one variable as a function of other variables. Also, a plot of the flow chart of a program showing its sequence of steps during execution can pinpoint incorrect branches and improper looping.

Text Editing

Text editing appears to be a simpler problem than program development because its difficulties are more subtle. Currently, many publishers use computers for automatic justification of typesetting machines. Keyboard operators type text in a continuous string to punch a so-called "raw" tape. Tapes from many punches are read into a computer, which calculates the size and location of spaces to be inserted between words in a line so that the left and right margins are justified. Some programs include automatic hyphenation, but the desirability of this is still a subject under debate. The commonest opinion is that machine hyphenation is as good as that of a "typical" linotype operator. This mode of operation does not allow a human editor the option of varying the rules to treat a specific instance, nor does it take into account the possibilities of inserting photographs or drawings of different sizes in a page of text.

The greatest usefulness of the console for text editing will be in the preliminary editing of rough draft material into final form. Insertions and deletions can be made by a combination of a light pen and keyboard entries, and there is no need for successive retyping of drafts. Many alternate forms of particular passages may be stored in the computer's memory in a list structure and varied selectively by the editor until he obtains the desired final forms. Software can provide rudimentary checks on paragraph length, spelling and punctuation.

On-Line Management Reporting and Procedure Generation

Various government agencies have experimental systems under development which allow the user to select and summarize information from extensive updated files, and to formulate and execute procedures particularly for planning or monitoring purposes. Although the cathode ray tube console and light pen are not used in this case for the construction of graphic figures, they provide a manager or scientist with the means for directing the retrieval from a large series of hierarchically structured files and calling standard mathematical functions and combining them in ways appropriate to a specific problem. A typical system uses a scientific-type computer with floating-point arithmetic, a mass storage unit such as a magnetic disc, one to four cathode ray tube terminals, and an auxiliary printer for hard-copy output. Each terminal has both light-pen control and typewriter input. Minimum reliance typically is placed on typewriter input, however, and a set of points for letters and numbers can be called up on the display surface for "hunt-and-peck" typing.

All data stored in the system is accessible by a sequence of selection actions in a structured series of index pages. Successive index entries provide the user with a greater level of detail with each successive reference. In this respect, an unfamiliar user may examine the computation procedure.

The manager of an organization has at his disposal all the data that might affect his responsibilities. He can call for management reports in an unlimited variety rather than simply a specific set of standard format reports.

The cathode ray tube display surface becomes the user's work space as well as his window for viewing results. It is common practice to divide the total area into a main window and one or more control areas. Usually a rectangular area, symmetric about the center of the display, is set aside for displaying the results of selective file retrieval or calculated or plotted values of results. The area outside the rectangle can be assigned control functions which can be exercised, irrespective of the display, at any instant. Typical controls in this category are the return to the initial page of the index of all system files, paging to the next page or the previous page of the current results printout, return to the first page of the current printout and return to the control page for program generation.

The conventional procedure in off-line generation of programs gives the programmer very few constraints. So although he has the potential of describing an unlimited number of processes, he has little in the way of guide posts to aid him in the formulation of a specific problem. By presenting him with an index to all of the files and a structured set of grammar rules for the programming language, the user is constrained to compose program statements which are valid and select file entries which exist in the system. Some users of the system will, in addition, be able to add new items to the files or to delete old items.

Let us discuss a general management report generation problem and then the scientific development problem. The key notion in management reporting is a file, which is a collection of information that can be referred to by a unique label. Files may be further categorized according to such characteristics as permanent or temporary, public or private, formatted or free-text. In formatted files, various parts of the file may be further subdivided; a typical categorization is that a file is made up of a number of records, each having a number of entries or fields. An entry is defined in terms of elementary characteristics such as type (for example, dollars or dozens) and range of expected values. Any report the user sees is, in fact, a file which may not be labeled as such; but provision should be made for the user to save the results he sees at his console on mass storage by giving a label to the page.

In this approach, the user can describe object names and property names of his files, format and arrangement of data. He also can generate an output from a formatted file in which he has the option of specifying the number of columns to be displayed, whether or not the columns are labeled with descriptive names, the order in which the columns are arranged, and the number of digits in each entry. In the simplest case of a small file where all records have lengths less than the characters in a line on the display, the console user can page through a file much as he would through a book. If file records are longer than the display line, two options are possible: the entire record can be displayed on two or more lines with suitable indentation between lines to remind the user which line is associated with which column heading, or for selective deletion of items he can reduce the text displayed to a single line. This system provides both prompting aids for the user during repeated use and an extensive initial teaching aid.

Two basic concepts for organizing the terms used in a set of files are akin to a glossary and a thesaurus. The glossary can be organized as an alphabetical listing of all terms with an indication of the file in which its value is contained, or an individual glossary for each file may be written. A thesaurus is a branching structure that relates words general in nature to those which are more specific. When applied to a file, there is frequently a collective name for a group of items, individual names for each item, then names for the attributes of the individual item. File retrieval consists of first finding the names of all files which contain the names of groups of objects or the names of properties of objects, then determining which file entries meet all the specified requirements, and accumulating a temporary file which is shown as output.

In the development and execution of simple programs for scientific users, the same glossary or thesaurus organization of names of data and operations on data can be displayed. For example, standard subroutines, such as trigonometric, logarithmic and exponential functions, can be displayed in the control area of the cathode ray tube. Light-pen picking of these functions can link functions to be calculated in proper sequence. Of course, the plus sign, minus sign, times and fraction bar plus letters and numbers and names of previously defined variables allow the console operator to compose new statements or equations in a way not unlike that in which a printer might assemble individual characters and words of movable type into a type box.

A good example of the presentation of summary information in tabular form with labelled columns is shown in Figure III.6. In this photograph, taken during the Columbia Broadcasting System coverage of the elections on November 8, 1966, the third display from the left shows current statistics on the senatorial races in nine states and the gubernatorial contests in 11 states.

Space Flight Mission Control

The Manned Space Flight Center of the National Aeronautics and Space Administration (NASA) in Houston has the largest single concentration of cathode ray tube consoles in the world (a relatively few of which are shown in the NASA photos in Figures III.7 and III.8). Although different forms of display are required at different operator

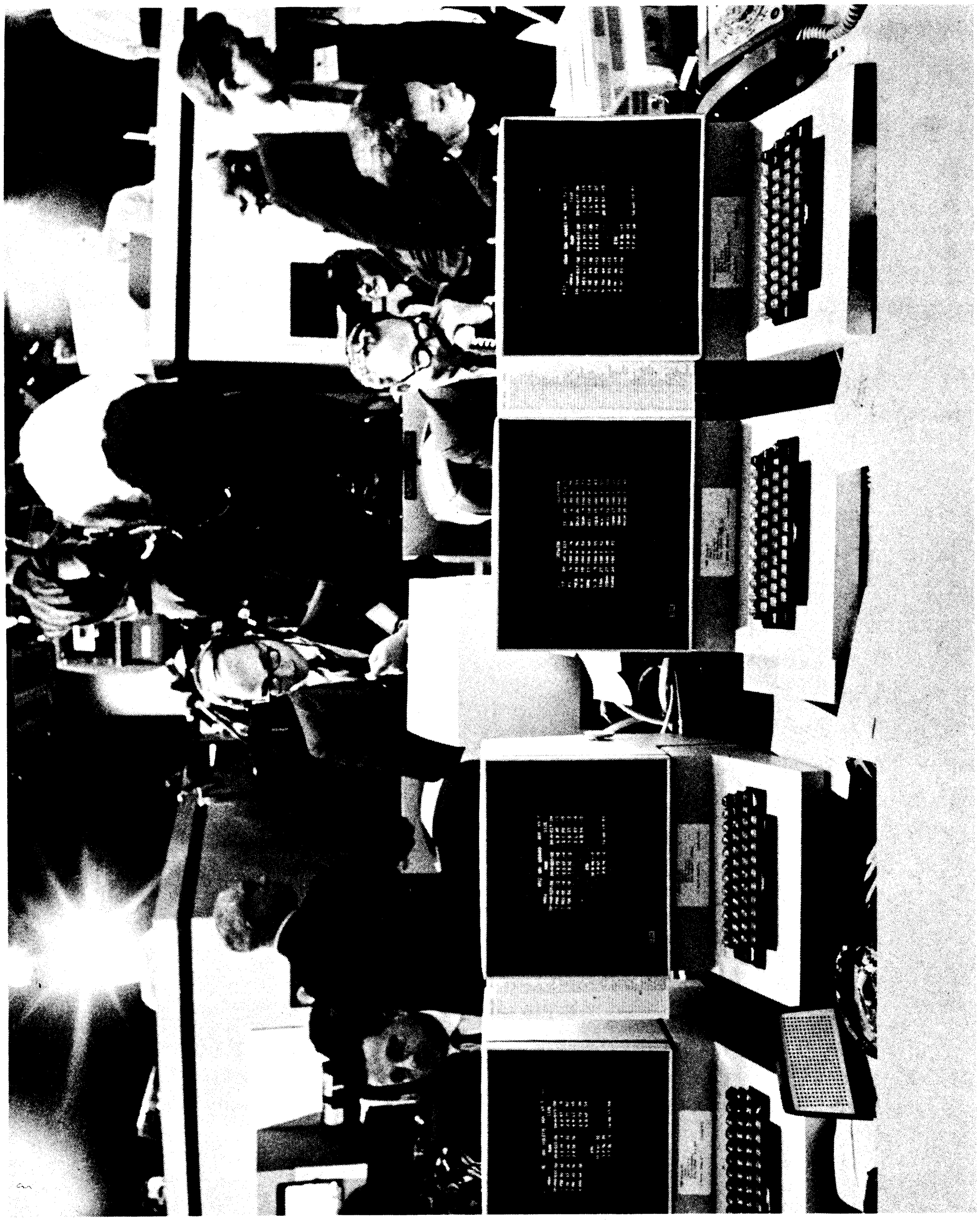


Figure III.6

ALPHANUMERIC DISPLAY CONSOLES
AT CBS ELECTION COVERAGE

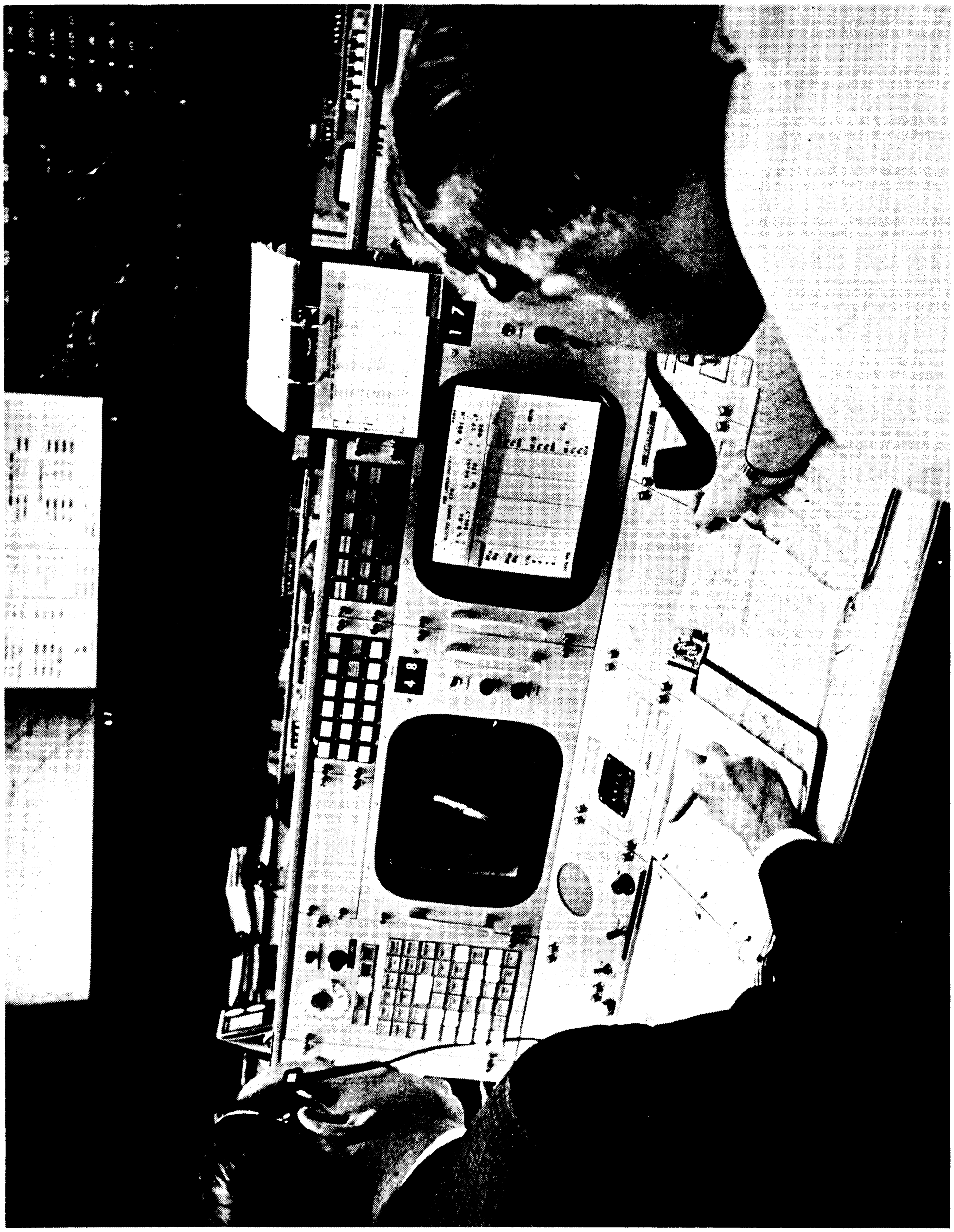


Figure III.7

GEMINI VI FLIGHT DIRECTOR'S CONSOLE
(Flight Directors Christopher C. Kraft Jr. (left) and John D. Hodge in Mission Control Center during Gemini VI launch)

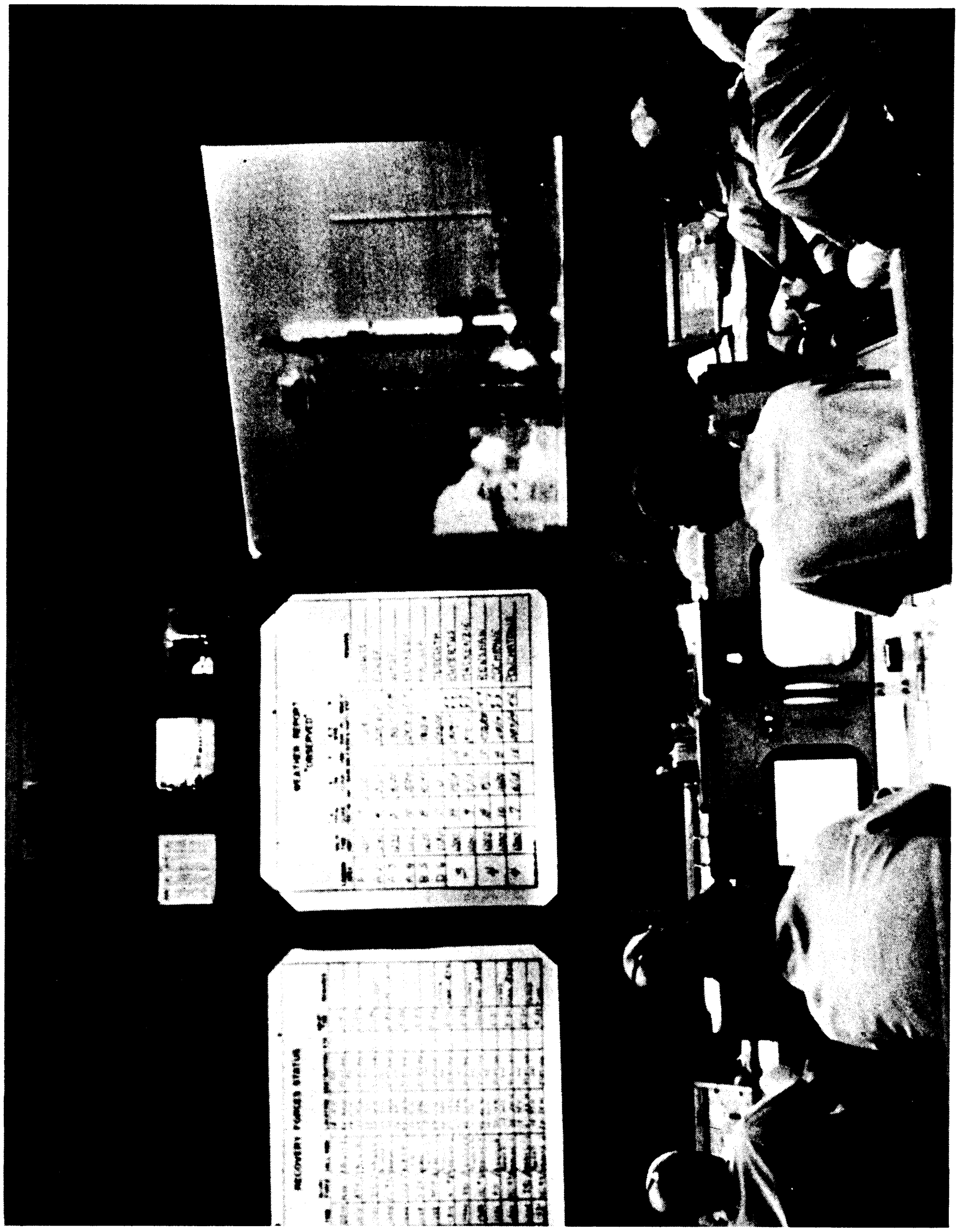


Figure III.8

GEMINI VI MISSION CONTROL CENTER

positions, a display generally must have one or more of the following capabilities: closed-circuit television, background slide information, and line generator and alphanumeric text information. Consoles are used to assign a specific function to a particular operating position while allowing other positions to act as backup. Interconnection of consoles provides a way in which controllers with overlapping functional responsibilities can be aware of subsidiary information relating to their primary function. None of these positions is used for programmed development or debugging, but there is a capability for executing on-line a limited number of functional software packages.

An important use in the future will be dynamic rescheduling of an astronaut's tasks. Constraints of satellite position, visibility from ground control stations, and many other factors make the rescheduling operation quite complex and solvable only by a computer. Displays to the flight controller can take the form of segments of PERT charts which can be modified by light-pen action in control fields. Bar graphs can also be used to illustrate time "windows" in which particular tasks can be performed where a time deadline occurs. During the critical prelaunch and launch phases, alphanumeric data can be superimposed on a television presentation of the capsule on the launching pad to give a controller both overall and specific information simultaneously.

Line-Drawing Consoles

Engineering Drawings

Engineering drawing has undergone many changes in recent years. At one time the draftsman's trade was almost an art, with finely constructed inked drawings and attractive hand lettering. Now, reproduction techniques permit the use of pencil drawings, templates are used wherever possible, and plastic stick-on symbols are replacing drawn symbols, especially for electronic schematics. Dimensions and text are often typed on transparent material and pasted to drawings in the proper locations.

However, producing drawings by hand still has many drawbacks. For a complex item described by a series of drawings, each drawing shows only a small part of the object, and it is often difficult to relate one drawing to another, particularly if there is a difference in drawing scales. The spatial relationships of parts in a drawing are shown, often ineffectively, by the traditional top, side, and end views. Each drawing may contain many elements that duplicate those on other drawings, at the same or a different scale.

The most perplexing problem associated with hand drawing is maintenance. A change in the design of one part can affect many drawings, for that item must be redrawn on each. A dozen or more changes may be made to a drawing during its life, and drawing maintenance is often three-fourths of an engineering drawing effort.

The conversion of drawing maintenance from its present to a semi-automated form poses a number of problems, the major one being how to convert slowly and orderly a limited part of a firm's engineering drawing masters. Each drawing has the problem of relating notes in the body of the drawing and revision notes to the graphic description in the body of the drawing. Also, drawings refer to other drawings, either directly or in an associated bill of material. A modification of a standard detailed part may require changes in many assembly drawings which reference it. Microfilm is an inexpensive and compact way of storing drawing masters; in fact, it is a standard way of insuring that everyone concerned with a particular drawing is using the latest revision. A film scanner and a film recorder shared by many users would be an important part of routine drawing maintenance. Alphanumeric information associated with a drawing could be stored redundantly in a digital mass memory so that the software for controlling the film scanner need not interpret strings of text.

With a digital computer, a highly accurate numerical model of the entire drawing is kept in the mass-storage unit. At any one time the draftsman works on only a small portion of the object as illustrated in Figure III.9, directing the computer to display that portion in as much detail as he requires. If he modifies one item of the object, all other occurrences of that item are also modified.

Applications of line-drawing consoles are proceeding along two parallel paths. The maintenance problem is an automated aid to the draftsman preparing or modifying detail or assembly drawings. A parallel development is automated aids to designers or engineers who are doing design calculations and checks prior to the preparation of the final engineering drawing. Aids to designers place less stringent requirements on the amount of storage needed in computer memory to keep track of the structure of a drawing itself. There will, however, be a requirement for storing items of information relating to a particular application area. For example, in kinematic analysis there would be stored equations of displacement, velocity and acceleration as a function of applied force which varies with time. In stress analysis the modulus of elasticity of different materials and the moment of inertia of different standard cross-sections of beams would be stored. In electronic applications, basic laws for calculating current in a particular path, voltage at a particular node, and power dissipation in a load would be stored along with standard values of available components and their ratings. In essence, a designer focuses his attention on one or more sketches which are the basis for calculations. Equations and constants used in these calculations are derived from sets of tables that may be quite extensive.

The digital computer also provides sophisticated versions of the engineer's drafting tools and contains programs to relieve the draftsman of many onerous chores, such as the copying of subdrawings. All this is done in a coordinate system that may be accurate to ten-thousandths of an inch for a drawing measuring several miles in breadth. Coordinate input is always accurate to the least count of the grid, and the draftsman can request as much detail to be dis-

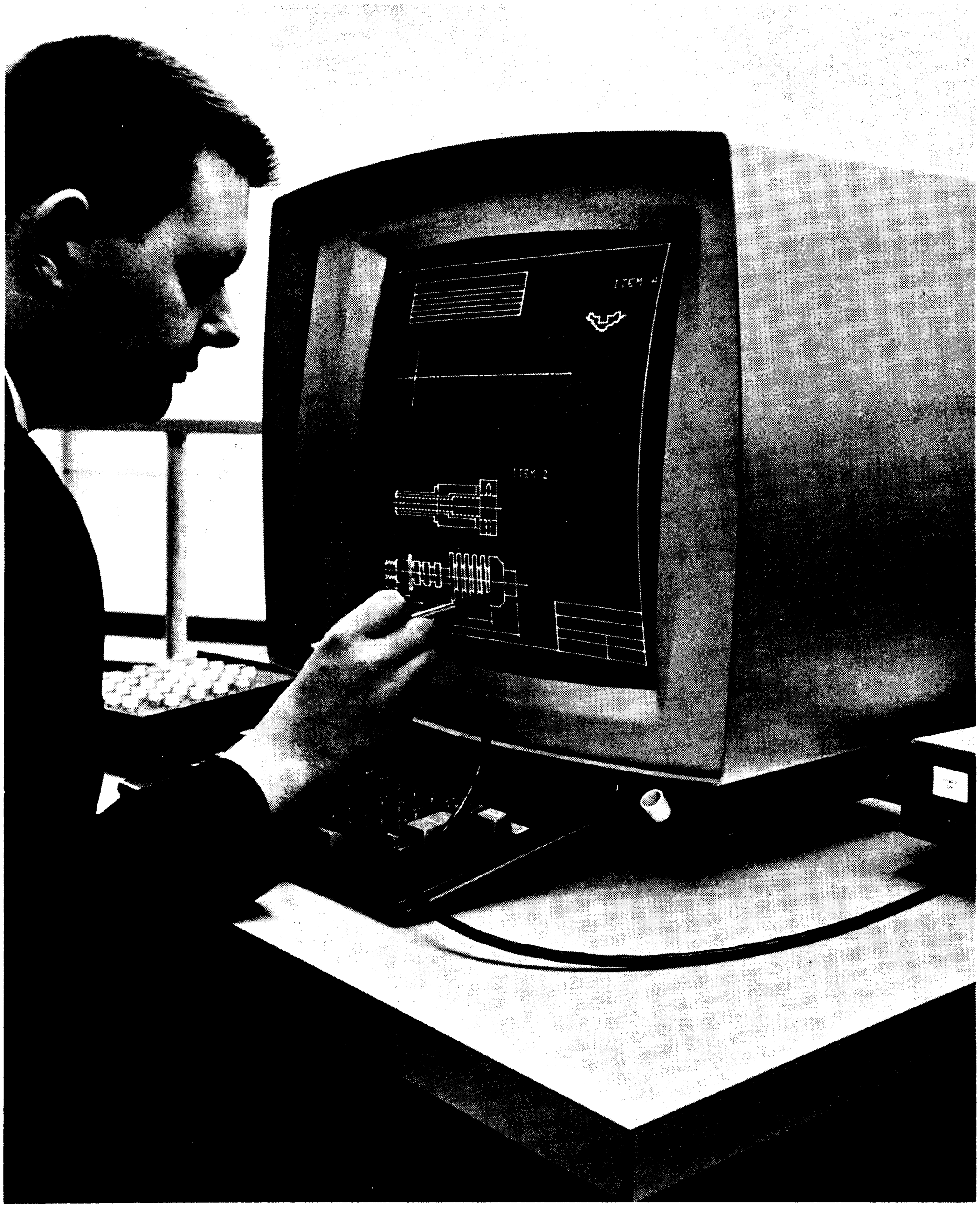


Figure III. 9

ENGINEERING DRAWING DEVELOPMENT
ON LINE-DRAWING DISPLAY CONSOLE

played as desired; this is illustrated in Figure III.10.

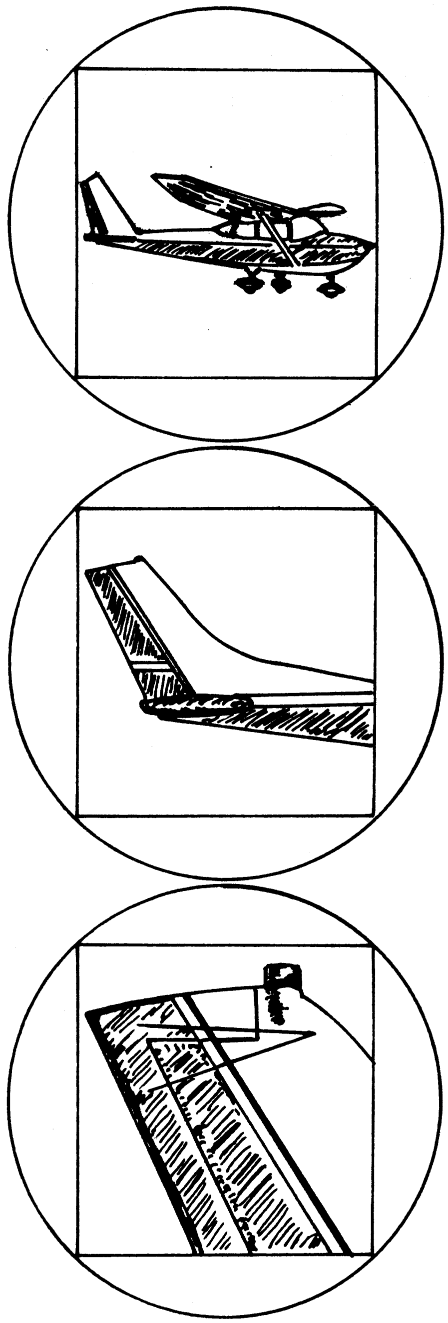
The methods used for input of elements vary from system to system, but certain techniques are basic to all systems. The pseudo point is used, either with free tracking or positioning by lock on, for the input of the coordinates required to define or manipulate figures. The function switches describe the action to be performed by the program, according to the position of the pseudo point. These function switches are generally used to 1) specify constraints on the motion of the pseudo point, 2) specify the geometric figures to be created or how figures are to be manipulated, and 3) modify selected parameters of the program, such as drawing scale, level of magnification, angle of constraint, or line type.

Examples of constraints on the pseudo point include horizontal, vertical and angular constrained motion along an existing figure; and lock on to end-points, mid-point, center-point or center of mass. Some of these constraints can considerably shorten drafting time by decreasing the amount of pen tracking needed.

A typical drafting program has the ability to draw points, straight line segments, circles and circular arcs, ellipses and elliptical arcs, parabolic and hyperbolic arcs, free sketching (handwriting), best-fit curves to a string of points or lines, text, and dimensions (automatically calculated).

Almost as important is the ability to manipulate figures, or groups of figures, that have already been drawn. Such manipulations might include producing copies of figures, translating, rotating and reflecting figures; rescaling figures, forming perspective views, partitioning figures, and temporary or permanent erasures.

The hard-core theoretical bases for automated drafting are the topics of analytic geometry and projective geometry which describe the relationship between algebra and geometry for two-dimensional figures and projections of three-dimensional figures on a plane. Brief consideration of some of the basic notions of analytic geometry, for example, illustrate how the many points in a picture may be represented by many fewer points; hence, the description of an object stored in digital memory may be much more compact than the drawing itself. A straight line segment, for instance, may be represented by labels of its end points or positions of these points



A

FULL VIEW OF DRAWING

B

MAGNIFIED VIEW OF
SUBASSEMBLY

C

FURTHER MAGNIFIED
VIEW OF COMPONENT

Figure III.10

ENGINEERING DRAWING DETAIL LEVELS

on a reference grid. The overall shape of an object and its parts may dictate a choice between rectangular or polar coordinates. Similarly, a circle may be described by the location of its center and radius. Also, conic sections in a plane may use few parameters to describe all the points on the curve. The most extensive study and use of different types of projections is in map making.

Following is a brief description of how the Control Data Digigraphic drawing program might be used to sketch a piece part. This description is offered only as an example of the manner in which a typical drafting program might operate.

The console operator positions the pseudo point at point A on the face of the CRT, as shown in Figure III.11. He presses two function switches indicating vertical constraint, and another switch to define the start point of a line. He tracks to point B, then releases the switches. The system displays the line A-B and stores a numerical definition of that line in its entity list. This line becomes permanent when an ACCEPT switch is pressed.

Line B-C is drawn in the same manner, using three function switches to specify a horizontal line. Vertical line C-D is drawn, then horizontal line D-E. To draw vertical line E-F, the function switches are depressed for a vertical line, then the pseudo point is locked onto point A to obtain the same y coordinate. The centerline type is then specified and the horizontal center line drawn.

To complete the part, a mirror image of the upper half is desired below the center line. The center line is identified with the light pen and the symbol Δ appears at one end to verify the selection. Depressing a function switch activates a program which calculates the reflected copy, as shown in Figure III.12.

Most drafting programs also contain some of the standard drafting constructions, such as a circle through three points, a tangent ellipse with selected foci, or round of a sharp corner with a circular arc of specified radius. The system can also be programmed to truncate all input coordinates to a certain tolerance, thus producing drawings whose components are multiples of a minimum size.

Translation, rotation, reflection and change of scale have simple counterparts in analytic geometry. The general problem of

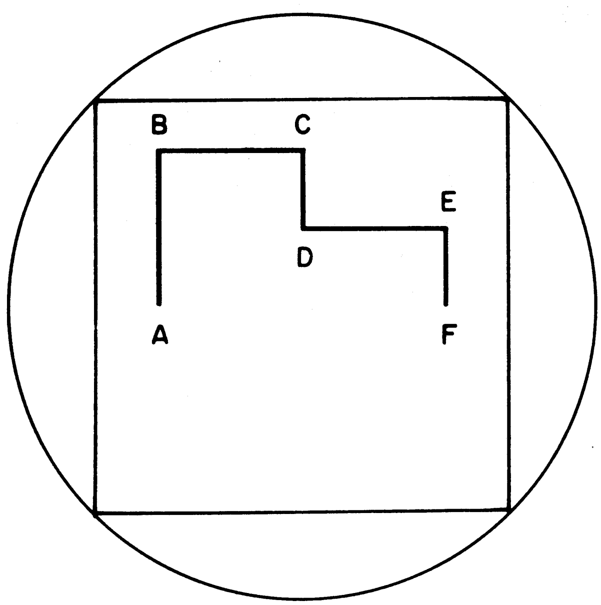


Figure III.11

SKETCHED PART OF A DRAWING

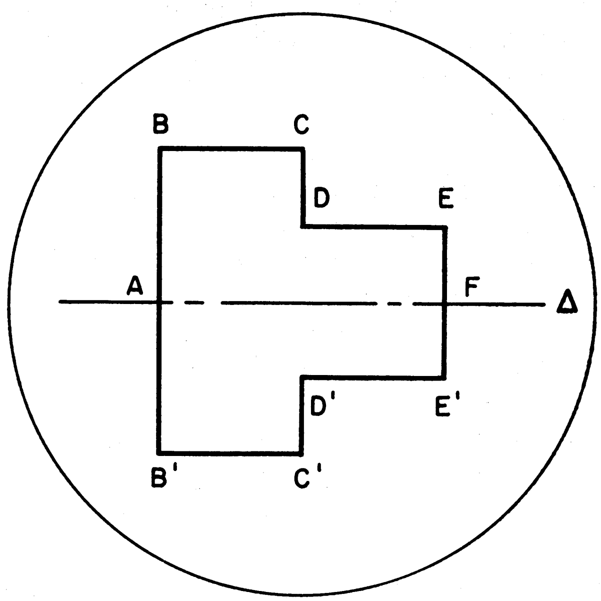


Figure III.12

PART COMPLETED BY REFLECTION

having a compact representation in computer memory of the object portrayed on the line-drawing console is related to the ability to translate the position, shape and size of geometric figures into their algebraic counterparts. This pertains to all common figures such as rectangles, circles and ellipses but not, in general, to free-hand curves.

While some experimental systems can do engineering drawing in three dimensions, the programming required is substantial and extremely complicated. To display solids effectively, the objects must be viewed from any desired perspective, and complex figures sliced with selected planes to outline their shapes. Some progress has also been made in developing programs to calculate hidden lines for a perspective view.

A formal solution already exists for calculating hidden lines relating to plane surfaces, and a solution is under development for curves represented by conic sections. At the present state of the art, it is generally quicker for the designer to specify, from an inspection of a three-dimensional representation, which lines are hidden lines when the object is viewed from a particular aspect. Calculations that accompany the text, such as areas, volumes, lengths, or weights of material involved, can be made (subject to cost and building code constraints) so that the architect can check the suitability of a part of his design as he progresses.

Illustrative of what is presently being done on line-drawing consoles is the isometric outline of a bridge structure shown in Figure III.13.

Architecture

Few design processes have greater visual content than the work of the architect. It is difficult to envisage an architect deprived of his graphic medium and working instead on designs described only in numerical terms. But this was the case for many years where computers were used to solve architectural problems; they were used for producing perspective drawings on a plotter, determining optimum dimensions for lecture halls, calculating acoustic requirements of rooms, and checking the structural properties of a prefabricated design. In each case the use of conventional periph-

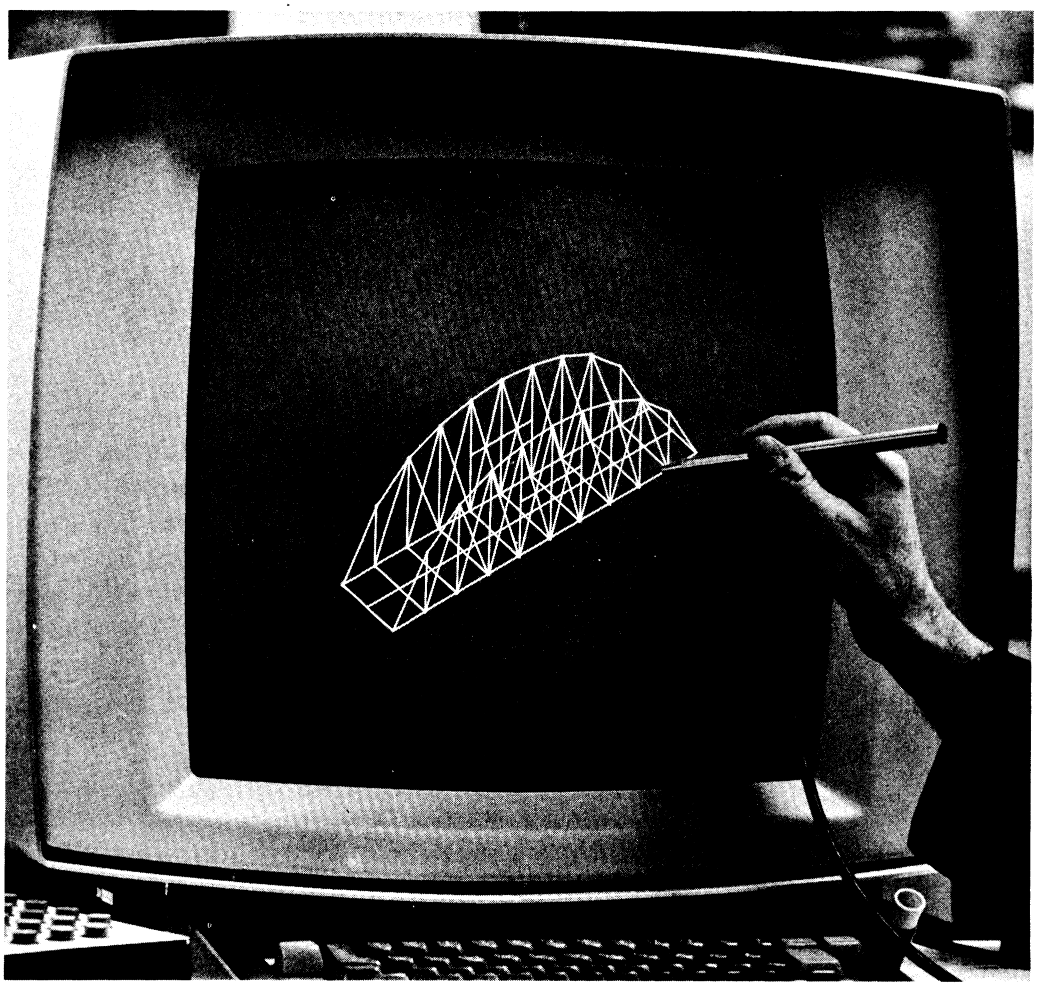


Figure III.13

ISOMETRIC OUTLINE OF A BRIDGE STRUCTURE

eral equipment made it necessary to convert either the design to numerical form for processing or the numeric output of the computer to graphic information.

The line-drawing display is presently the most powerful computer input-output device available to architects. It permits rapid manipulation of graphic information and enables an operator to present design information to the computer. (Figure III.14, for example, shows shear, moment and deflection diagrams of a beam which are automatically updated as the designer changes the characteristics of the beam or its load.) The line-drawing display also has the quick response time necessary for returning user messages and concise numeric results. Design tasks such as those described above can be performed on-line and as part of a comprehensive architectural design program.

In using the computer and line-drawing display console, the architect is working with a new medium, and although it can simulate the pencil and paper to which he is accustomed, he must also adapt his design process to extract maximum benefit from the computer. While the way he does this is his own choice, his software package would likely contain four basic parts, each centered around the display: 1) input of an initial design, 2) evaluation of the design by the computer, with a report to the console operator, 3) operator modification of the design based on the evaluation, and 4) graphic and tabular output of design characteristics.

While the light pen can be used to draw on the display screen as freely as with a pencil on paper, its principal use for the architect is to describe three-dimensional designs to the computer. Sketched input cannot do this unless it closely follows a set of rules contained in the design program. Consider Figure III.15A, showing two adjoining walls of different heights. One set of rules might require the architect to sketch the two views shown in Figure III.15B, and in this way write a description of the object into the computer memory. Alternatively, he might draw the single view shown in Figure III.15C, indicating the wall heights h and h with a rotating knob or a displayed target for the light pen. The method of Figure III.15 would be faster, but is not well suited to describing walls of continuously varying heights.

The display is also used to return to the architect informa-

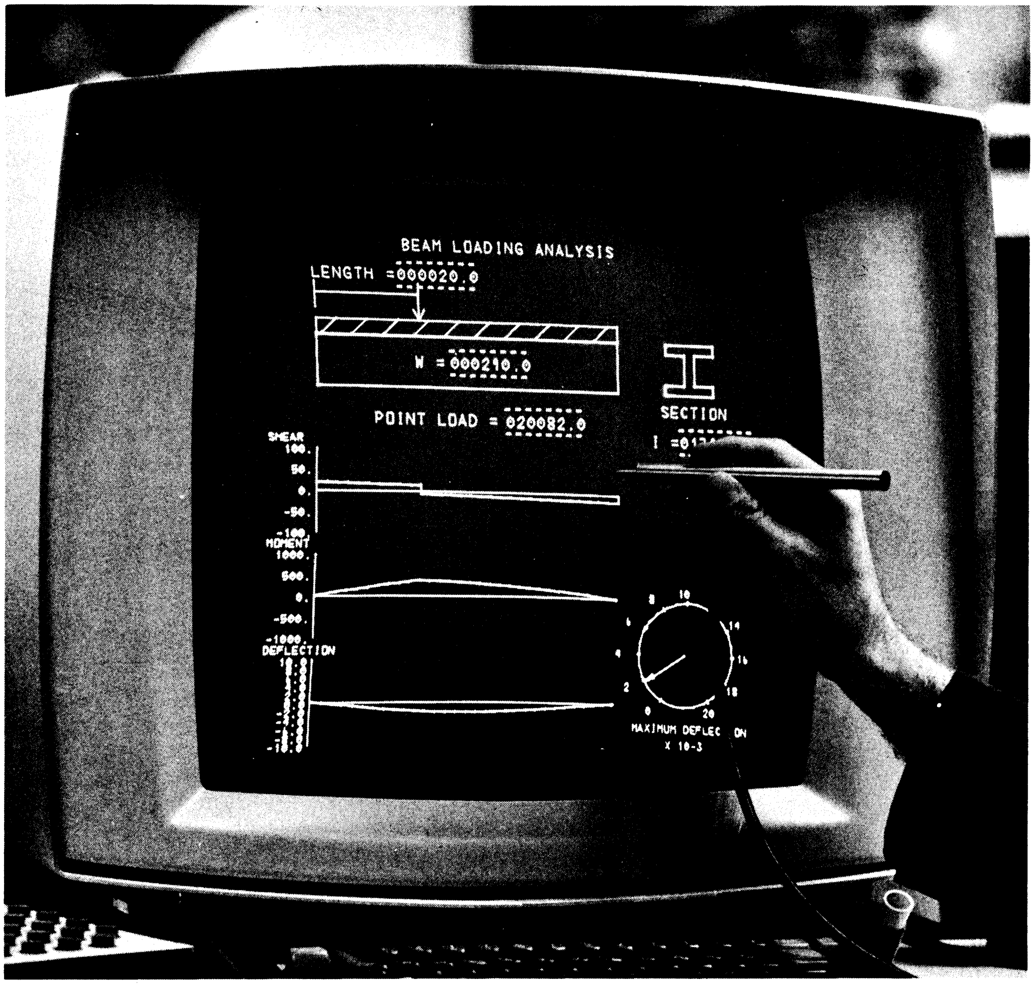


Figure III.14

ARCHITECTURAL DESIGN ON A LINE-DRAWING DISPLAY CONSOLE

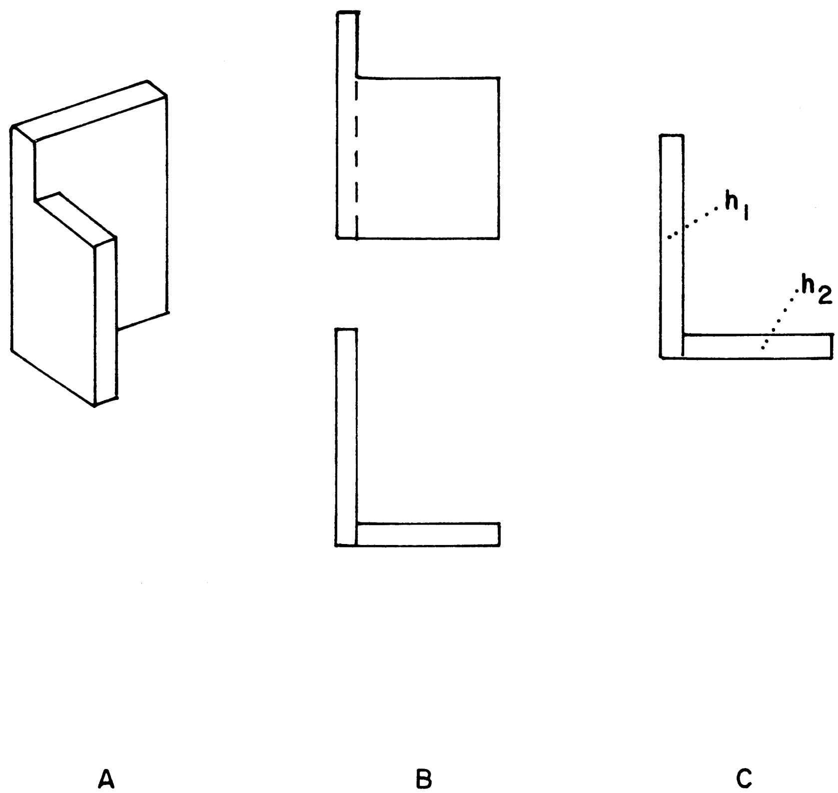


Figure III. 15

DESIGN DEVELOPMENT

tion on the progress of his design. Much of this information feedback is graphic or numeric data whose value is enhanced by being displayed; for example, floor areas can be calculated and displayed, each number appearing within the appropriate room.

A design program with comprehensive information feedback provides the architect with all the data he needs to work at maximum efficiency. The type of information included depends on the user. An architect unfamiliar with the system would benefit from a comprehensive set of error messages to help him learn the operating techniques; as he becomes more experienced, messages informing him of infringements of programming or structural rules can be included. The display can depict elevations and perspective views to reassure the architect that he is achieving a proper three-dimensional effect, and can emphasize certain aspects of the design, such as the distribution of circulation space, the routing of pipe-work, etc. Graphs showing the effect of altering certain parameters on the cost of implementing the design can be plotted.

The primary purpose of this information feedback is to indicate where modifications should be made to the design. The computer program must permit both a convenient method of describing the design and a rapid and flexible means of modifying that design.

It is appropriate to emphasize modification techniques rather than input methods, partly because the architect spends less time on the initial description and partly because there are logical problems in the interpretation of modifications. Modifications may include alterations to construction materials or use of floor space, or changes in layout. Where layout changes, which may be anything from deleting a single door to moving a large section of the design to a new position, conflict with the existing layout, the user should be made aware of this conflict and offered a choice of solutions.

A general system for architectural use needs several output devices, including a digital plotter and line printer, but the usefulness of the display for taking quick photographs should not be overlooked. Some consoles have cameras that can be operated under program control, permitting films to be made of animated displays.

In multiple-console systems the display can assist in communication of graphic information between architects in different offices, or even between the architect and his contractors and engineering consultants. With the cost of display equipment being steadily reduced, multi-console systems have become more feasible.

Design Automation

The use of a line-drawing console for design automation is similar to that for engineering drawings and architecture, except that the input data has sophisticated definitions associated with it, permitting complex computations to be performed on this data. For example, if a bridge is sketched on a CRT, a design automation program might compute its stress distribution or the required size of steel reinforcing rods in the concrete. The STRESS language, developed by the Civil Engineering Department of M.I.T., is an adjunct to the line-drawing routine for stress calculations in complex structures.

For the past 10 years, much effort has been devoted to applying computers to problems in diverse areas of design such as highways, bridges, buildings, circuits, digital logic, instruments, transformers, tanks, mechanical devices, automobiles, and electrical power distribution networks. In many of these areas the input data is graphic in nature, and it was necessary to spend many hours copying dimensions from drawings onto input forms for keypunching and subsequent computation. Some problems required several days to prepare data for one run. With line-drawing display units connected to a large time-shared data processing facility, the design engineer can make changes, have them evaluated by the computer, and the results returned to him in a few minutes. Suggested uses for such a system are described below.

Highways

The area through which a highway is to pass is photographed, and from these photographs a numerical model of the terrain is calculated. The engineer can examine on the display console either a contour map or a cross section of the terrain. Using the light pen (or pointer) and the function switches, he draws the route and cut of the highway. The computer calculates the volume of earth to be moved, taking into consideration drainage, road access and visibility, and the use of the land.

The engineer may want to modify the road design to achieve a suitable compromise of all pertinent factors and arrive at the lowest possible cost.

Mechanical Parts

The design engineer draws the required parts on the CRT, or inputs key information from which the computer calculates the shapes of the parts. The computer may also have a library of standard parts from which the engineer can select those he needs. As he assembles his device, he can request the computer to verify the meshing of the parts, and to warn him of untrustworthy designs. If linkages or gears are used, he can observe the device operating in slow motion on the CRT.

An important part of man-machine graphics is the ease with which repetitive regular patterns can be drawn. Examples of this are gears, particularly helical gears, and placements of rivets in rectangular plates. The real time-saver, of course, is in drawing three-dimensional assemblies which are lacking in simple symmetries. Cable routes, hydraulic lines and fuel lines in an aircraft are a good case in point. Cable or pipe crossings in conventional drafting practice are shown primarily at intersections where difficulties are anticipated and unsuspected interferences can occur at intermediate points.

On complex mechanical parts, computer graphics provide the starting point for numerically-controlled fabrication. The drafting process converts the specification of a working part into a form that can be manipulated by the computer in APT language for numerically-controlled tools or directly into the code accepted by milling machines, lathes and other fabrication tools.

Electronic Circuit Design

Electronic circuit design is another example where, as shown in Figure III.16, a sketch serves as a focal point of the process; but there is also a set of rules that apply as general principles and a set of equations that are specific to this particular design. Circuit design, like a number of other design processes, has many more variables or parameters than constraints so that many combinations of

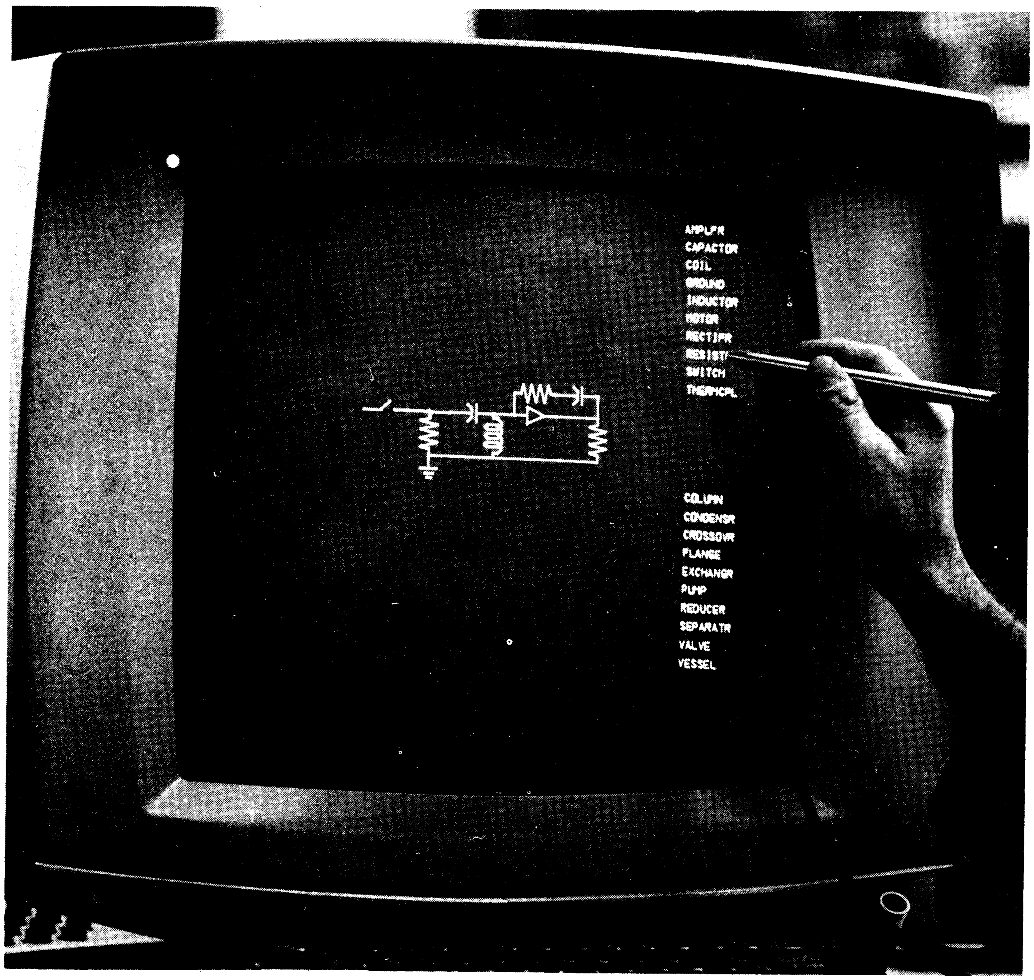


Figure III.16

ELECTRONIC DESIGN ON A LINE-DRAWING DISPLAY CONSOLE values may be equally acceptable.

In designing for mass production, the upper and lower limits on the tolerances of each component must be evaluated. Even for simple circuits, the number of combinations of all components is very large and making and testing all combinations is out of the question, even if the cost of the parts themselves were negligible. This is particularly true with integrated circuits, where the opportunity to modify an original design is limited to interchanging redundant components whose leads have been brought out of external connections. Modern circuit analysis allows circuit parameters to become the coefficients in a matrix where the performance characteristic being evaluated is the only remaining variable.

Rather than design in the purest sense, there is an intuitive "cut-and-try" process applied over and over to achieve a desired end result. The engineer is able to simulate the effect of various changes much more rapidly than if actual circuits had to be constructed.

Data Reduction and Analysis

Many persons associated with data reduction and analysis are aware of the problem of doing considerable processing on a batch of data, then waiting many hours for the results to be plotted, only to learn that the entire batch was bad and should have been corrected or discarded. If a competent analyst views this data before or during processing, substantial computer time is saved and it is not necessary to print reams of numbers or plot redundant output curves.

In a typical analysis system, digital data is read by the computer, scaled and displayed. The analyst can close gaps and eliminate noise by adjusting data points with the light pen and function switches. If the data is valid, he requests reduction and analysis, with intermediate results displayed for directing the next stage.

When processing is complete, the analyst can scale individual curves, add axes values, repair gaps or spikes, delete curves, combine curves with others, reposition curves, and add text. The results are saved by plotting on a graphic recorder or by photographing the picture on the console.

In Figure III.17, measured data is shown by * symbols and horizontal and vertical scales have been chosen automatically to give the largest graph that includes all points. A third-degree polynomial curve which is the least squares fit to the data is plotted and coefficients are calculated and displayed. The analyst is deleting a data point which apparently is erroneous.

Process Control

In process control, line-drawing consoles are used for two types of processes: closed-loop (or continuous) systems, and open-loop (or discrete) systems. In both, the computer presents status information and accepts control requests from the operators.

Closed-loop Systems

The control of an oil refining plant, nuclear reactor, chemical plant, paper-making machine, cement kiln, or blast furnace is typical of a closed-loop system. A computer continuously monitors up to several hundred variables, and from these measurements it modifies temperatures or the rate of flow of materials, or sounds alarms. The display console shows the previous and current status of key variables or a flow diagram of the system.

The operator can select a particular valve or junction with the pointer and function switches, and request information about it or command it to be adjusted. The effect of an adjustment can often be calculated and displayed, as illustrated in Figure III.18 before the process is modified. With all necessary data available through the display, the operator need make only occasional checks of the wall-mounted indicators or strip recorders.

Open-loop Systems

Rather than monitoring continuous processes, open-loop systems perform discrete operations, such as turning a motor on or off, opening or closing a valve, starting or stopping a conveyor, or measuring a specific quantity. These systems are used for controlling automatic warehouses, pipelines, transportation systems, and the flow of liquid or solid materials. The control indicators for a system without a display console are usually wall-mounted colored lights,

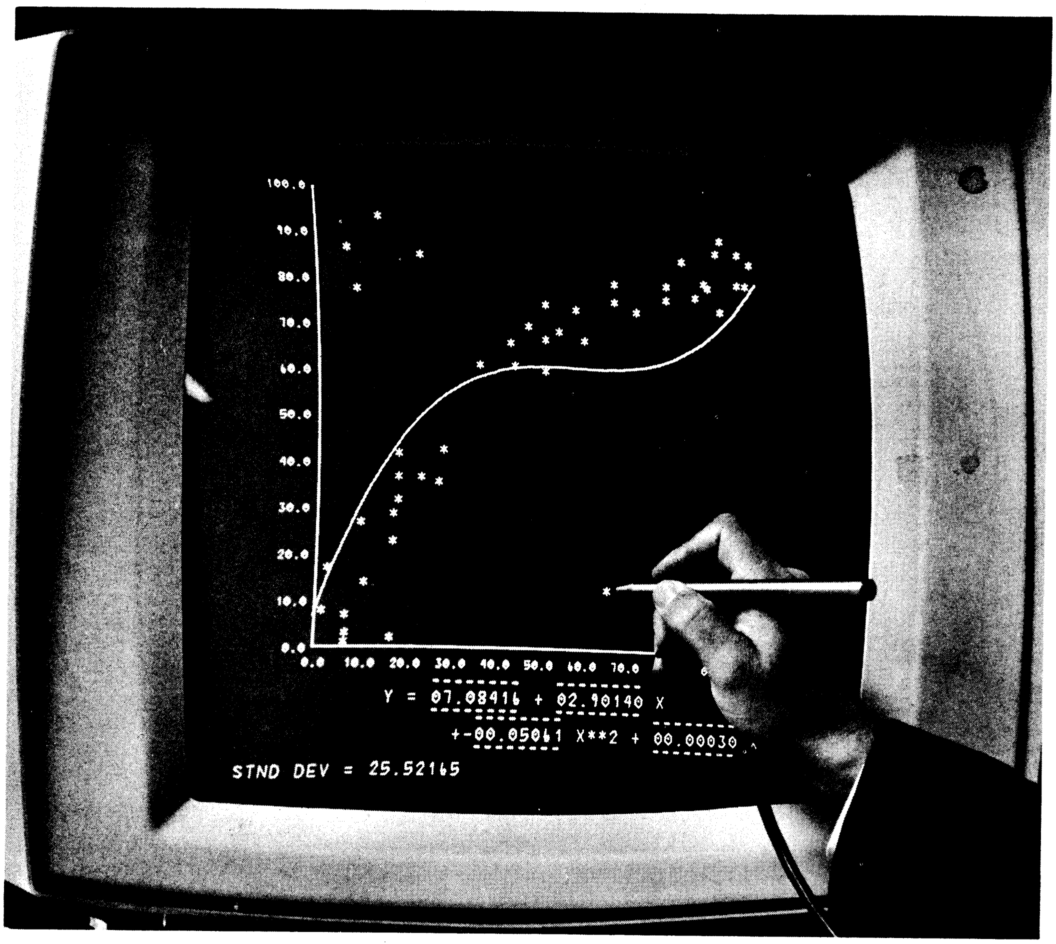


Figure III.17

DATA REDUCTION AND ANALYSIS
ON A LINE-DRAWING DISPLAY CONSOLE

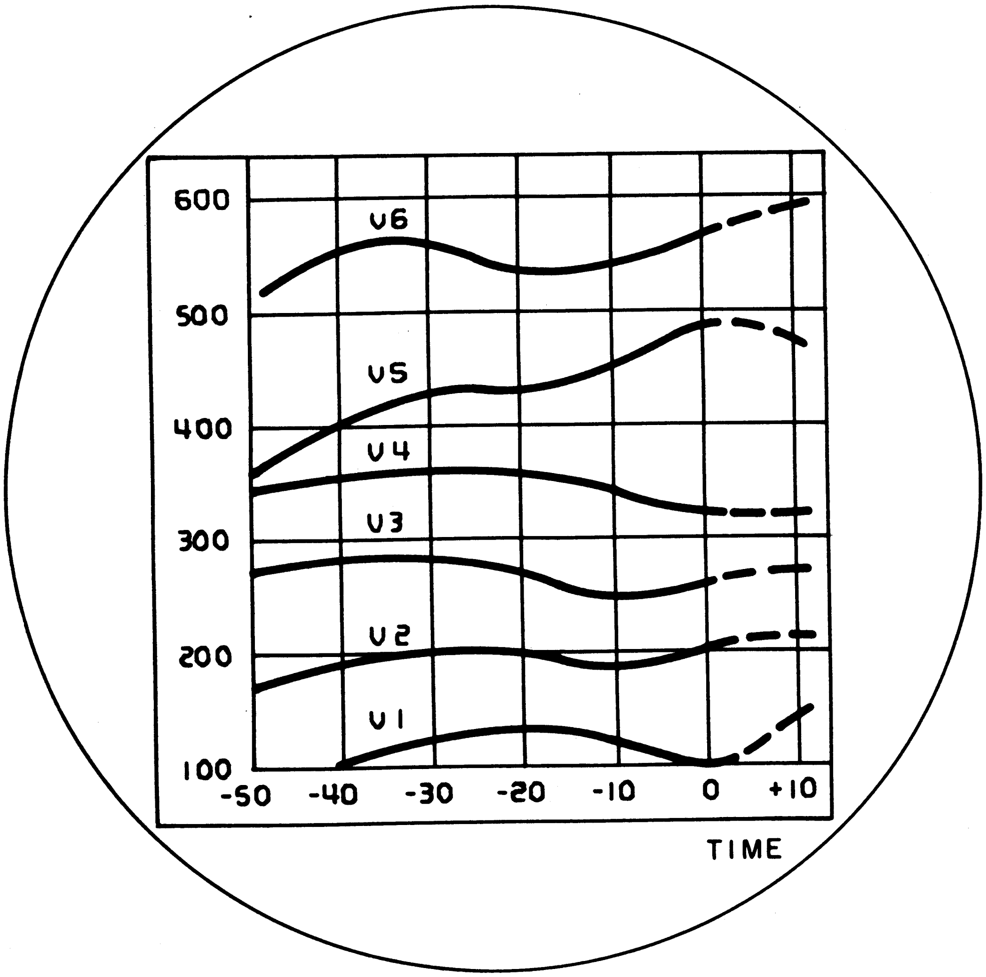
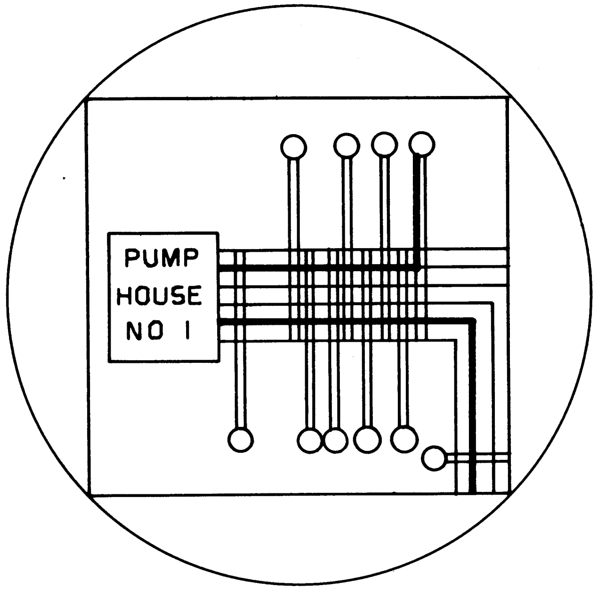
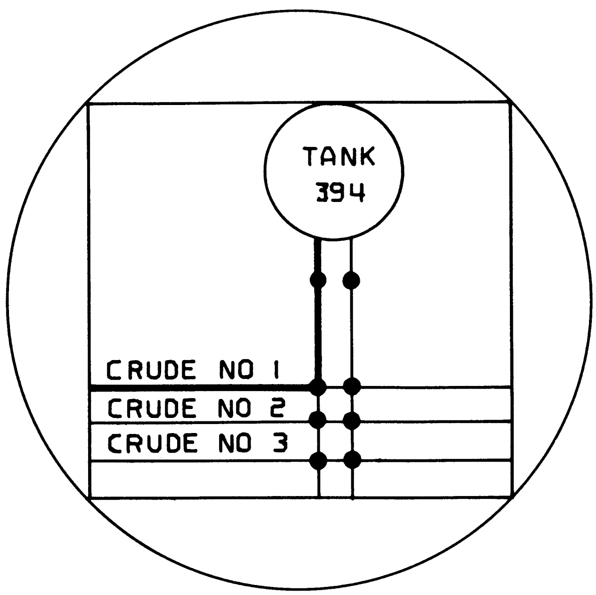


Figure III.18

DISPLAY OF PROCESS VARIABLES



LARGE AREA



SMALL AREA

Figure III.19

DISPLAY OF MOVEMENT SYSTEM

indicating whether a component is on, off, or out of operation. Components such as pipelines are represented by neon lights or background lighting. Changes to these panel indicators are difficult and costly to make, and in large systems the amount of detail that can be shown is limited.

A line-drawing console and computer permit the operator to view as much detail of the total process as he desires. The upper part of Figure III.19 shows a complete chemical or oil movement system, with only the storage tanks and the main transmission lines displayed. As the operator examines in detail a part of the operation, more information is turned on, as shown in the lower part of the same figure. Tanks and lines in use can be indicated by brightening or blinking their displayed counterparts.

Modifications to the process control system can be made either by reprogramming or by a file updating program. Specific controlling operations can be requested by composing messages from the keyboard of the line-drawing console; for example:

CLOSE SWITCH 739

or

STOP PUMP A71

or

MOVE 5,000 BARRELS FROM TANK 17 TO TANK 23 VIA LINE 12 TN WITH PUMP A72

Alternately, the operator can point to a particular element such as a valve, and push a function switch to indicate that the valve is to open or close. The computer accepts this command, transmits the signals to perform this operation, then confirms the request by modifying the flow pattern being displayed.

Information for Management

The trend in business data processing is to integrated management information systems. In the near future, displays may be used to present clear and concise data on a business operation. They might show PERT diagrams and other types of bar charts and graphs, plant layouts and location of production machinery, analyses of traffic patterns in sales and lobby areas, cash flow, profits, sales, return on investment, payroll costs, and product distribution patterns.

An excellent example of the kind of constantly changing information which could be furnished to management is shown in Figure III.20. In the November 1966 elections, during the Columbia Broadcasting System coverage, bar graphs displayed on an IBM console were used to show the estimated percentage of the votes cast for the two contestants in the Arkansas gubernatorial race between Winthrop Rockefeller (R) and James Johnson (D). With 27 of the 80 precincts reporting, the presentation shows Rockefeller leading with 53.8 percent of the votes cast.

Military Command-Control

The earliest application of light-pen devices used with cathode ray tube consoles was in Project SAGE, the North American air defense system. A console operator had a display of radar returns for a particular geographic sector. By placing a light gun over a particular target and depressing a switch, he identified the position of the object and initiated a search of computer memory. The computer stored a record of the coordinates of the geographic area displayed at each console and was able to extrapolate the latitude and longitude of an unidentified aircraft from the console number and the range and azimuth or horizontal and vertical coordinates of the display. Another cathode ray tube device was used to blank out troublesome radar returns from fixed objects such as mountains. The console operator could paint over a plastic overlay and logically gate out fixed returns from large areas which would distract the operator's attention.

Consoles with radar video input as well as computer line-drawing or alphanumeric capability is the main difference between government and commercial requirements. Most military command systems are similar in concept to management information systems of civilian firms. The hardware in the former case is frequently custom designed, however, to insure high reliability and rugged mechanical construction. Projection displays have been used with a

Figure III.20

BAR GRAPHS OF ELECTION RETURNS
IN ARKANSAS GUBERNATORIAL CONTEST

mixed degree of success to show computer-generated displays to large groups. This serves primarily the commander's requirement for briefings on a regular basis and in emergency situations. The information on the wall display is usually repeated on one or more cathode ray tube consoles where an officer with a specific responsibility can make computer inquiries by function switch or light-pen action. Similarly, output messages may be composed by combinations of light-pen and function-switch actions. Military equipment and developments often precede their civilian counterparts by many years because of the availability of research and development funds. The product which many government and private agencies are attempting to develop now is an inexpensive alphanumeric display which also produces hard copy, as required, with a minimum of mechanical parts.

Animation

Numerous applications use displays only for output and these consoles often have 16 or 35mm camera recording units. One interesting use of these recorders is the production of motion pictures of complex situations. For example, a film of the tumbling of a satellite orbiting the earth can be made by computing the orientation of the satellite at specific intervals and generating a display for each interval. These are photographed with the film advanced one frame, under computer control, between photographs. At the end of the run, the film is developed and the result shown at normal projection speeds.